The nature and extent of sexual dimorphism in dental and dermatoglyphic traits of twins

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ABSTRACT

Human teeth and fingerprints have similar embryological origins from epithelial-mesenchymal interactions.

The general aim of this study was to determine the nature and extent of sexual dimorphism in the teeth and fingerprints of Australian twins. The specific aims of this research were to

1. investigate the influences of genetic, epigenetic and environmental factors on observed variation in selected dental and dermatoglyphic features;
2. identify which dental and dermatoglyphic traits display sexual dimorphism and whether this is consistent with the Twin Testosterone Transfer Hypothesis; and
3. identify any evidence of associations and covariance between the studied dental and dermatoglyphic phenotypes.

These aims were investigated by measuring crown dimensions, mesiodistal (MD) and buccolingual (BL), of primary and permanent teeth; scoring the Carabelli trait (CT) on primary and permanent upper molars; counting friction ridges (RC) and white lines (WLC) of dermatoglyphs; and classifying fingerprint patterns (FP). Dental and dermatoglyphic development stages were assessed against intrauterine testosterone levels. Phenotypic variation was examined within the context of general somatic development and the properties of a Complex Adaptive System by exploring the possible effects of the Y chromosome and testosterone in utero and the role of epigenetic factors.

Results showed sexual dimorphism in both the primary and permanent dentitions, with the permanent teeth showing greater differences. Some sexual dimorphism was observed in the fingerprints. The correlations between teeth and fingerprints were found to be statistically significant but low in magnitude. Strong genetic influence in sexual dimorphism was suggested through MD and BL measurements of MZ twins; this was the only zygosity group where all tooth types were observed as sexually different. The additional role of environmental factors was suggested for the sexual dimorphism of WLC in DZSS twins. Epigenetic influence in sexual dimorphism has been observed in DZOS females, with MD and BL measurements and CT scores being larger than MZ and DZSS females. DZOS females were also observed to have more loop or whorl than arch fingerprints compared to MZ and DZSS females. The differences in tooth size and shape and fingerprint pattern provide further support on the Twin Testosterone Transfer (TTT) hypothesis. While teeth and fingerprints had low correlations in both sexes, it was observed that fingerprint patterns were associated with measurements of MD and BL in both primary and permanent teeth.

In conclusion, sexual dimorphism in teeth and fingerprints was confirmed by the larger tooth size and higher Carabelli scores in males, and in DZOS females; and the different WLC in DZSS and fingerprint patterns in DZOS. While teeth and fingerprints have low correlations in both sexes, it was observed that fingerprint patterns are associated with measurements of MD and BL in both primary and permanent teeth. Moreover, the findings provide further evidence that the development of teeth and the development of fingerprints are outcomes of Complex Adaptive Systems.

DECLARATION

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Chapter 1 Introduction

Human development is a complex adaptive process that is influenced by genetic, epigenetic and environmental factors (Brook et al., 2014). The genes interact with epigenetic and environmental factors at the molecular level and form complex networks within the cells. From these dynamics the higher level tissues arise.

Within the process of human growth, the dentition and dermatoglyphs have similar embryological origins resulting from sequential reciprocal interactions between adjacent epithelial and mesenchymal tissues (Nanci, 2008). Some genes, e.g. EDA and EDARADD, are active in both the development of teeth and of skin. During embryonic growth, the establishment of groups of cells with a proper relationship to each other and to surrounding tissues occurs. Patterning during morphogenesis is a longitudinal event that eventually leads to differentiation of cells which assume particular specialized functions and shapes. Primary teeth start to develop around 4 to 6 weeks in utero (Nanci, 2008), while ridged skin on the tips of the fingers begins to form around 10.5 to 16 weeks in utero (Kücken, 2007).

One of the phenotypic outcomes of human growth and development is sexual dimorphism, which is defined as phenotypic or observable differences between males and females of the same biological species. Many studies have been conducted on sexual dimorphism in the human dentition. In general, males have larger crown diameters than females (Moorrees et al., 1957; Ribeiro et al., 2013), and sexual dimorphism is greater in the permanent dentition than in the primary dentition (Harris and Lease, 2005; Schwartz and Dean, 2005; Ribeiro et al., 2012). In adult dermatoglyphs, studies on sexual dimorphism reveal that males have fewer ridges

than females (Acree, 1999; Gutiérrez-Redomero et al., 2008; Taduran et al., 2016; 2017).

Sexual dimorphism has been suggested by some researchers to be governed by sex chromosomes alone (Guatelli-Steinberg et al., 2008; Alvesalo, 2009) but there have been others who have suggested that hormones are also important (Dempsey et al., 1999; Ribeiro et al., 2013). Dental and dermatoglyphic patterns develop in utero, and their unique and persistent morphologies once formed make them valuable models in studying sexual dimorphism.

These aspects of human development are explored further in the studies reported in this thesis. The review of the literature shows that tooth dimensions and fingerprints have not been previously examined in the same individuals. This study aims to: determine the nature and extent of sexual dimorphism in fingerprints and teeth; investigate the influences of genetic, epigenetic and environmental factors; and identify possible developmental associations and covariance of fingerprints and teeth.

The samples examined were twins from the ongoing longitudinal twin studies of the Craniofacial Biology Research Group in the Adelaide Dental School at The University of Adelaide (Townsend et al., 2012b); this is one of the four most extensive studies of its type in the world (Hughes et al., 2014). Serial casts of primary and permanent teeth, and rolled ink fingerprints of individuals aged 8 to 10 years from a single cohort of monozygotic and dizygotic Australian twins (103 males and 112 females) were gathered and analysed. Dental casts showing wear, caries, or restorations and ten-prints with smudged ink and fingerprints with any scarred patterns were excluded.

A 2D imaging system was utilised to measure tooth crowns. Dental casts were oriented using a tripod to obtain correct plane or angle in taking images and a calibrated Image J software was used to digitize landmarks. The dental dimensions measured were the maximum mesiodistal crown diameter (MD), which refers to the distance between the mesial and distal contact points of the tooth crown (Brook et al., 1999; Brook et al., 2005), and the maximum buccolingual (BL) or labiolingual diameter, which refers to the breadth or distance between the buccal/labial and lingual surfaces of the crown (Brook et al., 1999; Brook et al., 2005). Measurements were obtained from central incisors (I1), lateral incisors (I2), canines (C), first molars (M1) and second molars (M2) of primary and permanent teeth. Molars were also scored for expression of the Carabelli trait, a feature that varies in expression from small pits and grooves to large accessory cusps, by strictly following the procedures indicated in the Arizona Dental Anthropology Scoring System (Turner et al., 1991).

The dermatoglyphic traits recorded were ridge count (RC), which was measured by counting friction ridges diagonally on a one-centimetre line (Taduran et al., 2017); and white lines count (WLC) which were extracted manually (Taduran et al., 2016). Fingerprint pattern (FP) was classified by type, that is, whether arches, loops or whorls.

Data were statistically analysed using R statistical software. Descriptive statistics including means, standard deviations (SD) and coefficients of variation (CV) were computed. Differences between sexes and sides were calculated using Student's **unpaired t-test. Differences among tooth types and fingers were examined with**

analysis of variance (ANOVA). Correlation coefficients were calculated to examine the strength of associations between the variables.

The results showed sexual dimorphism in both primary and permanent dentitions, with the latter showing greater magnitude of differences than the former. There were some sexual dimorphism observed in the fingerprints. The correlations between teeth and fingerprints were found to be statistically significant but low in magnitude.

This study has implications in a number of fields within human biology. It furthers our knowledge of human development, particularly on factors and interactions in early development. In dentistry, the results provide clinicians with new scientific findings to underpin their practice. In anthropology, the findings provide a basis for further understanding about human variation, sexual dimorphism and human evolution. The results can also be applied in medicine and forensic sciences, especially in diagnostics, biometrics and human identification cases.

Chapter 2 Literature review

2.1 The human dentition

2.1.1 Value as a model system

The human dentition provides a useful model system for studying developmental factors over time as the teeth start to form around four to six weeks after conception and continue to develop until around 21 years after birth (Townsend et al., 1994; Hillson, 1996; Townsend et al., 2009c). Furthermore, once a tooth crown has formed it does not change in shape or size, except due to post-eruption alterations such as processes of wear, caries, dental treatment or cultural issues (Townsend, 1976; Townsend et al., 1994). It is possible to have records of both the primary and permanent dentitions of the same individual by studying the tooth size and shape in living populations and in fossil collections, and also directly in the mouth or by using dental models (Hillson, 1996).

2.1.2 Dental crown size and shape

2.1.2.1 Mesiodistal crown diameters

Mesiodistal, crown diameters (MD) refer to the distance between the mesial and distal contact points of the tooth crown (Moorrees et al., 1957; Hunter and Priest, 1960).

2.1.2.2 Buccolingual crown diameters

Buccolingual (BL) or labiolingual (LL) crown diameters refer to the breadth or distance between the buccal/labial and lingual surfaces of the tooth crown (Moorrees et al., 1957; Hunter and Priest, 1960).

2.1.2.3 Carabelli trait

Carabelli trait is an additional cusp or groove on the mesiolingual surface of the maxillary second deciduous molar or permanent first molar. It emerges from the lingual surface of the protocone (the mesiolingual cusp of upper molars), and usually begins to form after the four major cusps of the molar have initiated (Kraus, 1965).

2.1.3 Dental development

With the advent of new technologies, many molecular studies have been carried out to elucidate the intricacy of odontogenic processes (Sharpe, 2001; Matalova et al., 2008; Brook, 2009; Lesot and Brook, 2009; Townsend et al., 2009a; Ishida et al., 2011). During odontogenesis or dental development, sequential stages of initiation, morphogenesis, differentiation, calcification and eruption of teeth occur (Brook et al., 2009a; 2014). When genetic, epigenetic and environmental factors interact with these stages, variations in dental phenotype will be observed (Brook et al., 2014).

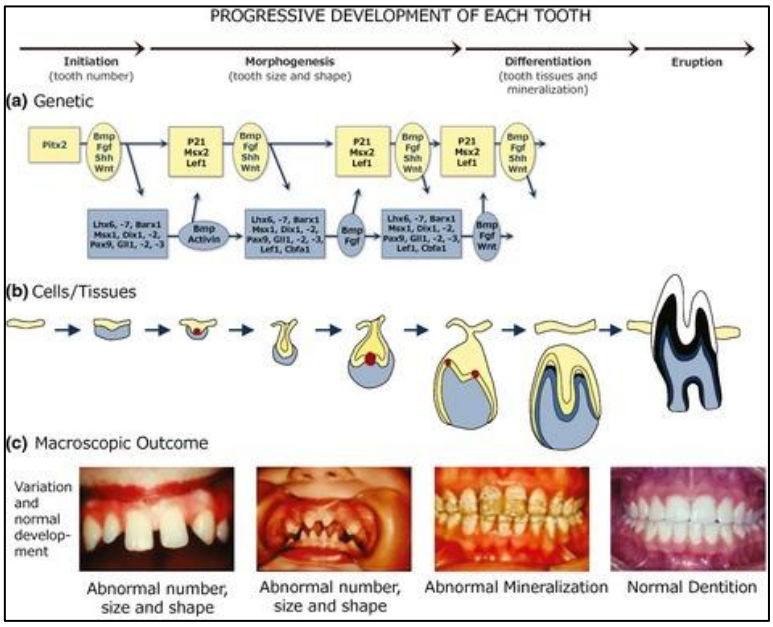

Figure 2-1. Overview of dental development (with permission from Australian Dental Journal, Brook et al., 2014).

2.1.3.1 Initiation and morphogenetic changes

The initiation stage begins with the formation of epithelium and mesenchymal tissues from the dental lamina (Nanci, 2008). Specific transcription factors, signalling molecules and homebox genes are responsible for controlling tooth number, shape and position (Brook, 2009). In a study by Liu et al. (2008), failure in expression of signalling molecules, such as Wnt/ β-catenin, was shown to affect tooth formation at the early bud stage while an increase in its function led to abnormal tooth shape. Transcription factors influence the signalling centres, called enamel knots, which control crown dimensions (Brook et al., 2014). The positions of these enamel knots, which appear at the site of the future cusp tips of the teeth, are influenced by epithelial signalling molecules which in turn regulate the spatial expression of homeobox genes found in the ectomesenchyme (Thesleff et al., 2001; Fleischmannova et al., 2008; Lesot and Brook, 2009).

Morphogenesis occurs when the epithelium interacts with the mesenchyme (Lesot and Brook, 2009). Cobourne and Sharpe (2003) and Brook et al. (2009a) reported that the cycle of activation and inhibition of signalling molecules leads to differential growth and folding of tooth germ producing a myriad of dimensions and tooth patterns. In a study by Brook et al. (2009a), the final shape of the crown was reported to be determined during the cap and bell stages where rapid proliferation of epithelial cells determines cusp shapes. The signalling molecule that helps determine final crown shape, because of its association with apoptosis leading to cessation of enamel knot activity, is the molecule Bmp4. Hence, apoptosis in the enamel knots determines dental crown size and shape (Brook et al., 2009a).The authors also added that homeobox genes also establish the molecular foundations for patterning of the skeletal

elements. Variations in tooth dimension and shape during tooth morphogenesis are also influenced by sex chromosomes and male intrauterine male hormones (Ribeiro et al., 2013).

2.1.3.2 Differentiation and mineralization stages

As the tooth develops, differentiation and mineralization take place. With the influence of genetic and epigenetic factors, the dentine-forming cells (odontoblasts) and enamel-forming cells (ameloblasts) differentiate and produce dentine and enamel, respectively (Brook et al., 2014). Dentine is produced when Tgf-B signalling influences Dspp expression in odontoblasts via epigenetic mechanisms (Nakatomi et al., 2013). Enamel, on the other hand, is produced when ameloblasts secrete enamel protein matrix by stimulating AMELX and ENAM proteins to control enamel mineralization (Brook et al., 2014). The deposition of enamel on the different parts of the tooth determines the final dimensions, both size and shape, of the tooth, building on the template of the dentinoenamel junction.

The following tables present the development timeline of human dentition.

Table 2-1. Development timeline of human primary teeth (from Ash, M.M. and Nelson, S.J. (2003). Wheeler's dental anatomy, physiology, and occlusion).

	Maxillary (upper) teeth				
Primary teeth	**Central incisor**	**Lateral incisor**	**Canine**	**First molar**	**Second molar**
Initial calcification	14th week (in utero)	16th week (in utero)	17th week (in utero)	15.5 week (in utero)	19th week (in utero)
Crown completed	1.5 month	2.5 month	9th month	6th month	11th month
Root completed	1.5 year	2nd year	3.25 year	2.5 year	3rd year
	Mandibular (lower) teeth				
Initial calcification	14th week (in utero)	16th week (in utero)	17th week (in utero)	15.5 week (in utero)	18th week (in utero)
Crown completed	2.5 month	3rd month	9th month	5.5 month	10th month
Root completed	1.5 year	1.5 year	3.25 year	2.5 year	3rd year

Table 2-2. Development timeline of human permanent teeth (from Ash, M.M. and Nelson, S.J. (2003). Wheeler's dental anatomy, physiology, and occlusion).

	Maxillary (upper) teeth							
Permanent teeth	**Central incisor**	**Lateral incisor**	**Canine**	**First premolar**	**Second premolar**	**First molar**	**Second molar**	**Third molar**
Initial calcification	3-4th month	10-12th month	4-5th month	1.5-1.75 year	2-2.25 year	at birth	2.5-3rd year	7-9th year
Crown completed	4-5th year	4-5th year	6-7th year	5-6th year	6-7th year	2.5-3rd year	7-8th year	12-16th year
Root completed	10th year	11th year	13-15th year	12-13th year	12-14th year	9-10th year	14-16th year	18-25th year
	Mandibular (lower) teeth							
Initial calcification	3-4th month	3-4th month	4-5th month	1.5-2nd year	2.25-2.5 year	at birth	2.5-3rd year	8-10th year
Crown completed	4-5th year	4-5th year	6-7th year	5-6th year	6-7th year	2.5-3rd year	7-8th year	12-16th year
Root completed	9th year	10th year	12-14th year	12-13th year	13-14th year	9-10th year	14-15th year	18-25th year

2.1.3.3 Tooth emergence

Tooth emergence is a developmental process in which the teeth enter the mouth and become visible. The deciduous, or primary teeth are the first human teeth to appear; they emerge into the mouth from around six months until two years of age. There are 10 deciduous teeth and the most frequent eruption pattern is: (1) central incisor; (2) lateral incisor; (3) first molar; (4) canine; and (5) second molar, with the maxillary teeth usually erupting before the mandibular. This primary dentition stage continues until a child is about six years old. During this stage, the tooth buds of permanent teeth develop inferior to the deciduous teeth, close to the palate or tongue (Ash and Nelson, 2003).

At around five or six years, the permanent first tooth, usually the first molar, emerges and begins a stage where there are both primary and permanent teeth. This is known as the mixed dentition stage, which lasts until the age of 10 to 12, when the last primary tooth is lost. There are 32 permanent teeth and maxillary and mandibular teeth erupt in different orders. The lower (or mandibular) teeth normally erupt in the following

order: (1) first molar; (2) central incisor; (3) lateral incisor; (4) canine; (5) first premolar; (6) second premolar; (7) second molar; and (8) third molar. The upper (or maxillary) teeth normally erupt in the following order: (1) first molar; (2) central incisor; (3) lateral incisor; (4) first premolar; (5) second premolar; (6) canine; (7) second molar; and (8) third molar (Ash and Nelson, 2003).

The last stage is called permanent dentition and it begins when the last primary tooth is lost, usually at 11 to 12 years. The permanent dentition stage lasts for the rest of a person's life, or until all of his or her teeth are lost (Ash and Nelson, 2003).

2.1.3.4 Dental development as a Complex Adaptive Process

The human dentition is regarded as a complex adaptive system being influenced by an interplay of genetic, epigenetic and environmental factors at the molecular level which result in a specific clinical phenotype (Brook and O'Donnell, 2012; Townsend et al., 2012a). In order to assess genetic, epigenetic and environmental influences, studies on variation in tooth size and shape within and between related individuals are of considerable importance (Garn et al., 1965a; Townsend, 1976; 1978; 1980; Townsend and Brown, 1978a; 1978b; Brook, 1984; Townsend et al., 2005).

Odontogenesis is a complex biological process that involves molecular, cellular, and tissue interactions, with time and space also contributing to phenotypic differences. Disturbances in the temporo-spatial coordination of odontogenesis may lead to dental abnormalities of number, size, form and structure (Brook, 2009). Anodontia, a condition that is characterised by the complete absence of all teeth; oligodontia, which refers to the absence of more than six teeth; and hypodontia, or the absence of one

to five teeth, seem to be associated with mutated genes, such as MSX1, PAX9, AXIN2 and EDA (Fleischmannova et al., 2008; Matalova et al., 2008; Brook, 2009) and WNT10A (Brook et al., 2014; Thesleff, 2006). Microdontia, a condition of having smaller tooth size and altered tooth morphology (peg-shaped crowns) (Parkin et al., 2009), was found out to follow the pattern of the morphogenetic fields, with the later-formed tooth in each field being more affected (Brook, 2009; Brook et al., 2009a). Hyperdontia, a condition of having teeth that appear in addition to the regular number of teeth, has been associated with genetic mutations and linked with increased tooth size (megadontia) (Khalaf et al., 2005; Brook et al., 2009a) and altered tooth shape (Brook, 2009; Brook et al., 2009a). Later instabilities in dental development will produce teeth with abnormal dentine and enamel structure, such as amelogenesis imperfecta and dentinogenesis imperfecta respectively (Fleischmannova et al., 2008; Brook, 2009).

2.1.3.5 Patterning within types

Dental studies conducted on mesiodistal crown diameters in different human populations have shown that variability across the tooth types of the dentition follows the same morphogenetic fields proposed by Butler (1939). While this holds true in general, Brook et al. (2009b) observed that overall crown sizes may vary according to the population studied. Another theory to explain patterning in the teeth is the clone theory (Osborn, 1978), which proposes that dental development of each class is determined by a clone or duplicate of mesenchymal cells that induces the dental lamina to commence tooth growth (Hillson, 1996; Townsend et al., 2009a). This theory, however, does not explain the development of the whole dentition. Lastly, the homeobox theory has been proposed (Sharpe, 1995; Townsend and Brook, 2008;

Townsend et al., 2009a), backed up by new data on the expression of different homeobox genes in the ectomesenchyme cells during odontogenesis. It has been suggested that the different types of teeth are established from overlapping or mixing of these homeobox genes (Nanci, 2008; Townsend et al., 2009a).

Studies of dental crown characteristics have been conducted to explain the link between the position of the enamel knots, the sequence of tooth development, and morphogenetic field patterning (Townsend and Brown, 1981; Townsend et al., 2009a). Intercuspal distances in Australian twins have been studied by Townsend et al. (2003a) and it has been observed that the intercuspal measurements were more varied and asymmetric compared with mesiodistal and buccolingual crown dimensions. This supports the idea that the position of cusp tips is influenced more by the environment or epigenetic effects during growth or development. Crown components of the upper molar teeth have been studied in a sample of Australian Aborigines by Takahashi et al. (2007) and it was noted that the last cusp to form, the hypocone, is also the most varied in terms of measurement and expression.

2.1.4 Methods for studying dental morphology

2.1.4.1 Models

To investigate further the influences brought about by genetic, epigenetic and environmental factors on tooth formation, accurate dental phenotyping must be undertaken. The use of traditional observational techniques, such as non-continuous indices, classifications and manual measurements of linear dimensions, i.e. mesiodistal and buccolingual crown dimensions, have provided useful methods for studying dental morphology. However, observers' variations exist with this approach.

Moreover, there is limited information when using linear measurements, especially when complicated shapes such as teeth and faces are encountered. Hence, more advanced techniques are needed in order to overcome these limitations.

2.1.4.2 Callipers

One of the widely used traditional techniques in measuring tooth size is the use of sliding callipers. These have beaks sharpened to fit in between the interdental spaces and can be used directly inside the mouth or indirectly on dental models (Moorrees et al, 1957; Hunter and Priest, 1960). Good levels of accuracy may be obtained when the direct method is used but access in the oral cavity can be limited. In a study by Lundström (1955), the author claimed that measurements made on the teeth themselves had a greater accuracy; however, this is often inconvenient or impracticable. Another study by Hunter and Priest (1960) compared both the accuracy and reproducibility of measurements made with dividers and callipers. The authors concluded that the use of dividers resulted in larger measurements than callipers. Some authors (DeKock, 1972; Howe et al., 1983; Harris, 1997) claimed that linear measurements made with callipers have a precision of 0.1mm. Compared to the indirect method, this method is more difficult to utilize as there are problems with access and in establishing the correct mesiodistal crown diameters of posterior teeth, especially in the maxilla (Hunter and Priest, 1960). The authors added that this method is patient-dependent, as the patient needs to be present every time a measurement is performed. Moreover, due to their sharp beaks, these hand-held callipers when used in the incorrect approach can damage dental casts and may alter future measurements (Barberia et al., 2009). Crowded and rotated teeth can hamper

acquisition of accurate measurements and thus these teeth are usually excluded from datasets (Brook et al., 1999; Brook et al., 2005; Smith et al., 2009a; 2009b).

2.1.4.3 2D/3D

New analytical techniques being developed have improved the accuracy and reliability of dental measurements. One of these methods is two-dimensional (2D) digital imaging. Using a digital camera, along with an adjustable stand to mount study models, standardised lighting and a scale for calibration, superior quality images of dental casts from occlusal and vestibular views are taken. This allows the acquisition of more data and has been shown to be accurate and reliable for measuring some tooth dimensions such as crown areas and perimeters. In crowded and rotated teeth, 2D digital imaging is able to measure linear dimensions of these types of teeth and more dental phenotypes can be obtained without damaging the dental casts (Brook et al., 1999; Brook et al., 2005; Smith et al., 2009a; 2009b). However, Smith and colleagues (2009a) have reported poor technique with this method may incur measurement errors, for example, image orientation (tilting of dental models), calibration procedures, as well as subjectivity in the identification of landmarks such as contact points and cervical areas.

Three-dimensional (3D) image analysis systems offer a better way to overcome these problems. These approaches involve obtaining images of dental casts in three different planes or axes using laser scanning, superimposing these images and creating a virtual 3D dental model. Compared to callipers and 2D systems, these techniques allow measurements of angles, volumes and other subdivisions of the tooth crown in 3D. With the recreation of dental casts in 3D views, curvatures and

contours of each tooth can be analysed and recorded (Smith et al., 2009a; 2009b). As with 2D systems, images can be stored for future use and manipulated using appropriate software. However, Ashar et al. (2012) have reported that this is an expensive and time-consuming procedure since the scanner can only pick up surface information within its field of view; hence, several scans are required to obtain a complete image of a dental cast.

2.1.5 Variations between populations

2.1.5.1 Size and shape of teeth

The amount of sexual dimorphism within and between populations can be quantified by studying tooth crown size (Moorrees et al., 1957; Garn et al., 1965c; Kieser, 1990). Many studies have shown that males have larger tooth dimensions, on average, than females. This is evident for both mesiodistal (Garn et al., 1965c; Garn et al., 1967; Harris and Lease, 2005) and buccolingual (Garn et al., 1966) diameters and for both deciduous (Black, 1978; Harris and Lease, 2005; Adler and Donlon, 2010) and permanent (Garn et al., 1966b; Schwartz and Dean, 2005) dentitions in humans.

According to Brook and co-authors (1984, 2002 and 2009), studies investigating tooth anomalies indicate that there is an association between variations of tooth number and size, as well as between sexes. The proponents have reported that hypodontia, which is the congenital absence of one or more teeth, is associated with microdontia (smaller teeth) and is more common in females, while hyperdontia or supernumerary teeth, which is the presence of one or more extra teeth apart from the normal dentition, is linked to megadontia (larger teeth) and is more common in males. Another study also reported that reduced tooth dimensions with variable degrees of severity were

found in the relatives of patients with hypodontia (McKeown et al., 2002; Brook et al., 2009a; Parkin et al., 2009). Brook et al. (2002 and 2009a) concluded that teeth adjacent to hypodontia/hyperdontia sites presented more abnormal development and morphology compared to patients with normal dentition, suggesting a combination of genetic, epigenetic and environmental factors are likely to be important in determining tooth number, size and morphology.

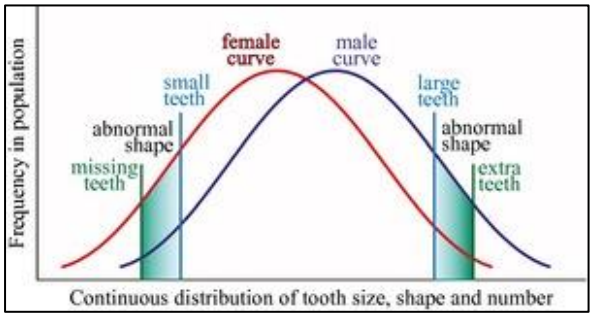

Figure 2-2. Continuous distribution of tooth size, shape and number (with permission from Australian Dental Journal, Brook et al., 2014).

In a study by Apps et al. (2004), researchers reported that female twins with low birthweight had smaller tooth size in both permanent and deciduous dentitions compared with twins with normal birthweight, suggesting that females may be more susceptible to environment disturbances than males.

2.1.5.2 Sexual dimorphism

Miller (1994) defined sexual dimorphism is defined as the phenotypic difference between males and females within the same species. The author stated that significant differences between males and females exist in relation to size, colour, body shapes, behaviours, weight and different tooth dimensions. Ribeiro et al. (2013) added that by studying tooth dimensions, the degree of sexual dimorphism within a population can be quantified.

Two major causes of observed phenotypic differences between males and females are sex hormones and sex chromosomes (McCarthy and Arnold, 2011). Dental studies involving families have noted that the X chromosome is important for permanent tooth crown size and dental development (Garn et al., 1965a; Alvesalo, 2009). Other important dental research have shown that the Y-chromosome influences dental growth by promoting both amelogenesis (growth of enamel) and dentinogenesis (growth of dentin), while the effect of the X chromosome on tooth growth has been considered to be limited to enamel formation (Guatelli-Steinberg et al., 2008; Alvesalo, 2009).

Studies have shown that sexual dimorphism is observed within both primary and permanent dentitions. Alvesalo et al. (1975), Alvesalo and Kari (1977), Alvesalo and Portin (1980) and Townsend and Alvesalo (1985a, 1985b) reported that the primary teeth and permanent teeth of 47,XYY males (males with an extra Y chromosome) and permanent teeth of 47,XXY males (males with an extra X chromosome) are generally larger than those of 46,XY (normal) male. Primary and permanent teeth of 45,X females and permanent teeth of 45,X/46,XX females (females with one X and normal XX cell lines) and 46,Xi(Xq) females (females with one normal X and one isochromosome with the long arm duplicated) were found to be smaller than those of normal 46,XX females (Filipsson et al., 1965; Kari et al., 1980; Townsend et al., 1984; Varrela et al., 1988; Mayhall et al., 1991; Mayhall and Alvesalo, 1992;). These results provide conclusive evidence of growth promoting effects of both the X and Y chromosomes on dental crown size, and that these chromosomes operate early and apparently in a continuous manner during dental development.

While the Carabelli trait has been found to be sexually dimorphic in the permanent dentition in some populations, with males displaying the cuspal form and females an absence or groove shape (Kieser, 1984; Hsu et al., 1997; Kondo and Townsend, 2006), no significant sex differences have been observed in the deciduous dentition (Joshi et al., 1972; Kieser, 1984; Hsu et al., 1997). However, there has been little research of sexual dimorphism in Carabelli trait using a suitable scoring method for the deciduous dentition. Moreover, the trend on the level of frequencies of the Carabelli trait expression may limit any extensive research. It has been reported that while there is an increase in Carabelli trait expression from Neolithic to modern times in Europe (Brabant, 1971), there is a decrease in Carabelli expression with overall dental reduction from Aboriginal to Modern Chinese populations (Hsu et al., 1997). Others have argued that the trait has decreased in frequency and level of expression over longer evolutionary time scales (Scott, 1979; Reid et al., 1991).

2.1.5.3 Symmetry/asymmetry

Bilateral structures in the human body tend to develop in general terms as mirror images of one another. However, Potter et al. (1976) demonstrated that they are rarely perfectly symmetrical even though they are often assumed to have the same genetic input. Van Valen (1962) suggested that these differences between bilateral structures reflects the inability of an organism to moderate the impact of accidents or noise during development. Asymmetries are defined as discrepancies between right and left sides of antimeric traits and they can be divided into directional asymmetry, fluctuating asymmetry, and antisymmetry. According to Hillson (1996), directional asymmetry is defined as “the tendency for one side to be consistently larger than the other”, whereas

fluctuating asymmetry refers to small random variations in phenotype expression between sides believed to occur as a result of developmental instability and/or failure of individual to buffer against developmental disturbances (Van Valen, 1962; Townsend and Brown, 1980; Hillson, 1996; Woodroffe et al., 2010). Van Valen (1962) further elaborated that antisymmetry refers to a less common condition where asymmetry is normally present but with a variable predominance between right and left sides. Handedness is a good example of antisymmetry in humans where right- and left-handed individuals are standard in the population while ambidextrous individuals are less common. Bailit et al. (1970), Townsend and Brown (1980), Townsend (1983) and Kieser et al. (1997) elucidated that bilateral asymmetries have a genetic component and seem to increase with inbreeding, genetic disorders and syndromes, as well as in unfavourable environmental situations, such as prenatal/maternal conditions, socio-economic status, malnourishment, limited physical habitat, extreme weather conditions, and diseases.

Since tooth crown size is determined before eruption into the oral cavity, and both right and left sides of the dental arches are presumed to be formed at the same time and under the same genetic influences (Perzigian, 1977), the dentition is particularly suitable for studying asymmetries. Bailit and Sung (1968) and Sciulli et al. (1979) have reported the importance of prenatal and neonatal environment in the development of asymmetries as well as the influence of some stressors such as cold, noise and lack of food on the determination of dental fluctuating asymmetry in rats. Bailit et al. (1970), Perzigian (1977) and Townsend and Brown (1980) have concluded that the more demanding the social, economic and health conditions operating on a population are, the higher the levels of asymmetry.

Some have found evidence of directional asymmetry in tooth emergence, dental crown size, and dental occlusion (Sharma et al., 1986; Townsend et al., 1999; Corruccini et al., 2005; Harris and Bodford, 2007; Harris and Smith, 2009; Mihailidis et al., 2009) most probably because of right hemisphere dominance of the brain over the left hemisphere. On the contrary, fluctuating asymmetry is thought to be caused by environmental disturbances (Boklage, 1987; Townsend et al., 1992; Townsend et al., 1994; Townsend et al., 1999). Asymmetry in studies using monozygotic and dizygotic twins has shown little or no genetic origin but fluctuating asymmetry was evident in both (Potter and Nance, 1976).

2.1.6 Causes of variation

2.1.6.1 Genetic, Epigenetic, Environmental

Variation in tooth number, size, and shape is determined by the complex interactions between genetic and environmental factors during tooth formation (Bailit, 1975; Kabban et al., 2001). It has been observed that teeth of monozygotic twins are strikingly similar that one can determine zygosity based on dental morphology (Townsend et al., 1988). The Carabelli trait has an estimated heritability of around 90% (Townsend and Martin, 1992), indicating strong genetic influence. Recent studies have demonstrated that epigenetic factors are important in explaining why phenotypic differences occur between monozygotic co-twins (Townsend et al., 2005; Brook, 2009; Townsend et al., 2009b).

The relative contributions of genetic, epigenetic and environmental influences vary depending on the phenotype being investigated. In one study, tooth emergence in the

primary dentition of Australian twins was found to be influenced mainly by genes and partly by the environment (Hughes et al., 2007; Woodroffe et al., 2010). In another study, interdental spacing in MZ twins was more congruent than that of DZ twins suggesting genetic influence (Thomas and Townsend, 1999). Palatal width and height have been found to be determined by genes, at least to some extent (Townsend et al., 1990). Occlusal features in MZ and DZ twins such as overbite, overjet and crossbite appear to be influenced mainly by the environment (Harris and Smith, 1980; Townsend et al., 1988). Moreover, asymmetry in dental arch shape seems to be affected by environmental factors mainly (Richards et al., 1990).

Researchers have defined 'epigenetics' as an alteration of gene expression without changing the DNA sequence which typically involves DNA methylation and histone modifications (Townsend and Brook, 2008; Barros and Offenbacher, 2009; Brook, 2009; Townsend et al., 2009b; Bell and Spector, 2011). It can be heritable and can be modified by environmental stimuli (Holliday, 1994; Russo et al., 1996). It plays an important role in determining phenotypic variations between monozygotic co-twins (Townsend et al., 2005; Brook, 2009; Townsend et al., 2009b).

2.1.6.2 Sex chromosome abnormalities

Tooth crowns are believed to be influenced by sex chromosomes during odontogenesis. Hence, a link between sexual dimorphism and sex chromosomes has been established (Garn et al., 1965b; Alvesalo, 2009). In studies by Townsend and Alvesalo (1985a; 1985b; 1999), it was found out that males with chromosomal abnormalities, such as males with an extra Y-chromosome (47,XYY) and males with Klinefelter syndrome (47,XXY), had larger tooth crowns than unaffected males. In

addition, the authors found that individuals with Turner syndrome (45,X) and females with the 45,X/46,XX chromosome mosaic syndrome had smaller tooth crowns compared with normal females (Varrela et al., 1988; Alvesalo, 1997; 2009).

Radiographic dentine and enamel thicknesses were also measured to determine the effect of sex chromosomes on dental tissues and to compare the results of normal males and females with those of males and females with chromosomal abnormalities. Alvesalo and colleagues (1987; 1991 and 2009) have demonstrated that both X and Y chromosomes have different influences on dental tissues. The X-chromosome is believed to affect crown enamel deposition while the Y-chromosome appears to be responsible for both dentine and enamel formation during tooth development (Alvesalo et al., 1987; Alvesalo et al., 1991; Alvesalo, 2009).

2.1.6.3 Family studies

Familial studies have established an association between anomalies of tooth size and number. One example is that found in the relatives of patients with hypodontia who also have reduced tooth dimensions (McKeown et al., 2002; Brook et al., 2009a; Parkin et al., 2009). Another is observed in individuals with abnormal tooth development adjacent to hypodontia/hyperdontia sites. This supports the notion that genetic, epigenetic and environmental factors are important determinants of tooth number, size and morphology (Brook et al., 2002; Brook et al., 2009a).

2.1.6.4 Twin studies (MZ vs DZ, MZ co-twin, MZ reared apart)

Studies of twins have been valuable in elucidating the roles of genetic, epigenetic and environmental influences on the phenotypic variations of dentofacial structures

(Lundström, 1948; Hatton, 1955; Horowitz et al., 1958; Osborne and De George, 1959; Lundström, 1963; Garn et al., 1965a; Townsend, 1978; Townsend and Brook, 2008) and of the human body, as a whole. Moreover, studies of twins have contributed to a better understanding of hormonal effects on dental development during the prenatal period (Dempsey et al., 1999; Ribeiro et al., 2013).

When two or more individuals occupy the same intrauterine space and resources, twin pregnancies occur (Townsend et al., 2009b). Twins can be classified as monozygotic (MZ) ("identical twins") or dizygotic (DZ) ("fraternal twins") (Townsend and Richards, 1990). MZ twins are two individuals who have the same sex and share the same genes whereas DZ twins come from two different zygotes each one having their own placenta, chorion and amnion. These are formed when the zygote cleaves soon after conception (Townsend and Richards, 1990).

MZ twins can be further classified to monochorionic and dichorionic depending on the number of placentas, chorions, amnions and timing of cleavage (Townsend et al., 1992; Townsend et al., 1999; Townsend et al., 2009c; Weber and Sebire, 2010). Monochorionic MZ twins are formed if the cleavage has occurred between the fourth and ninth day after conception and after implantation inside the uterus. They are characterized by a single placenta and two amnions. This type of MZ twins occur in 60% of MZ twin pairs. Dichorionic MZ twins are formed if the cleavage has occurred between the first and third day post-fertilization and prior to implantation. These twins will have separate placentas, chorions and amnions and occur in 20-30% of MZ twins. MZ twins whose zygote cleaved around the ninth or tenth day after conception and after implantation, will have a single placenta, chorion and amnion and around 3% of

twins fall in this category. If cleavage has occurred in a much later date, conjoined or Siamese twins are formed (Boklage, 1980; 1981; Townsend and Richards, 1990; Townsend et al., 1992; Race et al., 2006; Weber and Sebire, 2010).

Twins formed from two different zygotes are termed Dizygotic (DZ) or fraternal twins. Each has their own placenta, chorion and amnion and shares half of the genome. They can also have the same sex or opposite sex (Townsend and Richards, 1990). Since they are considered as full siblings genetically, they can serve as good research subjects in order to ascertain the influence of pre-natal environmental factors on dental morphology (Lauweryns et al., 1993; Townsend et al., 2003b).

The MZ co-twin model can be used to ascertain the epigenetic influences on phenotypic variations between MZ co-twins (Townsend et al., 2003b). According to Townsend et al. (2005), discordances are evident even between MZ co-twins. Studies of large samples of MZ twins have shown differences in expression of missing or supernumerary teeth between MZ twins. This may mean that the environment and/or epigenetic influences may have affected the dental development of these twins (Townsend et al., 2005; 2006).

The MZ co-twin reared-apart model involves MZ twins raised separately soon after birth and being taken care of by different family environments. This eliminates the possible confounding effects of common family environment (Townsend et al., 2003b; Townsend et al., 2009b; Townsend et al., 2009c). Boraas and colleagues (1988) have reported that by using MZ co-twin reared-apart model, there is a strong genetic control for dental traits such as incisor tooth crown size, occlusion, and caries predisposition.

2.1.6.5 Twin Testosterone Transfer (TTT)

The Twin Testosterone Transfer (TTT) hypothesis is another way of determining the influence of sex hormones, specifically testosterone, in the development of twin fetuses (Miller, 1994; Miller and Martin, 1995; Peper et al., 2009; Tapp et al., 2011). Studies supporting TTT hypothesis have shown evidence of masculinisation in human females from a male co-twin in terms of verbal ability (Record et al., 1970), mathematical performance and perceptual speed (Fischbein, 1978), otoacoustic emissions (McFadden, 1993), spatial ability (Cole-Harding et al., 1988) and sensation-seeking behaviour, including adventure seeking and susceptibility to boredom (Resnick et al., 1993). If this hormonal transfer does exist, along with its non-invasive and inexpensive nature, further research can be done to further elucidate the influences brought about by prenatal testosterone on the phenotypic and behavioural variations between twins.

Another study which supports the TTT hypothesis is the masculinised Disordered Eating (DE) attitude during puberty seen in females within opposite-sex twin pair. According to Culbert and colleagues (2013), this DE attitude was reported to be lower than in females with female co-twin or female singletons. It was proposed that this hormonal transfer may hasten sensitivity of neural androgen receptors making them more sensitive during pubertal hormone surges (Cohen-Bendahan et al., 2005a).

Increased Alcohol Use Disorder (AUD) symptoms (Ellingson et al., 2013), increased total brain volume (Peper et al., 2009), altered craniofacial growth and dental asymmetries (Boklage, 1985) and increased tooth crown size (Dempsey et al., 1999;

Ribeiro et al., 2013) were observed in females with co-twin brother. These suggest that hormonal transfer happened in utero influencing odontogenesis and other phenotypic variations (Dempsey et al., 1999; Ribeiro et al., 2013).

2.2 Human dermatoglyphs

2.2.1 Value as a model system

Human dermatoglyphs are distinct physical characteristics that remain unchanged throughout an individual's lifetime. They have been used extensively to establish human identity because no two persons, even pairs of monozygotic twins, have the same prints. The external structure of the friction ridge skin represents function, as the ridges and sweat pores allow the hands and feet to grasp surfaces firmly, while the creases allow the skin to flex (Maceo, 2011).

2.2.2 Fingerprint characteristics

2.2.2.1 Fingerprint patterns

The three main pattern types of fingerprints in humans are loops, whorls, and arches (Verbov, 1970; Kücken and Newell, 2005). Loops can occur as ulnar loops, or when the loop opens towards the small finger, or as radial loops, or when the loop opens toward the thumb. Such patterns are associated with a core, which is the centre of the loop, and one triradius or delta, which consists of three ridge systems converging to each other at a 120° angle. A whorl pattern will have two or more triradii, and can be further classified as symmetrical, spiral, or double-loop. Arches do not have a core or triradii, and they may be simple or tented, where a tented loop will have a centrally situated (Cummins and Midlo, 1943).

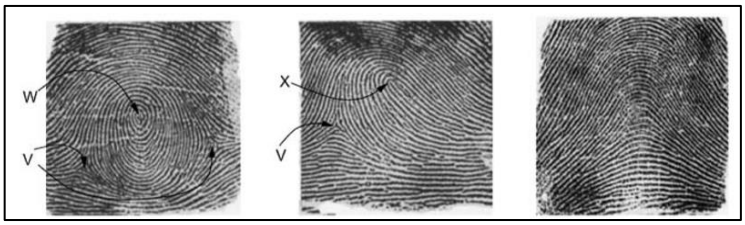

Figure 2-3. Fingerprint patterns. The three main types are whorls (a), loops (b), and arches (c). A core is associated with the whorl (w) and loop (x). The triradii (v) can also be seen (Kücken and Newell, 2005).

Individual ridges often show irregularity of direction, bifurcations, or discontinuities (Verbov, 1970). Such defects or minutiae include dislocations such as ridge endings and ridge bifurcations, island ridges, and incipient ridges (Kücken and Newell, 2005).

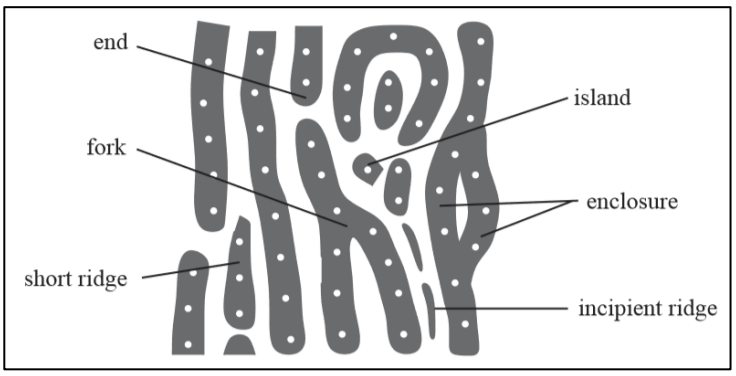

Figure 2-4. Different minutiae (Kücken and Newell, 2005).

Flexion creases are not epidermal ridges; they represent sites of attachment of the skin to underlying features (Verbov, 1970). The epidermal ridges themselves show orifices of sweat glands, with each ridge having a single row of pores spaced at regular intervals on the summit. As seen in their morphogenesis, fingerprint patterns occur at the interface between the dermis and the epidermis, and therefore cannot be destroyed by superficial skin injuries.

Pattern intensity reflects the number of triradii, and can be per individual, or as the average number per finger. Arches, loops, and whorls form a sequence of increasing pattern complexity – the plain arch has no triradii, the loop has one, and the whorl has

two. The determination of the value of pattern intensity in a mass sample may be made by compiling individual records of numbers of triradii or by translating the data of total frequencies of patterns (Cummins and Midlo, 1943). By using the index of pattern intensity, the values range from zero, which means all fingers are of plain arches, to 20, where all fingers are whorls.you

2.2.2.2 Ridge counts

Ridge count is the number of ridges that touch a straight line between two fixed points, i.e., two triradii or a triradius and a core (Miller, 1973). Despite modern methods of fingerprint feature assessment, it is still preferred that ridge counts are counted manually (Ponnarasi and Rajaram, 2012). They can be made from a traced radiant to a triradius, or along a 1-cm line placed at right angles to ridges (Cummins and Midlo, 1943).

The average ridge count in males is 145 and 127 in females (Penrose, 1967; Verbov, 1970). Holt (1968) used a method of measuring ridge counts that involves counting the number of ridges that cut or touch a straight line running from the triradius to the core of the pattern. However, using Holt's method may not be feasible with arch patterns having a score of zero. It is more difficult to apply for arch patterns that have no core or triradius and for whorl patterns with two triradii. To overcome this problem, Taduran et al. (2017) used a modified method of obtaining ridge count that employs the 1-cm line described by Cummins and Midlo. A strategic ridge, with the 1-cm line perpendicular to the ridges, was chosen for prints without a triradius, while the triradius with a higher ridge count was chosen for those with more than one triradius.

Other features such as pattern size and relative positions of triradii can also be measured linearly or by ridge counting (Bonnevie, 1924; Miller, 1973). Penrose (1967) stated that the number of ridges between the core and the relevant triradius is an index of pattern size.

2.2.2.3 White lines

White lines are skin folds found in friction ridges and are seen as white lines in print (Cummins and Midlo, 1943). The frequency of white lines increases later in life or when changes in subcutaneous body fat occurs (Ashbaugh, 1999; Cummins and Midlo 1943). White lines count show high significance in sexual determination, with females' fingerprints characterized as having a higher count of white lines than males' (Badawi et al., 2006; Taduran et al., 2016).

2.2.3 Development of fingerprints

Primary ridge fingerprint patterns start to emerge during the tenth week of gestation, and their formation is completed during the 16th week (Wertheim, 2011). Mulvihill and Smith (1969) have pointed out that dermal configurations reflect embryonic events and depend upon the morphology of the hand in general, particularly the embryonic volar pads. Kücken (2007) notes that areas that have been covered by the embryological volar pads are the sites where patterns like whorls and loops appear, whereas areas without the pads usually exhibit parallel ridges only.

2.2.3.1 Primary ridge formation

Volar pads emerge on the seventh week and continue to grow into high rounded hillocks with a defined base; they become less prominent on the tenth week of

pregnancy (Kücken, 2007).They occur at the fingertips, on the distal part of the palm between the digits, and in the thenar and hypothenar regions. According to Kücken and Newell (2005), undulations originating from the basal layer of the volar pad epidermis are responsible for the primary ridges, starting from the tenth week. The Folding Theory explains that intense cell proliferation in the basal layer during the tenth week produces compressive stress generated due to resistance of surrounding structures, which is evaded by folding.

Kücken and Newell (2005) have observed that stress generated in the basal layer originates from two effects: boundary effects, and normal displacements. It has been observed that ridges tend to align parallel to the creases and furrows, such as phalangeal creases and nail furrows. Because creases and furrows provide boundaries, the basal layer cannot expand towards the creases and become subject to compressional forces perpendicular to the creases. Ridges also usually arrive at a steep angle at the periphery of the palmar volar surface, never less than 45°. The palmar margins do not provide a resistance and so there is no perpendicular force; ridges will align perpendicular to the palmar margin. On the other hand, normal displacements from regression of volar pads lead to tangential stress. The regression of the volar pad is brought about by the faster growth of surrounding surface compared to the volar pad.

Bonnevie (1924) observed that the basal cells proliferate rapidly, and in order to alleviate the compressional pressure, the cells move away in periodic distances toward the dermis, as it is easier to penetrate compared to the upper epidermis. This theory has not yet been generally accepted, however, because it is not at all obvious

how cell proliferations can be organized in a way that they give rise to ridges (Kücken, 2007).

It is plausible that the presence of papillary nerves induces forces that pull in the epidermis. Such a theory originated from the finding of nerve fibers surrounded by blood vessels in the dermis projecting to the base of the primary ridges (Kücken, 2007). The nerve theory by Dell and Munger (1986) identified growth cones of nerve fibers that project to the epidermis, organized in a way that they coincide with the separation of the primary ridges. Because of the growth cones, afferent nerve fibers may provide a grid that could modulate the arrangement and spacing of the primary ridges (Dell and Munger, 1986). It has also been suggested that innervation could be the trigger mechanism for the onset of basal cell proliferation (Bonnevie, 1924). However, it is unlikely that nerves directly determine the flow of developing friction ridges. Ridge direction cannot be determined by the pattern exhibited by innervating axons (Kücken, 2007). It is more likely that nerve alignment is directed by the same stresses that establish ridge alignment, which explains why they coincide (Wertheim, 2011).

A third possible explanation of how primary ridges form is the fibroblast hypothesis, which arose when scientists observed that keratinocytes and fibroblast cells grown in culture align themselves on a petri dish in directional patterns reminiscent of ridge structure. Aside from these observations, no other evidence links fibroblast patterns with fingerprint patterns (Kücken, 2007).

The pattern on the fingertips is usually formed by three converging ridge systems: the ridge anlage or the area of high cell proliferation, the mantel ridge or the area along the nail furrow, and the basal ridge or the area distal of the flexion crease (Kücken, 2007). Ridge formation starts in the middle of the volar pad, the ridge anlage, and develop into the core of loops or whorls. It also starts along the nail furrow, the mantel ridge. Eventually, ridges spread over the volar pad, and the last areas to be covered become the triradii (Kücken and Newell, 2005). In other words, when the three ridge systems meet, triradii and minutiae are formed (Kücken, 2007).

The primary ridges may change by the introduction of minutiae, which may result from the faster growth rate of the hand compared to the breadth of the ridges leading to insertion of new ridges (Hale, 1952). The number of ridges increases to keep up with the hand's growth. As the finger expands, the existing ridges separate. New ridges pull away from existing primary ridges to fill in the gaps, thus creating bifurcation by mechanical separation. Ending ridges form when a developing ridge becomes sandwiched between two established ridges. It is important to note that other forces can influence minutiae formation; slight differences in mechanical stress, physiological environment, or variation in the timing of development could significantly affect the location of minutiae (Wertheim, 2011).

During the 14th to 15th week, the primary ridges experience growth in two directions: the downward penetration of sweat glands, and the upward push of new cell growth (Wertheim, 2011). Sweat gland ducts start to project from the bottom of the primary ridges into the dermis; this and the proliferation pressure of cells transfer the ridge pattern to the skin surface (Kücken, 2007).

2.2.3.2 Secondary ridge formation

Secondary ridges are also cell proliferations resulting in downfolds of the basal layer that appear between the primary ridges on the underside of the epidermis (Wertheim, 2011). They are shallower than primary ridges and do not contain sweat glands (Kücken, 2007). Though primary ridge formation ends on the 17th to 19th week, secondary ridges continue to mature from the 16th to the 24th week, producing furrows on the surface of the skin.

2.2.3.3 Dermatoglyphic development as a Complex Adaptive System

Human dermatoglyphs have been regarded as a complex adaptive system influenced by the interaction of genetic, epigenetic, and environmental factors (Taduran et al., 2016; 2018). Fingerprint patterns develop in the utero, and once established, it has a unique and persistent morphology that makes it a valuable model in understanding human development. Taduran et al. (2016) investigated subadult fingerprints of same Australian twins in two different age groups (eight to 10 years and 13 to 16 years), and they have noted that friction ridges expand as individuals grow and develop, and possibly more so in males than females.

2.2.3.4 Patterning within types

Patterning, wherein groups of cells establish themselves in proper relationship to each other and to surrounding tissues eventually leading to the differentiation of cells to assume specialized functions and shapes, occurs during embryonic growth. A possible relationship exists between the state of the volar pad and the ridge patterns that come with it, since the shape of the volar pad influences the stress across the skin

that determines ridge alignment (Kücken and Newell, 2004; Wertheim, 2011). Mulvihill and Smith (1969) state that patterns observed postnatally are a function of the height and contour of the embryonic pads during the period of regression in early foetal life, when primary ridge formation is occurring. For example, it was observed in monkeys that with persistent volar pads have predominant whorls on pronounced pads, loops on flatter and lengthier pads, and parallel ridges in regions without pads. In human embryos, whorls occur predominantly on embryos with early ridge formation, when the volar pads are still well-developed. Volar pad geometry is said to influence the fingerprint pattern; arches reflect the previous existence of low pads, loops reflect pads of intermediate height and asymmetry, and whorls reflect high pads (Miller, 1973). The size of the volar pad can also affect the ridge count from the core to the triradius during primary ridge formation (Wertheim, 2011).

The symmetry of the pad may influence the type of ridge pattern (Bonnevie, 1924; Kücken, 2005). According to Bonnevie (1924), radial loops occur frequently on the index finger, where the volar pad is usually slanted toward the small finger. Ulnar loops occur frequently on the small finger, where the volar pad is slanted towards the thumb. Lastly, whorls occur frequently on the thumb and on the ring finger, where volar pads are most symmetric. If the volar pad is symmetrical during the onset of primary ridge formation, then a symmetrical pattern such as a whorl or an arch will result. Similarly, the degree of asymmetry of the finger volar pad determines the asymmetry of the pattern type, such as “leaning” loops (Wertheim, 2011).

Table 2-3. Summary of events in fingerprint morphogenesis.

Time (in utero)	Event	Source
7th week	Emergence of volar pads	Kücken, 2007
10th week	Volar pads become less prominent; Start of primary ridge formation	Kücken, 2007
14th week	Penetration of sweat glands at the primary ridges End of primary ridge formation;	Wertheim, 2011
16th week	Start of secondary ridge formation	Kücken, 2007; Wertheim, 2011
24th week	End of secondary ridge formation	Kücken, 2007

2.2.4 Methods for studying dermatoglyphic trait

2.2.4.1 Ink

The traditional ink method by Cummins and Midlo (1943) is often used for recording fingerprints. A thin coat of black ink is directly applied to the skin's surface using a roller or by coating an inking plate with ink and rolling the fingers onto the plate. The inked skin is then pressed on a surface of contrasting color, such as a white piece of paper or fingerprint card (Cutro, 2011). Two types of impressions are produced: the rolled, where the fingers are rolled nail-to-nail, and the plain, where the impressions are pressed without rolling at the bottom of the fingerprint card. Rolled impressions are the upper ten finger impressions taken individually and are used to obtain all available ridge detail. They have more minutiae and are larger, and contain more data than plain impressions. Plain impressions are used to verify the sequence and accuracy of the rolled impressions (Van Hollen, 2009) as they are less affected by distortion and have clearer ridge structure (Feng et al., 2009).

A study by Gutierrez-Redomero et al. (2014) for estimating ridge density found differences in obtained values depending on the methodology of procuring fingerprint impressions. Notably, the radial area of the fingerprint has a lesser count value in plain

than in rolled impressions. They stressed the importance of using standardized methods of obtaining fingerprints, especially when involving a forensic application.

An explanation of the results of Gutierrez-Redomero et al. (2014) is that the areas where counting was done was different in plain from rolled impressions; because the area covered in rolled impressions are larger compared to plain impressions; the 5mmx5mm area chosen at the distal parts were farther out than the areas chosen for plain impressions (Figure 2-5). This might have led to the comparison of different areas thus resulting in different count values, rather than a change brought about by image distortion due to differing methods of impression procurement.

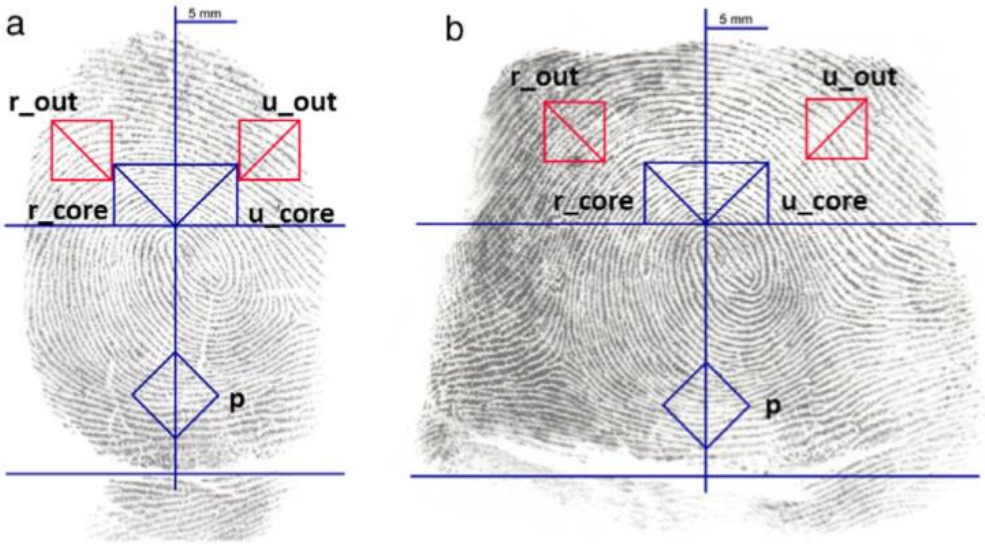

Figure 2-5. Location of the count areas used by Gutierrez-Redomero, et al. (2014) on the right thumb of the same subject. (a) Plain. (b) Rolled. r: radial, u: ulnar, p: proximal, out: external count area, core: core count area (Gutierrez-Redomero et al., (2014).

2.2.4.2 Ten print

Before computerization replaced manual filing systems in large fingerprint operations, fingerprint classification were done manually. They used to categorize fingerprints

based on general ridge formations, such as the presence or absence of circular patterns in various fingers (Adebsi, 2008).

In 1889, Sir Francis Galton defined the three basic fingerprint patterns as arch, loop, and whorl. He created a classification system based on alphabetical enumerations of the three patterns where an individual will have a classification code with ten letters based on the identified patterns from each ten fingers (Hutchins, 2011). This ten-print classification system has been adapted in modern times and became the basis for the Vucetich system developed in Argentina, and used in South America; the Roscher system developed in Germany, and used in Germany and Japan; and the Henry classification system developed in India, and used in most English-speaking countries.

It should be noted that, regardless of whether a plain impression is compared to a rolled impression or vice versa, match scores are still high (Nadgir and Ross, 2006). Fingerprint pattern and minutiae do not change over time, as long as the subject has not sustained any injury reaching the dermal layer of the skin.

2.2.4.3 Scanning

Fingerprint sensors can be used to acquire a livescan digital fingerprint image directly from the finger, without the use of ink and paper card (Moses, 2011). Latent fingerprints, which result from the perspiration on the skin, can also be chemically or physically developed, then electronically captured or manually lifted from the surface. From there the triradius index can be calculated by summing the number of triradii from the ten fingers.

2.2.4.4 AFIS

With the advent of technology, manual classification has been replaced with an automated one, which is faster and can facilitate the management of large fingerprint databases. The Federal Bureau of Investigation first started with punch cards and sorting machines, which developed into the use of interconnected computers. Programming of minutiae extraction software ensued. The Automated Fingerprint Identification System (AFIS) was developed in the early 1980s, where a mathematical map of each impression is created. Each map contains the computer-determined pattern type and the minutiae location and direction (Hutchins, 2011).

Current fingerprint verification and identification algorithms can be classified into two categories: image-based, and minutiae-based. Image-based methods include those involving optical correlation and transform-based features. Other aspects of fingerprint identification are orientation, segmentation, and core detection (Ponnarasi and Rajaram, 2012).

Performance of a fingerprint feature extraction and matching algorithm depends critically upon the quality of the input fingerprint image, or the clarity of the ridge structures in the image. Classification performance in such a method is highly dependent on pre-processing steps such as image enhancement, histogram equalization, and noise reduction. After converting the image into grayscale, the images can be subject to binarization, as the image involves only black pixels (representing the ridges), and white pixels (representing the valleys). For classification purposes, such as determination of ridge and valley thickness, the processed image

can be divided into non-overlapping blocks. Quality can also be assessed through this method.

Recent advances in computing and digital imaging technology have led to the introduction of new AFIS methodologies using electronic live-scan plain impression fingerprint images as the basis for identification. Plain impression AFIS applications are relatively new, with some well-publicized success and no documented reports of significant problems. They are also not as complex as the rolled impression methodology used in law enforcement. However, Dechman (1996) emphasizes that it has disadvantages. A plain impression print is has less area and therefore less data. It also tends to use and capture lesser fingers; the uncaptured fingers become unavailable for backup.

Moses (2011) notes that although automatic fingerprint matching algorithms can reduce the work involved, they are less accurate than a well-trained forensic expert. In fact, in law enforcement applications today, the AFIS produces only a candidate list of possible fingerprint matches. These have to be reviewed manually to determine if any of the candidate records is truly a match (Dechman, 1996).

Computer algorithms yield imperfect results because of large intraclass variations present in the fingerprints, which arise from factors that vary during the acquisitions of the same fingerprints. Such factors include displacement, rotation, partial overlap, nonlinear distortion, pressure, skin conditions, noise from the imaging environment, and errors in the automatic feature-extraction algorithm (Moses, 2011).

2.2.5 Variations between populations

2.2.5.1 Ridge counts

Differences in total ridge count frequencies between different populations may be expected because the frequencies of fingerprint patterns vary between populations (Namouchi, 2011).

A study by Sharma et al. (2007) revealed significant variations in total finger ridge counts between participants from the northern part of India versus those from the east, and those from the east versus from the west. Since total ridge counts are more likely genetically influenced, the results establish underlying genetic differences among these population groups.

2.2.5.2 Fingerprint patterns

Anthropological studies have been conducted on distinct populations to identify trends in fingerprint pattern formation. One of the most comprehensive reviews of was conducted by Mavalwala (1977), whose major result was the demonstration that intratribal variations in friction ridge pattern frequencies were greater than intertribal variations. Likewise, intraspecies variations in primates were greater than interspecies variations. The body of literature on ethnic variation suggests that multiple genes affect pattern formation and that those genes interact with respect to final pattern characteristics (Wertheim, 2011).

In Britain, loops are the commonest pattern type and represent about 70% of all finger patterns, while whorls represent 25%, and arches, 5% (Verbov, 1970). Higher frequency for loops in both sexes was also found in the Berber population of the high

Atlas of Morocco (Sabir et al., 2005), in Polish (Loesch, 1970), in Costa Ricans (Segura and Barrantes, 2009), Kenyans and Tanzanians (Igbigbi and Msamati, 2005), in Tunisians (Namouchi, 2011), in Iranians (Mehdipour and Farhud, 1978), and in Russians (Karmakar et al., 2007). Asiatic populations, however, have a much higher percentage of finger whorls (Holt, 1961). In Malays, 51% have whorls and about 40% have loops (Ismail et al, 2009). In Thais, about 45% have whorls and about 41% have loops (Nanakorn et al., 2013). In Filipinos, 40% have whorls but a higher 57% have loops (Taduran et al., 2016). In Han and Kam populations in southern China, frequencies of ulnar loop and simple whorl are the highest (Cheng et al., 2009). The most common pattern types in Nagaland Indians were whorls and loops, either of more or less equal frequency (Banik et al., 2009).

Sharma et al. (2007) conducted a study on five different populations groups from different regions in India, because different regions in India have different ethnic backgrounds. The results of the study show that those from the west had higher arch frequencies, while loops are more common in the north. This suggests that ancestral differences in dermatoglyphics do occur. However, fingerprints ridge pattern still cannot be used to classify a specific person's ancestry; there is no exclusive ridge pattern for a particular ethnic group (Verbov, 1970).

Table 2-4. Fingerprint pattern frequencies in different populations.

Population	% whorls	% loops	% arches	Source
Costa Rica	21.7	66.7	11.6	Segura and Barrantes, 2009
Brazil	30.8	64.3	4.9	Penhalber et al., 1994
Britain	25	70	5	Verbov, 1970
Poland	25.6	68.8	5.6	Loesch, 1983
Kenya	18.2	77.8	4.0	Igbigbi and Msamati, 2005
Tanzania	18.3	77.4	4.3	Igbigbi and Msamati, 2005
Russia	34.4	60.1	5.5	Karmakar, et al, 2007
Iran	38.5	56.9	4.6	Mehdipour and Farhud, 1978
India	41.8	52.2	6.0	Banik et al., 2009
China	48.6	47.6	3.8	Cheng et al., 2009
Malaysia	57	39.5	2.5	Ismail et al, 2009
Thailand	45.3	40.9	3.8	Nanakorn et al., 2013
Philippines	39.9	56.9	3.2	Taduran et al., 2016

2.2.5.3 Sexual dimorphism

The reasons for sexual dimorphism observed in the dermatoglyphic patterns can be supported by the fact that differences in heritability and developmental variation among sexes might account for these patterns (Meier, 1980). Dermatoglyphic research on sexual dimorphism has focused on pattern and metric variation among different geographic populations (Mundorff et al., 2014).

With regards to ridge patterns, females have a higher incidence for arches, but a lower incidence for whorls (Verbov, 1970). An eastern Andalusia population was described by more whorls and radial loops in males and by more arches and ulnar loops in

females (Luna and Pons, 1987). Data obtained by Banik et al. (2009) showed that females did have a higher frequency of arches, but their statistical analysis concluded that there was no significant difference between the two sexes with respect to frequencies of finger patterns. A study by Namouchi (2011) found that, in Tunisian populations, females had a significantly higher frequency for arches on the left little finger, while males had significantly higher frequency for loops on the left ring finger and thumb, and whorls on the left ring finger. In Middle Eastern Jews, males had more whorls and fewer ulnar loops than females (Kobyliansky and Micle, 1987).

Table 2-5. Pattern diversity between sexes.

Population	Sex	% whorls	% loops	% arches	Source
India	Males	52.19	47.70	0.11	Banik et al., 2009
	Females	55.69	42.81	1.50	
Africa	Males	18.54	76.52	4.94	Igbigbi and Msamati, 2005
	Females	17.46	79.43	3.11	
Middle East (Jews)	Males	47.35	50.39	2.29	Kobyliansky and Micle, 1987
	Females	31.77	63.86	4.36	
Russia	Males	36.2	58.9	4.9	Karmakar et al., 2007
	Females	32.4	61.5	6.1	
Thailand	Males	47.6	49.6	2.8	Nanakorn et al., 2013
	Females	44.2	51.6	4.2	

Because females show higher frequencies for arches, it could be expected that their pattern intensity index, which reflects the number of triradii, would be lower compared to males. In Middle Eastern Jews, males had higher pattern intensity indices as they have more whorls and radial loops, and less ulnar loops and arches (Kobyliansky and Micle, 1987). Malawian and Tanzanian males also had higher pattern intensity index compared to females (Igbigbi and Msamatii, 1999; 2005). However, the pattern intensity index was found to be higher in females than males in the Muzeina Bedouins from South Sinai Peninsula (Karmakar and Kobyliansky, 2012). Females also had higher pattern intensity index compared to males in Kenya (Igbigbi and Msamati, 2005). In populations from Nagaland India, no significant difference in pattern intensity index between the two sexes was observed (Banik et al., 2009).

It can be concluded from the data from different studies that calculating the pattern intensity index is not a good approach for sex determination, as it is heavily influenced by ethnicity rather than heritability and developmental variation among sexes.

It was stated earlier that higher testosterone level is predictive of greater dermatoglyphic asymmetry, showing higher values for digital radial count, digital ulnar count, and digital pattern intensity in the left hand; lower testosterone levels show higher values in the right hand (Sorenson Jamison et al., 1993). By this conclusion it is likely that women would have higher rightward asymmetry, or the ridge count of the fingers in the right hand are higher than the left. However, a study by Badawi et al. (2006) showed that there is no significant difference in the degree of asymmetry

between males and females, and so asymmetry will not be a good candidate for classification of fingerprints according to sex.

Badawi et al. (2006) have also noted that the fingerprints of females are of lower quality than males. Their results show that the fingerprints in females are characterized by high counts of white lines, with the exception of a small percentage having few or no white lines. On the other hand, the fingerprints in males are characterized by having few or no white lines, with an exception of a small percentage having high count for white lines. Taduran et al. (2016) observed similar results in white line counts in Filipinos. In both research, it has been concluded that white line counts show high significance in the classification process (Badawi et al., 2006; Taduran et al., 2016).

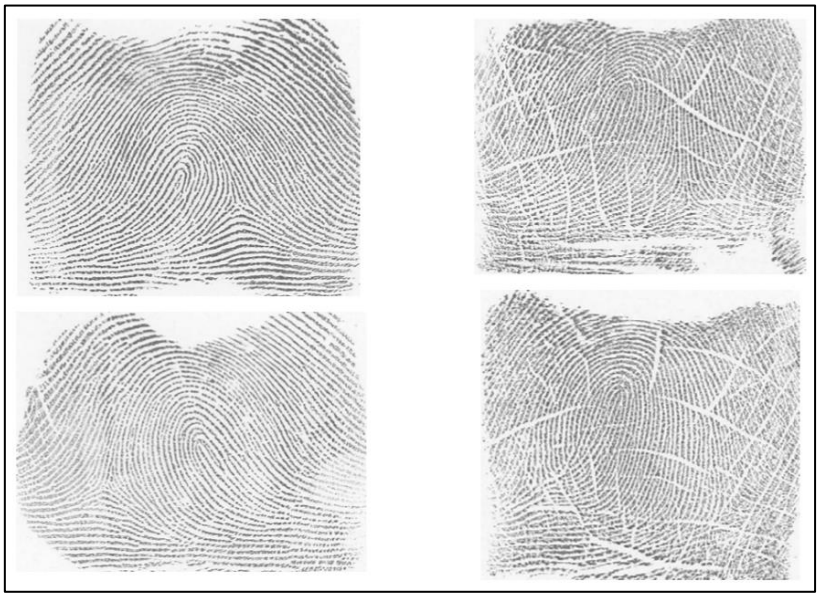

Figure 2-6. Comparing white line counts in males and females. Male fingerprints (A and B) are noted to have fewer white lines compared to female fingerprints (C and D) (Badawi et al., 2006).

There are not many studies with regards to using white lines for sex determination, but it is important that subjects in such studies be homogenous so that factors that may

influence white lines count can be minimized. Scarring is a factor that may influence the presence of white lines; a possible approach is to use subjects of the same age group and occupation, as lifestyle and activity may influence the probability of scarring.

With regards to ridge counts, Sanna et al. (2004) studied two Sardinian linguistic groups, and found out that total finger ridge count and ulnar ridge count are two dermatoglyphic variables that demonstrate significant differences between males and females. A study involving Muzeina Bedouins from South Sinai Peninsula by Karmakar and Kobyliansky (2012) found that the mean ridge count of a pattern of a given type is greater in males than in females; this is also true with regards to the total finger ridge count. A similar result was obtained in Rengma Nagaland Indians (Banik et al., 2009), Kenyans, and Tanzanians (Igbigbi and Msamati, 2005), as well as Middle Eastern Jews (Kobyliansky and Micle, 1987). Verbov (1970) has noted in his paper that males have higher total finger ridge counts than females, averaging 145 in males and 127 in females.

Females have lower ridge counts compared to males and Penrose (1968) stated that this is due to the presence of an X chromosome that has twice the effect on finger pattern size reduction as the Y chromosome. This is in contrast to the case in Malawans, where females had higher total ridge counts than males (Igbigbi and Msamati, 1999).

The trend in Malawans can be explained by the study of Acree (1999), which found that females had finer ridge detail and higher ridge density, and therefore higher ridge counts, compared to males. Verbov (1970) agreed with the statement that ridges tend

to be set wider apart in males than in females, but he also stated that on average the total finger ridge count of males is higher than in females. Namouchi (2011) found no significant difference in finger ridge counts between sexes in the Tunisian population, although males still had higher total ridge counts than females. In select populations in Nagaland India, mean values of their total ridge counts were also higher in males, but this was not found to be statistically significant (Banik et al., 2009).

Table 2-6. Total finger ridge counts between sexes of different populations.

Population	Male	SD	Female	SD	Source
Muzeina Beduins (India)	160.81	36.27	155.96	37.46	Karmakar and Kobyliansky, 2012
Rengma Nagaland Indians	156.39	-	152.85	-	Banik et al., 2009
Tunisians	141.829	-	135.8	-	Namouchi, 2011
Kenyans	125.60	39.0	116.26	32.16	Igbigbi and Msamati, 2005
Tanzanian	115.05	32.14	114.9	32.50	Igbigbi and Msamati, 2005
Middle Eastern Jews	151.70	46.90	128.22	53.00	Kobyliansky and Micle,1987
Malawans	123.72	39.82	140.15	48.70	Igbigbi and Msamati, 1999

No definite conclusion can be made about significant differences in ridge counts between sexes, as different studies using different population samples yield different results. Studies have confirmed that the degree to which sexual dimorphism is expressed varies between populations (Mundorff et al., 2014). Because of this, using

ridge counts for sex determination is not definitive; other dermatoglyphic traits should be used.

A study by Gutierrez-Redomero et al. (2008) explored epidermal ridge density, which is determined by the ridge width and the distance between ridges. Since women have finer ridges than men (Acree, 1999), it is expected that they have greater ridge density. Acree (1999) established a threshold of gender differentiation which says that a ridge count in a 5×5 mm2 of $\leqslant$11 is more likely male while $\geqslant$12 is more likely female. This is in agreement with the ridge densities found in Indians (Gungadin, 2007), Chinese, and Malaysians (Nayak, et al., 2010) and Filipinos (Taduran et al., 2016). The study by Gutierrez-Redomero et al. (2008) on Spanish Caucasians found that indeed, women tend to have significantly higher ridge density in all 10 fingers than men, but this is specifically in the distal regions; this trend is not seen in the proximal region. Such a finding by Gutierrez-Redomero et al. (2008) strongly suggests that ridge density values are dependent on the area chosen, and a standard area should be used when doing studies about ridge density. Jantz and Owsley (1977) explain that the differences in ridge density are due to different developmental instructions in those different parts.

Table 2-7. Ridge density between sexes of different populations

Population	Male	SD	Female	SD	Source
European- American	11.14	1.31	13.32	11.24	Acree, 1999
African-American	10.90	1.31	12.61	1.43	Acree, 1999
Indian	12.80	0.90	14.60	0.08	Gungadin, 2007
Spanish	16.23	1.39	17.91	1.47	Gutierrez-Redomero et al., 2008
Chinese	11.73	1.07	14.15	1.04	Nayak et al., 2010
Malaysian	11.44	0.99	13.63	0.90	Nayak et al., 2010
Indian	11.05	1.11	14.20	0.63	Nayak et al., 2010
Mataco-Mataguayo	16.62	2.71	17.82	2.87	Gutiérrez-Redomero et al., 2011
South Indian	12.57	1.49	14.15	1.68	Nithin et al., 2011
North Indian	15.84	1.23	17.94	1.23	Krishan et al., 2013
Ramal Argentinian	17.04	1.68	19.08	1.84	Gutiérrez-Redomero et al., 2013
Puna-Quebrada Argentinian	16.67	1.78	18.47	1.56	Gutiérrez-Redomero et al., 2013
Filipino	14.57	1.43	15.89	1.69	Taduran et al., 2016

A study by Mundorff et al. (2014) showed that males have a significantly higher mean ridge breadth compared to females. Their data also showed that larger individuals tend to have greater ridge breadth compared to smaller individuals, leading to some females being misclassified as males and vice versa when ridge breadth was used.

2.2.5.4 Symmetry/asymmetry

Namouchi (2011) found that the total finger ridge count in both sexes among Tunisians was higher on the right hand than on the left one. Gutierrez-Redomero et al. (2008) discovered that the thumb and index fingers of Spanish Caucasians show lesser ridge density in the radial and ulnar areas than in any other fingers, implying that there is a presence of thicker ridges in the two fingers. However, in the proximal region of the finger, the ridge density is greater in the two fingers. They also found that the ridge count in the ulnar and radial areas of the finger increases from thumb to ring finger, implying that the finest ridges occur in the anatomical axis of the hand. The mean ridge density was also found to be greater in the left hand, meaning the left had has finer ridges than the right hand (Gutierrez-Redomero et al., 2008). Jantz and Owsley (1977) explain that the differences in ridge density of different areas within the digital fingerprint may be due to different developmental instructions; it is advised that radial, ulnar, as well as proximal have different counts.

Mundorff et al. (2014) observed that mean ridge breadth decreases from digits I to IV, or from thumb to ring finger; the mean ridge breadth were also found to be greater for right fingers than left fingers. These findings are consistent with those of Gutierrez-Redomero (2008). Results of Mundorff et al. (2014) also show that there are significant interfinger differences in mean ridge breadths for each hand.

Certain patterns have been found to occur more frequently on certain fingers than on others. Whorls are found to have maximum frequency on thumbs and ring fingers, radial loops are most commonly found on the index finger, and ulnar loops have the

highest frequency on the little finger (Verbov, 1970; Cummins and Midlo, 1943). This observation agrees with that of Bonnevie (1924), which explains the influence of volar pad symmetry. The symmetry of the volar pad is said to influence the type of ridge pattern formed (Bonnevie, 1924; Kücken and Newell, 2005). According to Bonnevie (1924), radial loops occur frequently on the index finger, where the volar pad is usually slanted toward the small finger. Ulnar loops occur frequently on the small finger, where the volar pad is slanted towards the thumb. Lastly, whorls occur frequently on the thumb and on the ring finger, where volar pads are most symmetric. Simply put, if the volar pad is symmetrical during the onset of primary ridge formation, then a symmetrical pattern such as a whorl or an arch will result. Similarly, the degree of asymmetry of the finger volar pad determines the asymmetry of the pattern type, such as “leaning” loops (Wertheim, 2011).

In a study on Middle Eastern Jews, Kobyliansky and Micle (1987) observed that index fingers show the greatest diversity of pattern types, while small fingers are the less variable; index fingers also present the lowest frequency of pairs bearing the same pattern in right and left digits, while small fingers present the highest. In addition, whorls and radial loops are more common on right hands (Verbov, 1970).

In Muzeina Bedouins from South Sinai Peninsula, thumbs have the highest ridge counts, followed by the ring finger (Karmakar and Kobyliansky, 2012). A study by Namouchi (2011) found that in the Tunisian population, the highest number of ridges in both sexes is also the thumb. Esteban and Moral (1992) explains that the reason why thumbs tend to have higher ridge counts is because of their elevated frequency of whorls, as seen in a population in Murcia, Spain. The mean ridge counts of pattern

types decrease from whorl to ulnar loop to radial loop (Kobyliansky and Micle, 1987). In addition, Kobyliansky and Micle (1987) states that patterns located on the thumbs have higher ridge counts than the patterns of the same type located on the other fingers.

2.2.6 Causes of Variation

2.2.6.1 Genetic, epigenetic, environmental

It is currently thought that several main genes, in conjunction with a number of modifying genes, may be responsible for volar patterning, and hence also the type of fingerprint pattern (Kücken, 2007). Langenburg (2005) explained that the spacing and arrangement of the primary ridges is a random process but is dictated by the geometry and topography of the volar pad. The timing of volar pad regression and primary ridge appearance is genetically linked; the exact arrangements of the ridges, minutiae and other identifying features, however, are not (Langenburg, 2005).

Although the capacity to form friction ridges is inherent within the developing embryo, the patterns that these ridges form are limited. Genetics may direct when and where ridges will form by providing the proteins, but the boundaries for patterning are determined through physical mechanisms (Ball, 1999). An example that illustrates this is monozygotic twins, who share identical genetic information and similar intrauterine environments, yet have different fingerprints.

It is well established that friction ridge patterning is also affected by the environment and is not solely influenced by genes (Wertheim, 2011). This agrees with earlier section of this review that this development is a Complex Adaptive System. Genetics

may influence pattern formation indirectly by contributing to the timing of the onset of friction ridge skin, volar regression, and growth rate of the foetus. Finger ridges are formed through regression of embryonic volar pads on fingers, and the number of ridges is largely related with the time and degree to which these pads sink (Loesch, 1983). It is more likely that total finger ridge counts, which estimate the pattern size, are influenced by genetics, since genetically controlled timed events would be less susceptible to environmental factors (Wertheim, 2011). Holt (1968) has concluded that total ridge count is an inherited metrical character that is controlled by the action of a number of perfectly additive genes, and that the environment plays a comparatively small part in its expression. Verbov (1970) agrees with this, stating that the total finger ridge count is the most consistent and reliable measurement for familial investigations and is an inherited metrical character in which a number of perfectly additive genes are concerned; environment plays a comparatively small part.

2.2.6.2 Sex chromosome abnormalities

According to Verbov (1970), patients with sex chromosomal aberrations have been found to have disturbances in their epidermal ridge arrangements. Those with Turner's syndrome, whose karyotype is 45 X, have total finger ridge counts that are increased as compared to the normal male, while those with conditions that have increased numbers of X chromosomes have reduced total finger ridge counts, as seen in patients with Klinefelter's syndrome (XXY). Loesch (1983) also noted that abnormal sex chromosomes cause dermatoglyphic abnormality, especially in finger ridge counts, suggesting the existence of genes on sex chromosome that control dermatoglyphic formation.

Namouchi (2011) also agrees that finger ridge counts follow genetic modes of major genes. Medland et al. (2007) have observed a similar mode of inheritance for finger ridge counts in which significant genomic linkage has been found on chromosomes 5 and 1; contributing genes of finger ridge counts are located at 5q14.1, which include several zinc finger genes controlling gene expression. According to Cheng et al. (2009), total finger ridge count is related to heterozygous genotypes. Different alellotypes of these genes may be associated with directions of finger ridges, and so the heterozygosity for zinc finger genes may produce finger ridges with more directions and complex distributions, as well as increase finger ridge counts (Cheng et al., 2009). Axial triradius angles have also been shown to have notable heritability.

Penrose (1967) notes that the fingertip pattern size, as measured by the total ridge count, is also an autosomal trait which is independently influenced by sex-chromosome complement. The presence of an X chromosome has twice or thrice the effect on finger pattern size reduction as the Y chromosome (Penrose, 1967; 1968). Namouchi (2011) found out from her study of Tunisian populations that multivariate analysis of several quantitative digito-palmar dermatoglyphic traits represents a powerful tool in intra-population genetic differentiation; this conclusion can be deduced from molecular marker analyses. It can be noted that a dermatoglyphic approach may also be useful as a screening method for identifying patients who are likely to have chromosomal aberrations (Verbov, 1970). Dermatoglyphic changes has been found in clinical conditions where neither a single gene nor a chromosomal basis has been discovered, examples of which are maternal rubella or thalidomide intake that both lead to exogenous embryopathies.

2.2.6.3 Family studies

Holt (1968) stated that in no case has the inheritance of a dermal ridge trait been unequivocally explained by single factor inheritance. A study conducted by Slatis et al. (1976) involved the analysis of the fingerprints of 571 members of the Habbanite, an Israeli community who formerly lived in Habban in South Yemen and Beida in Yemen, and suggested that ridge patterns and pattern sequences are genetically inherited. The study assumes that the basic fingerprint pattern sequence is all ulnar loops, as this was the most common. A variety of genes then cause deviations from this pattern sequence, forming whorls, arches, or radial loops. Through pedigree analysis, the study concluded that the presence of arches is caused by a dominant gene; the same conclusion was made for the presence of radial loops on the index fingers, and for the pattern sequence that involves whorls on all fingers except for an ulnar loop on the middle finger. A semi-dominant gene is proposed for the whorled thumb phenotype, and for whorls on ring fingers. Lastly, a recessive gene is proposed for radial loops on the ring and small fingers. The researchers noted that these genes may act independently, or may show epistasis or masking.

2.2.6.4 Twin studies (MZ vs DZ, MZ co-twin, MZ reared apart)

Karmakar et al. (2011) did a familial study on twins in Moscow, Russia. Using monozygotic twins, and female dizygotic twins, they first obtained the frequency of coincidence for the four basic types of finger patterns (ulnar loop, radial loop, arch, and whorl) on each finger in monozygotic and female dizygotic twins separately, then they analysed the genetic and environmental components of distribution on 10 fingers for the three basic patters (loop, arch, and whorl) in the whole sample. The results of their statistical analysis show that monozygotic twins had the highest rate of

concordance in the frequency distribution of the four patterns as compared to dizygotes, solidifying the idea of genetic factors playing a big role in dermatoglyphic inheritance.

Karmakar et al. (2011) also notes that arches more likely appear on fingers where the mechanical pressure due to muscular tone is significant, and suggested that mechanical inheritance of this pattern can include genes responsible for different muscular tone.

A separate twin study was done by Machado et al. (2010), and their study results show that the left hand thumb, ring finger and little finger, as well as the right hand thumb, have the lowest heritability values, pointing out that the intra-uterine environment can result to different microdetails.

A study by Cheng et al. (2009) explored Han and Kam communities in southern China. Under the assumption that fingerprint pattern type followed a multi-gene model, they found out that the simple arch pattern may be produced by homogenous genotypes of different alleles on a single locus. The hypothesis of bifactorial inheritance for fingerprint patterns was proposed by Grüneberg in 1928, which states that the simple arch pattern is controlled by homozygous alleles on two different gene loci (Cheng et al., 2009). The results from the study by Cheng et al. (2009) show that the simple arch reflects homozygosity at gene loci.

Namouchi et al. (2011) notes that the distribution of interdigital patterns has also been proven to follow a multi-allelic major gene mode of inheritance.

The twin study by Machado et al. (2010) showed that ridge counts for right hand, left hand, and most individual fingers show high heritability, confirming that there is a predominant genetic influence on total ridge counts.

2.2.6.5 Twin Testosterone Transfer (TTT)

The twin testosterone transfer (TTT) hypothesis refers to the phenomenon in which testosterone synthesised by a developing male foetus diffuses to a female co-twin and influences development and various traits relating to sexual differentiation (Miller, 1994; Miller and Martin, 1995; Peper et al., 2009; Tapp et al., 2011). It predicts that the higher level of prenatal testosterone in the amniotic fluid of a male foetus would result to “masculinisation” of some features of the female co-twin (Cohen-Bendahan et al, 2005; Wallen, 2005; Tapp et al, 2011).

Aside from the possible effect of sex chromosomes on ridge counts, it can be noted that the Y chromosome may indirectly induce dermatoglyphic asymmetry when comparing the left and right hands. The development of the testes, which produces foetal testosterone, is encoded in the sex determining region Y gene located in the short arm of the Y chromosome. Prenatal testosterone serves as a stimulus for both Nerve Growth Factor and Epidermal Growth Factor, and so is very likely to affect dermatoglyphic development (Jamison et al., 1993). A study by Jamison et al. (1993) explored the possible relationship of dermatoglyphic asymmetry to testosterone levels taken from salivary samples of adult males. Since internal environmental factors are known to affect dermatoglyphic traits, the study investigated whether prenatal testosterone levels affect dermatoglyphic development in the foetus. Under the

assumption that secondary testosterone levels may reflect prenatal testosterone levels, it was found out that a higher testosterone level is predictive of greater dermatoglyphic asymmetry, showing higher values for digital radial count, digital ulnar count, and digital pattern intensity in the left hand; lower testosterone levels show higher values in the right hand.

Studies on prenatal testosterone have always been accompanied with methodological challenges. The direct sampling of it in the amniotic fluid in pregnant human mothers, via amniocentesis, is too dangerous and invasive, and performed only when there is a legitimate medical reason, therefore generating small and potentially unreliable data (van de Beek et al, 2004; Baron-Cohen et al, 2004; Tapp et al, 2011). Exogenous manipulations of testosterone have been conducted in non-human species, and the high doses of exposure to this hormone have been found out to cause greater phenotypic changes in foetuses compared to the ones exposed to lower doses (Cohen-Bendahan et al, 2005). Clearly, hormonal manipulation in human foetuses is unethical and inhumane. This is why TTT hypothesis serves as an important alternative, a more convenient yet still reliable and objective approach because it can be investigated by comparing sexually dimorphic phenotypes in females from dizygotic opposite-sex twins (DZOS) with females in dizygotic same-sex twins (DZSS) and females of monozygotic twins (MZ). There has been no published work on TTT in dermatoglyphics as of this writing. Taduran et al (2016) investigated fingerprints of subadult Australian twins but their samples did not have enough DZOS females to make definitive conclusions.

2.3 Associative studies of teeth and fingerprints

The development of the human dentition and of dermatoglyphs has similar embryological origin from epithelial-mesenchymal interactions (Nanci, 2008). Most studies have been conducted on the human dentition and dermatoglyphs separately, and no effort has been made to explore possible correlations between the two, except for two published research by Taduran et al (2016, 2018), where they explored possible correlations between the human dentition and dermatoglyphs in sub-adult Australian twins. Some studies (Chinmaya et al., 2016; Singh et al., 2016) claimed that fingerprints could be good indicators for dental caries in humans.

2.4 Gaps in knowledge

From the literature reviewed, it is concluded that there is a need for more research on sexual dimorphism of teeth and fingerprints. Only a few studies have suggested that sexual dimorphism of teeth could be the result of prenatal environment factors, while no research has been published associating dermatoglyphics on this matter. Not too many studies discoursing on the interaction of genetic, epigenetic and environmental factors in the development of teeth and fingerprints are available in the scientific literature.

Studying both dentition and dermatoglyphs and their variation in size, shape and pattern has provided, and will always provide, key understandings into the control and influences on human development. Both dental and dermatoglyphic development are self-regulating and self-organising Complex Adaptive Systems that need to be studied together.

Chapter 3 Aims of this research

The general aim of this study was to determine the nature and extent of sexual dimorphism in teeth and fingerprints of Australian twins. The specific aims of this research were:

To investigate the influences of genetic, epigenetic and environmental factors on observed variation in selected dental and dermatoglyphic features;

To identify which dental and dermatoglyphic traits display sexual dimorphism that is consistent with the Twin Testosterone Transfer Hypothesis; and

To identify any evidence of associations and covariance between the studied dental and dermatoglyphic phenotypes.

These aims were investigated by measuring crown dimensions (mesiodistal and buccolingual) of primary and permanent teeth; scoring the Carabelli trait on primary and permanent upper molars; counting friction ridges and white lines of dermatoglyphs; and classifying fingerprint patterns. Teeth and fingerprints have similar embryological origins and their development stages were assessed against intrauterine testosterone levels. Phenotypic variation was examined within the context of general somatic development and the properties of a Complex Adaptive System by exploring the possible effects of the Y chromosome and testosterone in utero and the role of epigenetic dynamics.

The null hypotheses were:

There is no significant difference between males and females in the expression of dental and dermatoglyphic traits;

There is no significant difference between females from dizygotic opposite sex (DZOS) twin pairs and females from monozygotic (MZ) and dizygotic same sex (DZSS) twin pairs in dental and dermatoglyphic traits;

There is no correlation in the phenotypic expression of teeth and fingerprints.

The aims of the study are addressed by presenting results of research performed while enrolled in a PhD at the Adelaide Dental School, The University of Adelaide. Some of the results have already been published and these papers are reproduced in an Appendix at the end of the thesis.

Chapter 4 Materials and methods

4.1 Introduction

This research has expanded on the work on the dentition of Ribeiro et al. (2013) by analysing both dentitions (deciduous and permanent) and also dermatoglyphs. Tooth sizes were measured using a 2D image analysis system (Brook et al., 1999) and the Carabelli trait was scored using the Arizona State University Dental Anthropology System. Friction ridges and white creases were counted manually and fingerprint patterns were classified from electronic scans of ten prints.

The importance of teeth and fingerprints as a model system for general human development is further emphasised through the updated methodologies and correlations in both phenotypes.

4.2 Sample size and zygosity determination

Twin samples were obtained from the ongoing longitudinal studies of the Craniofacial Biology Research Group in Adelaide Dental School at the University of Adelaide (Townsend et al., 2012b), which is one of the four most extensive investigation of its type in the world (Hughes et al., 2014). The total cohort is made up of approximately 300 twin pairs, each with serial models of primary, mixed and permanent dentitions, oral examination records, intra-oral photographs, mono and stereo photographs, palm and finger prints, blood and cheek cell samples for zygosity determination, medical history, laterality tests, and other questionnaire data from the involved families.

The study sample included 103 males and 112 females, which were further divided by zygosity into six groups: 43 MZ same-sex female (MZF), 34 MZ same-sex male

(MZM), 34 DZ same-sex female (DZSSF), 34 DZ same-sex males (DZSSM), and 35 DZ opposite-sex females (DZOSF), and 35 DZ opposite-sex males (DZOSM) twin pairs. Zygosity was determined by comparing a number of genetic markers serum enzyme (GLO, ESD, PGM1, PGD, ACP, GPT, PGP, AK1) and protein polymorphisms (HP, C3, PI, GC), as well as in the blood (ABO, Rh, Fy, Jk, MNS). Six highly variable genetic loci (FES, vWA31, F13A1, THO1, D21S11, FGA) were analysed on six different chromosomes by using DNA extracted from buccal cells. The probability of dizygosity, given concordance for all systems, was greater than 99% (Townsend et al., 1995; Townsend et al., 2005; Hughes et al., 2007). All participants were of European ancestry and had no relevant medical and dental history that could influence the study (Townsend et al., 2005; Hughes et al., 2007).

4.3 Inclusion and exclusion criteria

Serial dental casts of primary and permanent dentitions, and rolled ink prints of fingers of individuals aged 8 to 10 years of the same set of monozygotic and dizygotic Australian twins were collected and analysed. Dental casts showing wear, caries, or restorations and ten-prints with smudge ink and scarred patterns in any of the fingerprints were excluded in the sampling.

To avoid bias, only one co-twin from each pair of same sex MZ and DZ twins was chosen randomly to be included in this study. On the other hand, both male and female twin from opposite sex DZ pairs were selected for inclusion because they are both essential to the study in showing sexual dimorphism and consistency with the Twin Testosterone Transfer Hypothesis.

4.4 Study design—dental

4.4.1 Tooth selection

Measurements were obtained from central incisors, lateral incisors, canines, first molars and second molars of primary and permanent dentition. Scoring of Carabelli trait was conducted on first and second molars of primary and permanent dentition. Calcification of primary teeth starts in utero and any intrauterine hormonal influence on dental crowns should be observable. Both dentitions were selected for all individuals to assess the entire process from a longitudinal perspective.

4.4.2 2D image analysis system

The dental casts selected for this research were positioned on a platform that can be adjusted in different orientation of surfaces of interest, with four multidirectional spot lights. The digital camera (Canon EOS 50D digital SLR camera, Cannon, Australia) with a resolution of 15.1 megapixels and image array of 4752 x 3168 pixels, was mounted horizontally above the dental casts on an adjustable rod. A 100mm lens (Elicar macro lens) was fitted to capture clear images with camera settings: aperture (f) f16, ISO speed 160 and shutter speed 0.3 seconds.

Images were acquired and collected with EOS Digital Software (Cannon Australia PTY. LTD) and later moved and saved to a computer (Intel Pentium 4 CPU 3.20GHz, 3192 MHz, 1 core, 2 logical processors, Australia) as JPEG files into the designated directory for later calibration and measurement using the ImageJ software (National Institute of Health, USA).

A length of steel rule with a millimetre scale was placed adjacent to the tooth surface being photographed and at the same plane of the tooth (see Figure 4-1). Each tooth was photographed from the labial and occlusal views. Images for maximum mesiodistal width of incisors and canines was obtained from the labial view, and molars from the occlusal view. Images for maximum buccolingual width was obtained from the occlusal view of all teeth.

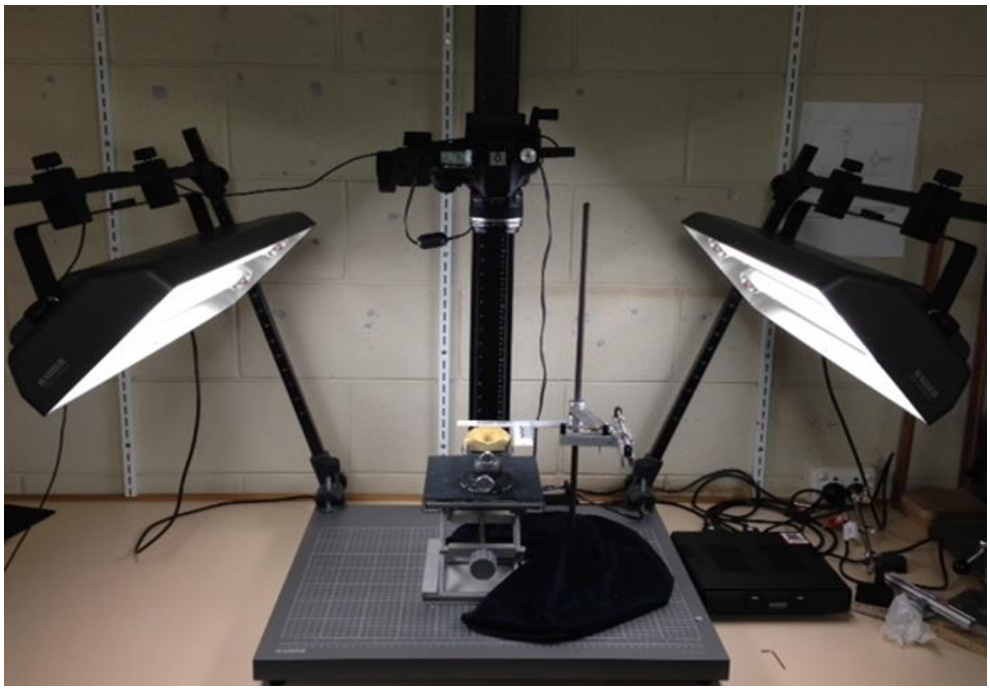

Figure 4-1. 2D image analysis system.

4.4.3 The Arizona State University Dental Anthropology Scoring System

The Arizona State University Dental Anthropology System (ASUDAS) is a morphological scoring system used by anthropologists to collect data on human dentition. It was originally designed for use in permanent teeth (Lease, 2003) but commonly applied to bioarchaeological and paleoanthropological investigations (Smith, 1978; Bailey, 2002, 2006; Irish et al., 2013; 2014; Kimbel, 2013).

4.5 Measurements and score

4.5.1 Mesiodistal crown diameter

The maximum mesiodistal (MD) crown diameter refers to the maximum distance between the mesial and distal proximal surfaces of the dental crown and. In cases like minimal dental crowding or missing adjacent teeth, the measurement would be taken from anatomical positions where contact occurred (Moorrees et al., 1957; Brook et al., 1999; Brook et al., 2005).

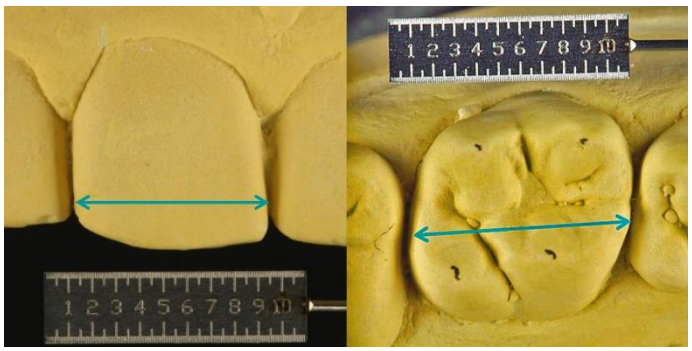

Figure 4-2. Mesiodistal (MD) crown dimension measured on a permanent upper central incisor from the labial view (left) and on a permanent upper first molar from the occlusal view (right).

4.5.2 Buccolingual crown diameter

The maximum labiolingual or buccolingual (BL) crown dimension refers to the maximum breadth or distance between buccal and lingual surfaces of the crown perpendicular to, and intersecting the line defining the mesiodistal dimension (Kieser, 1990; Brook et al., 1999; Brook et al., 2005).

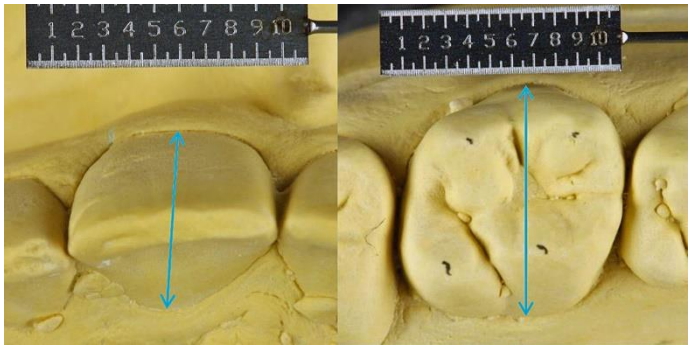

Figure 4-3. Buccolingual (BL) crown dimension measured on a permanent upper central incisor (left) and on a permanent upper first molar (right) from the buccolingual view.

4.5.3 The Carabelli trait

The Carabelli trait is an additional cusp or groove on the mesiolingual surface of the maxillary permanent first molar or second deciduous molar. It emerges from the lingual surface of the protocone (the mesiolingual cusp of upper molars), and usually begins to form after the four major cusps of the molar have initiated (Kraus, 1965). The Carabelli morphology was observed and recorded from dental casts under supplemental lighting following the Arizona State University Dental Anthropology System (ASUDAS) standards (Turner et al., 1991).

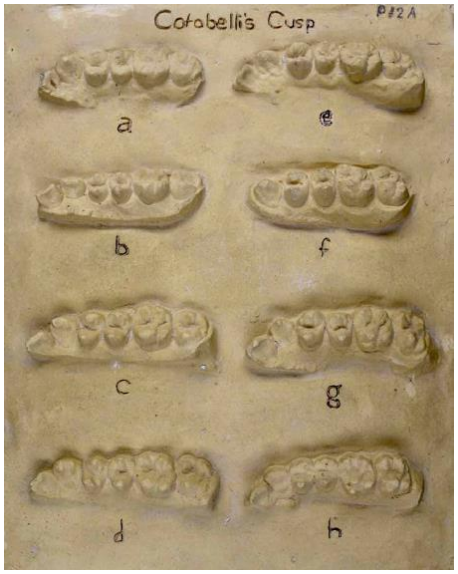

Figure 4-4. Dahlberg's plaque P12A for classifying Carabelli trait, with increasing size of the feature from a to h.

According to ASUDAS (Turner et al., 1991), there are eight categories represented when scoring the Carabelli trait in upper permanent molars: (0) no expression; (1) a groove; (2) a pit; (3) a small Y-shaped depression; (4) a large Y-shaped depression; (5) a small cusp without free apex; (6) a medium-sized cusp with an attached apex; and (7) a large free cusp.

For the primary upper second molar, since ASUDAS was originally designed for use in permanent teeth (Lease, 2003), a modified scoring system of the Carabelli trait was formulated, as influenced by Grine's (1986) criteria on deciduous teeth: (0) no expression; (1) a pit or groove; (2) two grooves; (3) a cusp without free apex; and (4) a cusp with free apex.

4.6 Study design—dermatoglyphic

4.6.1 Fingerprint selection

Ridge and white line counts, and fingerprint patterns were obtained from all the fingerprints. Ridge formation starts in utero and any intrauterine hormonal influence of fingerprints should be observable. Fingers were identified by the numerical sequence 1–10, with finger 1 being the right thumb and finger 10 as the left-hand little finger.

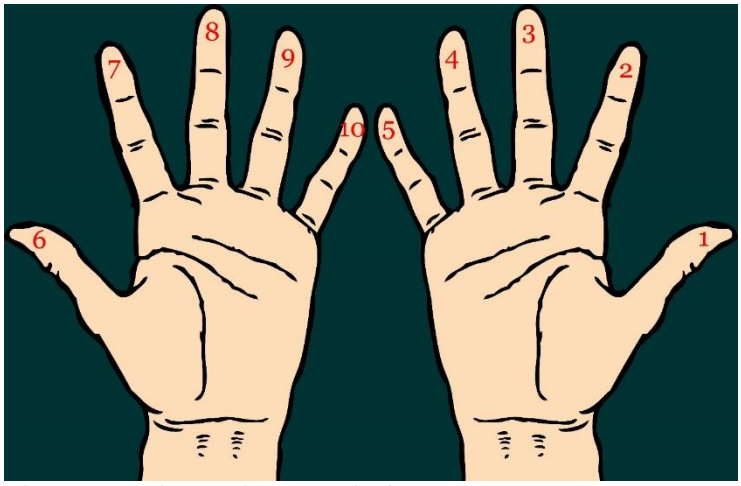

Figure 4-5. Fingerprint numerical sequence.

4.6.2 Fingerprint scans

The ten-prints selected for this research were scanned using EPSON Perfection V700-V750. The scanner settings were adjusted to 1200 dpi (dots per inch) to maximise image dot density and print quality, which would make the tone and colours of each scanned ten-print sharper and smoother at the same time.

Images were later moved and saved to a computer (Intel Pentium 4 CPU 3.20GHz, 3192 MHz, 1 core, 2 logical processors, Australia) as JPEG files into the designated directory for later calibration and measurement using the ImageJ software (National Institute of Health, USA). An American Board of Forensic Odontology (ABFO) type L-shaped ruler with millimetre scales was placed along each ten print during scanning.

4.7 Pattern and counts

4.7.1 Fingerprint pattern classification

In this study, classification of fingerprints was categorized to three main fingerprint patterns: whorl, loop and arch (see Figure 4-6). Numerical values were assigned for each pattern, two (2) to fingers that contain a whorl pattern; one (1) to fingers that

contain a loop pattern; and zero (0) to fingers that contain an arch pattern. Whorls have ridges entering at the side of the finger and spiralling inward ending at the centre; loops have ridges entering at one side of the finger and leaving on the same side; and arches have ridges entering on one side of the finger and leaving on the opposite side.

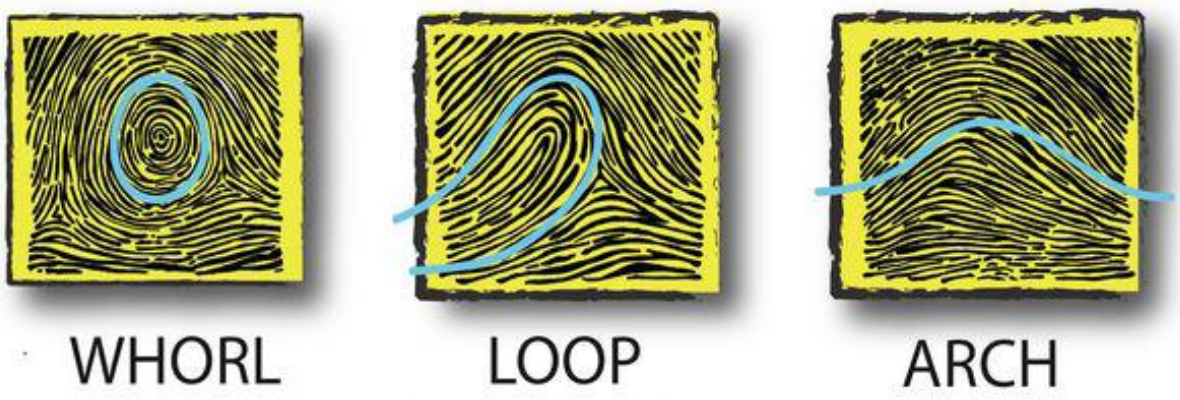

Figure 4-6. Three main fingerprint patterns.

4.7.2 Ridge counts

Ridge counts (RC) are defined as the number of ridges that touch a straight line between two fixed points, i.e., two triradii, or a triradius and a core. A modified method (Taduran et al., 2017) of obtaining ridge counts that is not influenced by finger patterns was employed (see Figure 4-7), as described by Cummins and Midlo (1943). The triradius was first identified for each fingerprint, then a one-centimetre line from the triradius towards the core was drawn, and the number of ridges that touched the line was counted. For prints without a triradius, i.e., those with an arch pattern, a strategic ridge was chosen, as long as the line was perpendicular to the ridges. For prints with more than one triradius, i.e., those with a whorl pattern, the triradius with the higher ridge count was chosen. Lines that were part of a fork or an eye were counted

separately. Island ridges and dots were counted as well. Image J was used to aid in ridge counting.

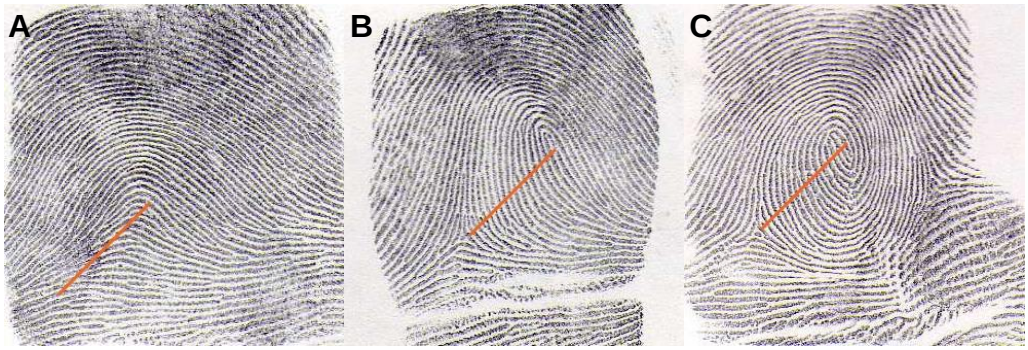

Figure 4-7. Sample locations of ridge count areas in fingerprint type (a) arch, (b) loop, and (c) whorl.

4.7.3 White line counts

White line counts (WLC) are defined as the number of white lines counted on a fingerprint. This is a straightforward method. Badawi et al. (2006) introduced counting white lines as a reliable method for sex determination using fingerprints, with females having a greater number of white lines than males. Another study by Taduran et al. (2016) found similar results in Filipino fingerprints.


Figure 4-8. Fingerprint samples of males (left) and females (right), showing a greater number of white lines in females.

4.8 Statistical analysis

A power analysis was conducted to estimate the appropriate sample size required for each sex and zygosity that would suitably test the hypotheses. For the teeth, the dependent variable was tooth size in millimetres and the smallest meaningful group difference (Δ) was set at 0.2 mm. For the fingerprints, the dependent variable was ridge count and the smallest meaningful difference (Δ) was set at 1 ridge.

Assumptions were made in these calculations, and they were:

- equal numbers in each group;
- equal variances between groups;
- standard deviation of 0.5;
- type I error rate (α value) of 0.05; and
- desired power (β value) of 0.8.

Results of the power analysis determined that approximately 40 individuals per group would be needed to provide the desired power and these were randomly selected from the total sample of twins in the collection.

Data were evaluated for conformity to a normal distribution. Descriptive statistics of mean values, standard deviations (SD) and coefficients of variation (CV) were computed for all dental and dermatoglyphic variables to summarise and describe data. Unpaired Student's t-tests were used to make comparisons between males and females, while Mann–Whitney U tests were used to make comparisons between male and female ordinal data in the Carabelli scoring of teeth and fingerprint pattern

classification. To compare variables among zygosities, one-way ANOVA and Kruskal-Wallis test were undertaken as parametric and non-parametric tests, respectively.

Correlation coefficients were applied to test all the dental and dermatoglyphic variables' degree of relationship with each other. Principal Components Analysis (PCA) was utilised to discover underlying structure in the data. Multivariate analysis and post-hoc comparisons were performed to determine statistically significant covariances, interactions and associations between variables.

4.9 Error analysis

4.9.1 Introduction

No physical quantity can be measured with absolute certainty. There will always be errors in any measurement. Experimental errors can be either systematic or random (Moorrees et al., 1957; Hunter and Priest, 1960; Houston, 1983).

Systematic errors influence the accuracy of a measurement, while random errors impact the precision of a measurement. In this study, systematic errors could have happened during the dental impression and casting procedures, fingerprint rolling, imaging and scanning process, and/or in measuring and counting.

Random errors could have occurred from inconsistent positions of dental casts, camera, ten-prints, and light intensity, all of which could impede with the measurements. An operator's experience in recording dental and dermatoglyphic data is the most influential factor that improves accuracy and precision, and performing

repeated measurements are the best method to obtain the closest possible value to the true size (Hunter and Priest, 1960).

The aim of the error analysis was to quantify the errors of measurements in the methodology. This study analysed both the systematic and random errors of the methods employed by evaluating the intra-operator repeatability tests. Paired t-tests were used to assess the systematic errors. Dahlberg statistics was computed to assess random errors (Dahlberg, 1940).

4.9.2 Minimisation of errors

Systematic errors that could have happened during the casting of dental impressions were minimised by pouring type III yellow stone immediately after they were taken to minimise distortion. A standardised method was strictly followed to set-up the 2D image analysis, as explained in section 4.4. Systematic errors that could have occurred during the rolling of fingerprints were minimised by applying light pressure and using very little ink to capture legible prints.

Random errors were lessened by the fixed position of the camera, the light sources, and standardising the position of the dental cast. External light sources were turned off during image capture to keep the light intensity and image quality consistent. The dental crown surface to be photographed was positioned parallel to the lens of the camera. Random errors for fingerprints were minimised by strictly following a standardised method in scanning of the ten-prints, as explained in section 4.6.

To minimise errors in this research, all dental and dermatoglyphic variables were evaluated by repeated measurements (Houston, 1983) to obtain the closest possible value to the true measurement.

4.9.3 Repeatability tests

The double determination analysis was conducted on 100 different teeth, evaluating the mesiodistal breadth (MD), buccolingual width (BL), and Carabelli trait score (CT); and 100 different fingerprints, evaluating the fingerprint pattern (FP), ridge count (RC), and white lines count (WLC). Error analysis focused on obtaining these measurements from ten randomly selected individuals. The operator calibrated and measured the images of dental casts twice using the Image J software, and scored the Carabelli cusp twice following ASUDAS guidelines. The operator calibrated the scans and counted finger ridges and white lines twice, and classified fingerprint pattern twice. The intra-operator repeatability compared the first and second measurements, scores, counts, and classifications from the same operator.

Consistency between two or more measurements of an object under the same experimental conditions can be improved further by repeat measurements (Harris and Smith, 2009). Paired t-tests were employed to detect any systematic errors in data collection from the first and second trials of measured and counted variables. Dahlberg statistics was used to calculate random errors in measurements using the formula $d = \sqrt{\sum} (X1 – X2)^2/2n$ where X1 is the first measurement, X2 is the second measurement, and n is the sample size or number of repeated observations. The error variance was calculated and presented as percentage of observed variance for each variable to determine the extent of experimental error in the observed variance (Eguchi et al.,

2004). Kappa coefficients were calculated to show intra-operator concordance and random errors that could have occurred in the first and second trials of the Carabelli score and fingerprint pattern classification.

4.9.4 Results of error testing

Data for intra-observer repeatability are presented in Tables 4-1, 4-2 and 4-3, respectively.

In Table 4-1, mean differences for dental and dermatoglyphic variables were minimal. No variables showed significant differences between the two measurements conducted by the same operator ($p<0.05$).

Table 4-1. Paired t-tests results.

Variable	Mean difference	p-value
MD	0.056	0.720
BL	0.060	0.558
RC	0.242	0.520
WLC	0.607	0.358

Dahlberg statistics values, which represent intra-operator random errors, are summarised in Table 4-2. Intra-operator random error percentages for dental and dermatoglyphic variables are all below 2%.

Table 4-2. Dahlberg statistics results.

Variable	d-value	Error %
MD	1.036	0.027
BL	0.928	0.043
RC	0.423	0.425
WLC	0.332	1.018

Table 4-3 shows the high level of agreement between two trials of the same operator, which means random errors in scoring the Carabelli trait and classifying fingerprint patterns were very small.

Table 4-3. Kappa coefficients.

Variable	Percentage agreement	κ-statistic
CT	87.0%	0.781
FP	94.0%	0.899

4.9.5 Discussion of error testing

Based on the results of the paired t-tests and κ-statistic, no significant systematic errors occurred in the research. No evidence of substantial random errors was observed according to the Dahlberg formula as well. Overall, the chance of errors in data collection was highly unlikely or slim to none.

Chapter 5 Results of statistical analysis of dental variables

5.1 Introduction

Comparing tooth size and shape within and between individuals provides a way to analyse genetic, epigenetic and environmental influences on dental variation (Horowitz et al., 1958; Garn et al., 1965a; Townsend, 1976; 1978; Townsend and Brown, 1978a; Brook, 1984; Townsend et al., 2005; Townsend et al., 2009c).

This chapter describes the different dental variables (mesiodistal, MD; buccolingual, BL; Carabelli trait, CT) in terms of means, medians, standard deviations (SD) and coefficients of variation (CV) for sexes, zygosities and dentitions. It also aims to determine the magnitude and pattern of sexual dimorphism for each phenotype in primary and permanent dentitions of both MZ and DZSS twins, as well as to compare the amount of sexual dimorphism between the primary and permanent dentitions of samples of both MZ and DZSS twins consisting of the same individuals.

Associations were also quantified between the different dental variables using Pearson's and Spearman's coefficient. Correlation coefficients between teeth from right and left sides, as well as correlations between teeth from the same side in the upper and lower arches, were calculated for all variables in both sexes and all zygosities. Other correlations calculated included correlations between primary and successional permanent teeth and correlations between all variables in the same tooth, also making associations with the timing of formation of each dimension studied.

5.2 Sexual dimorphism

Shown in Table 5-1 are the mean values, SDs and CVs of mesiodistal (MD) measurements of primary and permanent teeth. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of MD crown dimensions of males were consistently greater than females for all teeth. Permanent teeth displayed greater sexual dimorphism compared to primary teeth. There were no significant left-right differences (i.e., directional asymmetry) observed in MD measurements of any primary or permanent teeth based on paired t-tests.

Table 5-1. Descriptive statistics for mesiodistal (MD) dimensions of primary and permanent teeth in Australian male and female twins.

	Males								Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	78	6.34	0.37	5.85	83	6.32	0.42	6.57	86	6.23	0.39	6.20	92	6.22	0.41	6.61
c	103	6.87	0.37	5.40	101	6.84	0.36	5.33	111	6.70	0.39	5.81	111	6.69	0.37	5.51
m1	100	7.05	0.44	6.19	103	7.12	0.41	5.71	110	6.83	0.38	5.61	109	6.90	0.40	5.80
m2	101	8.86	0.47	5.29	99	8.83	0.43	4.85	111	8.62	0.40	4.66	108	8.63	0.41	4.69
Mandibular																
i1	53	4.05	0.31	7.71	53	4.03	0.30	7.41	61	3.92	0.27	6.84	60	3.90	0.28	7.22
i2	85	4.61	0.35	7.50	86	4.62	0.32	6.99	91	4.50	0.31	6.99	87	4.49	0.31	7.01
c	100	5.89	0.33	5.63	102	5.90	0.32	5.49	110	5.73	0.30	5.20	110	5.74	0.32	5.60
m1	98	7.87	0.49	6.24	101	7.91	0.44	5.50	109	7.67	0.38	5.00	107	7.65	0.40	5.21
m2	101	10.07	0.47	4.69	101	10.03	0.46	4.60	111	9.81	0.41	4.14	110	9.77	0.41	4.23
Permanent																
Maxillary																
I1	98	8.70	0.49	5.63	98	8.64	0.48	5.50	110	8.43	0.53	6.26	108	8.43	0.48	5.68
C	62	8.13	0.41	5.01	62	8.18	0.45	5.55	70	7.71	0.46	6.00	74	7.66	0.41	5.31
M1	95	10.45	0.52	4.94	95	10.46	0.52	4.95	105	10.09	0.51	5.03	108	10.11	0.48	4.77
M2	28	10.35	0.58	5.58	28	10.46	0.64	6.12	28	9.86	0.53	5.42	26	9.81	0.56	5.69
Mandibular																
I1	96	5.42	0.33	6.06	96	5.46	0.32	5.93	102	5.30	0.33	6.17	100	5.29	0.33	6.18
I2	87	6.00	0.37	6.08	90	5.98	0.34	5.65	95	5.80	0.37	6.36	96	5.78	0.37	6.42
C	74	7.19	0.42	5.89	77	7.17	0.44	6.15	82	6.66	0.40	6.06	82	6.65	0.41	6.15
M1	89	11.31	0.63	5.58	94	11.33	0.60	5.27	97	10.83	0.63	5.79	100	10.85	0.62	5.68
M2	26	10.95	0.71	6.44	28	11.11	0.79	7.11	33	10.21	0.55	5.38	35	10.42	0.67	6.45

Presented in Table 5-2 are the mean values, SD and CV of buccolingual (BL) measurements of primary and permanent teeth. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of BL crown sizes of males were consistently greater than females for all types of teeth. Permanent teeth displayed greater sexual dimorphism compared to primary teeth. There were no significant left-right differences (i.e., directional asymmetry) observed in BL measurements of any primary or permanent teeth based on paired t-tests.

Table 5-2. Descriptive statistics for buccolingual (BL) dimensions of primary and permanent teeth in Australian male and female twins.

	Males								Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	84	5.07	0.33	6.44	86	5.12	0.33	6.38	91	4.92	0.34	6.97	92	4.96	0.36	7.25
c	102	6.20	0.42	6.81	101	6.18	0.42	6.87	112	6.10	0.39	6.41	111	6.08	0.38	6.23
m1	102	8.79	0.43	4.88	103	8.76	0.42	4.77	111	8.55	0.34	3.96	112	8.54	0.34	4.01
m2	102	10.00	0.48	4.76	103	9.96	0.43	4.37	112	9.68	0.40	4.12	111	9.64	0.39	4.02
Mandibular																
i1	53	3.88	0.30	7.62	55	3.83	0.25	6.40	61	3.72	0.27	7.30	62	3.71	0.24	6.58
i2	87	4.40	0.33	7.48	91	4.38	0.31	6.99	90	4.28	0.29	6.71	89	4.29	0.28	6.60
c	101	5.65	0.36	6.40	100	5.65	0.36	6.32	110	5.58	0.38	6.90	110	5.58	0.35	6.29
m1	99	7.09	0.38	5.31	101	7.17	0.37	5.16	109	6.86	0.40	5.77	109	6.94	0.37	5.29
m2	103	8.72	0.38	4.36	101	8.72	0.38	4.35	110	8.38	0.40	4.82	110	8.41	0.37	4.36
Permanent																
Maxillary																
I1	96	7.27	0.56	7.69	95	7.29	0.55	7.55	102	7.04	0.55	7.75	97	7.04	0.56	7.93
C	60	8.32	0.56	6.73	60	8.41	0.61	7.28	64	7.91	0.54	6.81	71	7.97	0.56	6.96
M1	98	11.79	0.56	4.79	99	11.73	0.54	4.60	106	11.22	0.53	4.75	109	11.16	0.50	4.48
M2	28	11.95	0.70	5.88	28	12.07	0.84	7.00	34	11.18	0.69	6.14	34	11.07	0.61	5.48
Mandibular																
I1	94	6.19	0.46	7.41	97	6.13	0.51	8.34	98	5.93	0.46	7.74	95	5.97	0.43	7.23
I2	87	6.47	0.53	8.23	90	6.41	0.55	8.51	98	6.25	0.53	8.41	95	6.28	0.47	7.47
C	67	7.66	0.65	8.50	73	7.66	0.65	8.45	78	7.20	0.48	6.64	81	7.29	0.57	7.77
M1	96	10.54	0.47	4.48	97	10.56	0.50	4.70	103	9.99	0.48	4.78	103	10.07	0.48	4.77
M2	31	10.70	0.58	5.39	30	10.64	0.61	5.70	46	10.01	0.61	6.12	46	10.07	0.57	5.68

Table 5-3 shows the median values of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1). Highlighted in yellow are p-values of the sexually dimorphic molars, where CT scores are different between sexes at $p < 0.05$. CT scores of males were consistently greater compared to females in all types of molars. In general, M1 showed greater sexual dimorphism compared to m2. There were no left-right differences observed in CT scores of both molars, based on Wilcoxon signed-rank test.

Table 5-3. Descriptive statistics for Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian male and female twins.

	Australian Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
m2	3.00	2.00	< .00001	3.00	2.00	< .00001
M1	5.00	2.00	0.00	5.00	2.00	0.00

Table 5-4 is a table that shows the frequency of occurrence of CT scores in both m2 and M1. It also shows that the CT scores assigned were not normally distributed.

Table 5-4. Frequency of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian male and female twins.

	Males				Females			
	Right		Left		Right		Left	
Score	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**
0	2	11	4	15	7	34	15	41
1	7	7	8	6	33	14	29	9
2	16	11	10	4	19	7	16	8
3	45	1	44	1	31	3	35	3
4	29	9	34	7	20	7	14	5
5	NA	25	NA	23	NA	13	NA	10
6	NA	20	NA	28	NA	15	NA	20
7	NA	15	NA	15	NA	16	NA	15
Total	99	99	100	99	110	109	109	111

5.3 MZ twins

Shown in Table 5-5 are the mean values, SDs and CVs of mesiodistal (MD) measurements of primary and permanent teeth of Australian male and female monozygotic (MZ) twins. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of MD crown dimensions of males were consistently greater than females for all teeth. Permanent teeth displayed greater sexual dimorphism compared to primary teeth. There were no significant left-right differences (i.e., directional asymmetry) observed in MD measurements of any primary and permanent teeth based on paired t-tests.

Table 5-5. Descriptive statistics for mesiodistal (MD) dimensions of primary and permanent teeth in Australian male and female monozygotic (MZ) twins.

	MZ Males								MZ Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	23	6.39	0.41	6.38	27	6.36	0.41	6.43	34	6.21	0.36	5.85	35	6.21	0.33	5.36
c	34	6.90	0.33	4.79	33	6.85	0.34	4.91	42	6.63	0.44	6.61	43	6.64	0.39	5.92
m1	33	7.11	0.39	5.53	34	7.12	0.41	5.78	42	6.78	0.33	4.83	43	6.84	0.36	5.19
m2	34	8.90	0.43	4.81	32	8.88	0.42	4.78	43	8.53	0.35	4.12	43	8.55	0.35	4.13
Mandibular																
i1	16	4.03	0.33	8.25	16	4.06	0.31	7.52	23	3.88	0.27	6.92	21	3.83	0.26	6.68
i2	27	4.58	0.32	7.08	28	4.64	0.34	7.24	36	4.45	0.31	6.98	33	4.39	0.30	6.82
c	34	5.92	0.28	4.69	34	5.89	0.27	4.52	42	5.74	0.26	4.56	42	5.71	0.29	5.01
m1	32	7.90	0.39	4.90	33	7.92	0.38	4.86	42	7.60	0.33	4.35	40	7.60	0.35	4.64
m2	34	10.07	0.44	4.34	33	10.03	0.45	4.47	42	9.71	0.33	3.40	42	9.71	0.34	3.52
Permanent																
Maxillary																
I1	33	8.68	0.54	6.22	33	8.63	0.45	5.20	43	8.42	0.53	6.24	42	8.40	0.48	5.75
C	19	8.13	0.39	4.80	21	8.17	0.49	5.95	29	7.54	0.33	4.36	28	7.54	0.35	4.67
M1	33	10.46	0.43	4.11	33	10.41	0.47	4.51	41	10.01	0.46	4.62	42	10.06	0.43	4.23
M2	13	10.49	0.49	4.65	10	10.57	0.47	4.42	8	9.62	0.53	5.52	7	9.67	0.38	3.97
Mandibular																
I1	32	5.38	0.38	7.06	31	5.44	0.33	6.05	41	5.27	0.30	5.67	40	5.34	0.29	5.38
I2	27	6.03	0.35	5.88	30	6.02	0.31	5.21	40	5.81	0.39	6.66	41	5.76	0.35	6.07
C	24	7.21	0.40	5.57	25	7.20	0.40	5.50	33	6.54	0.36	5.52	33	6.56	0.34	5.11
M1	29	11.34	0.64	5.63	32	11.36	0.57	5.02	41	10.69	0.61	5.68	41	10.71	0.55	5.14
M2	12	11.00	0.45	4.11	12	11.32	0.57	5.01	15	10.12	0.41	4.06	14	10.24	0.51	4.99

Presented in Table 5-6 are the mean values, SDs and CVs of buccolingual (BL) measurements of primary and permanent teeth of Australian male and female monozygotic (MZ) twins. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of BL crown sizes of males were consistently greater compared to females in all types of teeth. Permanent teeth displayed greater sexual dimorphism compared to primary teeth. There were no significant left-right differences (i.e., directional asymmetry) observed in BL measurements of any primary or permanent teeth based on paired t-tests.

Table 5-6. Descriptive statistics for buccolingual (BL) dimensions of primary and permanent teeth in Australian male and female monozygotic (MZ) twins.

	MZ Males								MZ Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	25	5.14	0.28	5.51	27	5.19	0.23	4.48	37	4.91	0.31	6.31	35	4.97	0.28	5.70
c	33	6.24	0.33	5.30	33	6.23	0.32	5.10	43	6.10	0.41	6.76	43	6.09	0.41	6.68
m1	33	8.90	0.38	4.30	34	8.87	0.32	3.66	43	8.54	0.32	3.77	43	8.52	0.31	3.66
m2	34	10.09	0.44	4.36	34	10.02	0.44	4.35	43	9.69	0.38	3.94	43	9.58	0.37	3.89
Mandibular																
i1	16	3.90	0.27	7.00	15	3.87	0.20	5.21	22	3.63	0.32	8.92	22	3.65	0.29	8.04
i2	27	4.42	0.28	6.27	28	4.39	0.27	6.20	36	4.28	0.28	6.60	34	4.24	0.28	6.63
c	34	5.70	0.32	5.65	34	5.69	0.30	5.27	42	5.58	0.39	6.99	42	5.59	0.39	6.94
m1	32	7.09	0.31	4.41	33	7.22	0.34	4.75	42	6.81	0.40	5.90	41	6.97	0.36	5.23
m2	34	8.77	0.39	4.41	33	8.81	0.38	4.26	42	8.22	0.41	4.96	42	8.36	0.38	4.60
Permanent																
Maxillary																
I1	33	7.24	0.52	7.12	32	7.25	0.54	7.45	39	7.10	0.43	6.06	39	7.06	0.51	7.23
C	16	8.37	0.55	6.53	20	8.50	0.47	5.55	27	7.72	0.39	5.11	28	7.84	0.41	5.20
M1	33	11.91	0.57	4.78	33	11.82	0.54	4.59	42	11.11	0.48	4.30	42	11.03	0.46	4.15
M2	13	12.06	0.62	5.11	10	12.24	0.64	5.24	10	11.01	0.42	3.81	10	10.92	0.39	3.57
Mandibular																
I1	29	6.22	0.45	7.28	31	6.10	0.44	7.14	39	5.90	0.40	6.75	37	5.96	0.38	6.33
I2	26	6.53	0.40	6.15	27	6.53	0.38	5.83	41	6.21	0.46	7.41	38	6.26	0.45	7.13
C	20	7.85	0.67	8.49	24	7.83	0.65	8.29	32	7.23	0.49	6.81	33	7.34	0.50	6.78
M1	32	10.54	0.50	4.70	33	10.59	0.51	4.83	42	9.89	0.47	4.79	41	9.96	0.45	4.50
M2	13	10.78	0.53	4.92	12	10.78	0.46	4.24	21	9.84	0.55	5.60	21	9.91	0.54	5.44

Table 5-7 shows the median values of Carabelli trait (CT) scores of m2 and M1 of Australian male and female monozygotic (MZ) twins. Highlighted in yellow are p-values of the sexually dimorphic molars, where CT scores are different between sexes at $p < 0.05$. CT scores of males were consistently greater compared to females in all types of molars. In general, M1 showed greater sexual dimorphism compared to m2. There were no left-right differences observed in CT scores of both molars, based on Wilcoxon signed-rank test.

Table 5-7. Descriptive statistics for Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian male and female monozygotic (MZ) twins.

	MZ Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
m2	3.00	2.00	0.05	3.00	2.00	0.00
M1	5.00	1.00	0.01	5.00	1.00	0.00

Table 5-8 is a table that shows the frequency of CT scores in both m2 and M1 of MZ twins. It also shows that the CT scores assigned were not normally distributed.

Table 5-8. Frequency of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian male and female monozygotic (MZ) twins.

	MZ Males				MZ Females			
	Right		Left		Right		Left	
Score	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**
0	0	4	0	4	3	15	6	20
1	5	1	5	2	13	7	13	4
2	6	5	3	0	11	2	8	1
3	15	0	15	0	6	0	8	2
4	8	3	10	2	9	2	7	2
5	NA	11	NA	9	NA	9	NA	4
6	NA	6	NA	12	NA	2	NA	5
7	NA	4	NA	4	NA	5	NA	5
Total	34	34	33	33	42	42	42	43

5.4 DZSS twins

Shown in Table 5-9 are the mean values, SDs and CVs of mesiodistal (MD) measurements of primary and permanent teeth of Australian male and female dizygotic same sex (DZSS) twins. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of MD crown dimensions of males were consistently greater than females for all teeth even in the few which did not reach significance. Permanent teeth displayed greater sexual dimorphism compared to primary teeth. There were no significant left-right differences (i.e., directional asymmetry) observed in MD measurements of any primary and permanent teeth based on paired t-tests.

Table 5-9. Descriptive statistics for mesiodistal (MD) dimensions of primary and permanent teeth in Australian male and female dizygotic same sex (DZSS) twins.

	DZSS Males								DZSS Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	28	6.33	0.33	5.18	27	6.27	0.39	6.26	28	6.24	0.41	6.60	29	6.22	0.45	7.20
c	34	6.86	0.42	6.19	34	6.82	0.42	6.21	34	6.76	0.37	5.41	33	6.73	0.36	5.42
m1	34	7.03	0.49	7.04	34	7.13	0.40	5.65	34	6.91	0.49	7.04	33	6.96	0.46	6.66
m2	32	8.78	0.41	4.66	32	8.78	0.38	4.35	34	8.71	0.44	5.02	31	8.68	0.47	5.36
Mandibular																
i1	20	4.00	0.26	6.51	21	4.00	0.24	6.00	24	3.93	0.27	7.00	23	3.90	0.27	6.87
i2	30	4.63	0.31	6.76	28	4.62	0.30	6.54	31	4.49	0.37	8.24	29	4.49	0.31	6.90
c	33	5.86	0.42	7.16	34	5.92	0.37	6.27	34	5.71	0.35	6.11	34	5.72	0.35	6.08
m1	32	7.83	0.59	7.49	34	7.91	0.46	5.79	33	7.66	0.32	4.24	34	7.64	0.39	5.04
m2	32	10.11	0.45	4.46	33	10.08	0.42	4.15	34	9.80	0.46	4.67	34	9.77	0.48	4.91
Permanent																
Maxillary																
I1	32	8.75	0.46	5.20	30	8.68	0.47	5.46	33	8.36	0.49	5.82	32	8.38	0.41	4.92
C	19	7.99	0.32	3.94	18	8.11	0.34	4.21	20	7.79	0.61	7.83	22	7.66	0.43	5.57
M1	30	10.45	0.52	4.96	30	10.52	0.54	5.17	31	9.98	0.50	5.03	33	10.01	0.49	4.93
M2	4	10.03	0.53	5.34	5	10.21	0.22	2.18	6	9.71	0.67	6.90	10	9.76	0.67	6.85
Mandibular																
I1	31	5.45	0.26	4.83	31	5.51	0.33	5.91	32	5.26	0.34	6.48	29	5.18	0.32	6.09
I2	30	5.99	0.34	5.69	30	5.95	0.31	5.15	31	5.73	0.38	6.60	27	5.67	0.33	5.85
C	23	7.16	0.30	4.22	24	7.14	0.41	5.69	24	6.67	0.40	6.04	24	6.65	0.49	7.44
M1	31	11.30	0.56	4.99	31	11.30	0.57	5.02	29	10.82	0.66	6.06	30	10.78	0.65	6.03
M2	2	10.89	0.08	0.71	4	10.92	0.52	4.76	11	10.34	0.64	6.17	11	10.47	0.65	6.25

Presented in Table 5-10 are the mean values, SDs and CVs of buccolingual (BL) measurements of primary and permanent teeth of Australian male and female dizygotic same sex (DZSS) twins. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of BL crown sizes of males were consistently greater compared to females in all types of teeth even in the few which did not reach significance. Permanent teeth showed greater sexual dimorphism compared to primary teeth. There were no significant left-right differences (i.e., directional asymmetry) observed in BL measurements of all primary and permanent teeth based on paired t-tests.

Table 5-10. Descriptive statistics for buccolingual (BL) dimensions of primary and permanent teeth in Australian male and female dizygotic same sex (DZSS) twins.

	DZSS Males								DZSS Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	30	5.02	0.30	6.04	29	5.09	0.35	6.81	28	4.89	0.39	8.02	29	4.92	0.40	8.09
c	34	6.16	0.51	8.33	34	6.10	0.51	8.35	34	6.00	0.34	5.71	33	5.97	0.33	5.56
m1	34	8.70	0.42	4.79	34	8.66	0.44	5.06	33	8.55	0.32	3.74	34	8.50	0.31	3.61
m2	33	9.92	0.44	4.48	34	9.91	0.44	4.44	34	9.61	0.41	4.29	33	9.57	0.39	4.05
Mandibular																
i1	21	3.78	0.25	6.55	23	3.77	0.24	6.31	24	3.77	0.24	6.44	24	3.73	0.22	5.82
i2	31	4.33	0.33	7.61	32	4.34	0.30	6.98	30	4.21	0.28	6.70	29	4.23	0.28	6.51
c	34	5.62	0.41	7.23	33	5.59	0.40	7.07	34	5.46	0.33	6.04	34	5.51	0.32	5.80
m1	33	7.07	0.44	6.26	34	7.13	0.41	5.82	33	6.82	0.33	4.78	34	6.83	0.34	4.99
m2	34	8.72	0.39	4.53	33	8.67	0.39	4.50	34	8.35	0.34	4.08	34	8.33	0.34	4.09
Permanent																
Maxillary																
I1	33	7.23	0.52	7.13	33	7.21	0.49	6.85	31	6.85	0.64	9.34	26	6.84	0.57	8.28
C	19	8.23	0.49	5.98	18	8.24	0.57	6.90	19	7.94	0.60	7.59	20	8.10	0.60	7.37
M1	30	11.76	0.45	3.85	31	11.70	0.43	3.71	30	11.11	0.53	4.73	33	11.10	0.46	4.11
M2	3	11.93	0.56	4.66	5	11.95	0.42	3.53	10	11.06	0.62	5.57	12	11.00	0.51	4.64
Mandibular																
I1	33	6.12	0.41	6.69	34	6.04	0.48	7.89	31	5.86	0.47	8.01	29	5.83	0.44	7.48
I2	32	6.36	0.55	8.61	32	6.32	0.52	8.21	30	6.11	0.58	9.45	29	6.13	0.50	8.13
C	21	7.53	0.71	9.39	22	7.51	0.72	9.52	23	7.17	0.50	6.94	24	7.11	0.65	9.15
M1	32	10.58	0.39	3.71	31	10.63	0.37	3.48	31	9.89	0.47	4.71	33	10.02	0.49	4.88
M2	4	10.62	0.19	1.76	6	10.53	0.56	5.34	13	10.07	0.57	5.69	12	10.16	0.57	5.62

Table 5-11 shows the median values of Carabelli trait (CT) scores of m2 and M1 of Australian male and female dizygotic same sex (DZSS) twins. Highlighted in yellow are p-values of the sexually dimorphic molars, where CT scores are different between sexes at $p < 0.05$. CT scores of males were consistently greater compared to females in both types of molars. In general, M1 showed greater sexual dimorphism compared to m2. There were no left-right differences observed in CT scores of both molars, based on Wilcoxon signed-rank test.

Table 5-11. Descriptive statistics for Carabelli trait (CT) of of primary second molars (m2) and permanent first molars (M1) of Australian male and female dizygotic same sex (DZSS) twins.

	DZSS Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
m2	3.00	1.00	< .00001	3.00	1.00	< .00001
M1	5.00	1.00	0.01	5.00	1.00	0.01

Table 5-12 is a table that shows the frequency of CT scores in both m2 and M1 of DZSS twins. It also shows that the CT scores assigned were not normally distributed.

Table 5-12. Frequency of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian male and female dizygotic same sex (DZSS) twins.

	DZSS Males				DZSS Females			
	Right		Left		Right		Left	
Score	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**
0	1	3	3	5	4	11	7	14
1	1	4	1	1	17	6	13	4
2	3	4	3	4	6	5	6	5
3	16	1	15	1	5	3	5	1
4	11	0	12	0	2	0	2	0
5	NA	5	NA	7	NA	1	NA	2
6	NA	4	NA	5	NA	2	NA	4
7	NA	9	NA	8	NA	4	NA	4
Total	32	30	34	31	34	32	33	34

5.5 DZOS twins

Shown in Table 5-13 are the mean values, SDs and CVs of mesiodistal (MD) measurements of primary and permanent teeth of Australian dizygotic opposite sex (DZOS) twins. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of MD crown dimensions of males were consistently greater compared to females in all teeth even in the few which did not reach significance. Permanent teeth displayed greater sexual dimorphism compared to primary teeth. There were no left-right differences (i.e., directional asymmetry) observed in MD measurements of all primary and permanent teeth based on paired t-tests.

Table 5-13. Descriptive statistics for mesiodistal (MD) dimensions of primary and permanent teeth in Australian dizygotic opposite sex (DZOS) twins.

	Males								Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	27	6.31	0.39	6.17	29	6.34	0.45	7.11	24	6.25	0.40	6.46	28	6.21	0.47	7.57
c	35	6.84	0.36	5.28	34	6.83	0.34	4.91	35	6.72	0.34	5.11	35	6.73	0.34	5.11
m1	33	7.01	0.42	5.98	35	7.11	0.42	5.85	34	6.82	0.33	4.79	33	6.91	0.39	5.62
m2	35	8.89	0.55	6.24	35	8.82	0.48	5.39	34	8.66	0.41	4.74	34	8.70	0.40	4.63
Mandibular																
i1	17	4.12	0.35	8.52	16	4.05	0.37	9.12	14	3.96	0.27	6.72	16	4.00	0.32	8.01
i2	28	4.63	0.41	8.75	30	4.59	0.34	7.35	24	4.58	0.23	4.95	25	4.63	0.30	6.49
c	33	5.90	0.29	4.90	34	5.90	0.33	5.66	34	5.74	0.29	5.11	34	5.80	0.34	5.82
m1	34	7.88	0.49	6.25	34	7.90	0.47	5.95	34	7.76	0.48	6.14	33	7.73	0.46	5.94
m2	35	10.04	0.53	5.30	35	9.99	0.52	5.18	35	9.93	0.41	4.15	34	9.86	0.42	4.25
Permanent																
Maxillary																
I1	33	8.67	0.48	5.56	35	8.61	0.51	5.93	34	8.50	0.57	6.72	34	8.50	0.53	6.27
C	24	8.25	0.46	5.60	23	8.26	0.51	6.13	21	7.87	0.40	5.05	24	7.78	0.43	5.46
M1	32	10.44	0.61	5.81	32	10.46	0.55	5.25	33	10.29	0.53	5.11	33	10.26	0.51	4.99
M2	11	10.32	0.68	6.60	13	10.46	0.84	8.03	14	10.05	0.43	4.23	9	9.98	0.55	5.56
Mandibular																
I1	33	5.45	0.34	6.16	34	5.44	0.32	5.94	29	5.40	0.34	6.30	31	5.33	0.37	6.90
I2	30	6.00	0.41	6.79	30	5.98	0.39	6.60	24	5.89	0.32	5.43	28	5.91	0.41	6.91
C	27	7.21	0.53	7.36	28	7.17	0.52	7.19	25	6.81	0.42	6.23	25	6.77	0.39	5.82
M1	29	11.29	0.71	6.26	31	11.32	0.67	5.90	27	11.06	0.58	5.23	29	11.11	0.61	5.47
M2	12	10.90	0.96	8.79	12	10.97	1.03	9.38	7	10.20	0.70	6.85	10	10.61	0.87	8.24

Presented in Table 5-14 are the mean values, SDs and CVs of buccolingual (BL) measurements of primary and permanent teeth of Australian dizygotic opposite sex (DZOS) twins. Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are significantly different between sexes at $p < 0.05$. Mean values of BL crown sizes of males were mostly greater compared to females, except for the few highlighted in red. Permanent teeth showed greater sexual dimorphism compared to primary teeth. There were no left-right differences (i.e., directional asymmetry) observed in BL measurements of all primary and permanent teeth based on paired t-tests.

Table 5-14. Descriptive statistics for buccolingual (BL) dimensions of primary and permanent teeth in Australian dizygotic opposite sex (DZOS) twins.

	DZOS Males								DZOS Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																
Maxillary																
i1	29	5.06	0.38	7.51	30	5.09	0.38	7.42	26	4.97	0.34	6.86	28	4.99	0.41	8.20
c	35	6.20	0.41	6.61	34	6.22	0.42	6.79	35	6.19	0.39	6.35	35	6.17	0.37	5.98
m1	35	8.77	0.47	5.34	35	8.74	0.46	5.26	35	8.56	0.38	4.46	35	8.58	0.41	4.76
m2	35	9.97	0.53	5.35	35	9.94	0.43	4.36	35	9.73	0.41	4.20	35	9.77	0.39	3.95
Mandibular																
i1	16	3.97	0.35	8.78	17	3.88	0.28	7.30	15	3.75	0.21	5.54	16	3.76	0.20	5.36
i2	29	4.44	0.37	8.35	31	4.39	0.34	7.79	24	4.38	0.28	6.47	26	4.42	0.26	5.79
c	33	5.63	0.36	6.33	33	5.66	0.38	6.62	34	5.69	0.40	7.08	34	5.64	0.33	5.83
m1	34	7.10	0.37	5.26	34	7.16	0.35	4.93	34	6.96	0.44	6.32	34	7.01	0.38	5.45
m2	35	8.67	0.36	4.19	35	8.68	0.37	4.21	34	8.61	0.36	4.16	34	8.53	0.35	4.06
Permanent																
Maxillary																
I1	30	7.37	0.65	8.85	30	7.42	0.61	8.26	32	7.16	0.54	7.54	32	7.17	0.58	8.06
C	25	8.36	0.63	7.49	22	8.46	0.75	8.81	18	8.17	0.57	6.97	23	8.04	0.65	8.14
M1	35	11.71	0.64	5.46	35	11.69	0.62	5.33	34	11.46	0.54	4.70	34	11.39	0.53	4.62
M2	12	11.85	0.85	7.15	13	11.98	1.09	9.14	14	11.40	0.85	7.47	12	11.28	0.80	7.13
Mandibular																
I1	32	6.22	0.51	8.27	32	6.24	0.60	9.62	28	6.05	0.52	8.54	29	6.13	0.45	7.39
I2	29	6.53	0.61	9.36	31	6.39	0.68	10.58	27	6.47	0.51	7.83	28	6.45	0.42	6.57
C	26	7.61	0.58	7.62	27	7.62	0.57	7.49	23	7.17	0.46	6.35	24	7.39	0.54	7.37
M1	32	10.50	0.53	5.03	33	10.47	0.58	5.53	30	10.24	0.41	3.99	29	10.28	0.46	4.46
M2	14	10.65	0.70	6.56	12	10.56	0.76	7.24	12	10.26	0.71	6.87	13	10.23	0.60	5.90

Table 5-15 shows the median values of Carabelli trait (CT) scores of m2 and M1 of Australian dizygotic opposite sex (DZOS) twins. Median CT scores of both sexes were equal, indicating a lack of sexual dimorphism. There were no left-right differences observed in CT scores of both molars, based on Wilcoxon signed-rank test.

Table 5-15. Descriptive statistics for Carabelli trait (CT) of primary second molars (m2) and permanent first molars (M1) of Australian dizygotic opposite sex (DZOS) twins.

	DZOS Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
m2	3.00	3.00	0.85	3.00	3.00	0.16
M1	5.00	6.00	0.45	5.00	5.50	0.56

Table 5-16 is a table that shows the frequency of occurrence of CT scores in both m2 and M1 of DZOS twins. It also shows that the CT scores assigned were not normally distributed.

Table 5-16. Frequency of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian dizygotic opposite sex (DZOS) twins.

	DZOS Males				DZOS Females			
	Right		Left		Right		Left	
Score	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**
0	1	4	1	6	0	8	2	7
1	1	2	2	3	3	1	3	1
2	7	2	4	0	2	0	2	2
3	14	0	14	0	20	0	22	0
4	10	6	12	5	8	5	4	3
5	NA	9	NA	7	NA	3	NA	4
6	NA	10	NA	11	NA	11	NA	11
7	NA	2	NA	3	NA	7	NA	6
Total	33	35	33	35	33	35	33	34

5.6 Male twins

Shown in Table 5-17 is the comparison of mean values, SDs and CVs of mesiodistal (MD) measurements of primary and permanent teeth of Australian male twins. There was no observed significant difference of mean values among zygosities at $p < 0.05$. Mean values of MD crown dimensions of MZ males were consistently greater compared to DZSS and DZOS males except for the few highlighted in red.

Presented in Table 5-18 is the comparison of mean values, SDs and CVs of buccolingual (BL) measurements of primary and permanent teeth of Australian male twins. There was no observed significant difference of mean values among zygosities at $p < 0.05$. Mean values of BL crown dimensions of MZ males were consistently greater compared to DZSS and DZOS males except for the few highlighted in red.

Table 5-17. Comparison of mesiodistal (MD) dimensions in the primary and permanent dentitions of Australian male twins.

	MZ Males								DZSS Males								DZOS Males							
	Right				Left				Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																								
Maxillary																								
i1	23	6.39	0.41	6.38	27	6.36	0.41	6.43	28	6.33	0.33	5.18	27	6.27	0.39	6.26	27	6.31	0.39	6.17	29	6.34	0.45	7.11
c	34	6.90	0.33	4.79	33	6.85	0.34	4.91	34	6.86	0.42	6.19	34	6.82	0.42	6.21	35	6.84	0.36	5.28	34	6.83	0.34	4.91
m1	33	7.11	0.39	5.53	34	7.12	0.41	5.78	34	7.03	0.49	7.04	34	7.13	0.40	5.65	33	7.01	0.42	5.98	35	7.11	0.42	5.85
m2	34	8.90	0.43	4.81	32	8.88	0.42	4.78	32	8.78	0.41	4.66	32	8.78	0.38	4.35	35	8.89	0.55	6.24	35	8.82	0.48	5.39
Mandibular																								
i1	16	4.03	0.33	8.25	16	4.06	0.31	7.52	20	4.00	0.26	6.51	21	4.00	0.24	6.00	17	4.12	0.35	8.52	16	4.05	0.37	9.12
i2	27	4.58	0.32	7.08	28	4.64	0.34	7.24	30	4.63	0.31	6.76	28	4.62	0.30	6.54	28	4.63	0.41	8.75	30	4.59	0.34	7.35
c	34	5.92	0.28	4.69	34	5.89	0.27	4.52	33	5.86	0.42	7.16	34	5.92	0.37	6.27	33	5.90	0.29	4.90	34	5.90	0.33	5.66
m1	32	7.90	0.39	4.90	33	7.92	0.38	4.86	32	7.83	0.59	7.49	34	7.91	0.46	5.79	34	7.88	0.49	6.25	34	7.90	0.47	5.95
m2	34	10.07	0.44	4.34	33	10.03	0.45	4.47	32	10.11	0.45	4.46	33	10.08	0.42	4.15	35	10.04	0.53	5.30	35	9.99	0.52	5.18
Permanent																								
Maxillary																								
I1	33	8.68	0.54	6.22	33	8.63	0.45	5.20	32	8.75	0.46	5.20	30	8.68	0.47	5.46	33	8.67	0.48	5.56	35	8.61	0.51	5.93
C	19	8.13	0.39	4.80	21	8.17	0.49	5.95	19	7.99	0.32	3.94	18	8.11	0.34	4.21	24	8.25	0.46	5.60	23	8.26	0.51	6.13
M1	33	10.46	0.43	4.11	33	10.41	0.47	4.51	30	10.45	0.52	4.96	30	10.52	0.54	5.17	32	10.44	0.61	5.81	32	10.46	0.55	5.25
M2	13	10.49	0.49	4.65	10	10.57	0.47	4.42	4	10.03	0.53	5.34	5	10.21	0.22	2.18	11	10.32	0.68	6.60	13	10.46	0.84	8.03
Mandibular																								
I1	32	5.38	0.38	7.06	31	5.44	0.33	6.05	31	5.45	0.26	4.83	31	5.51	0.33	5.91	33	5.45	0.34	6.16	34	5.44	0.32	5.94
I2	27	6.03	0.35	5.88	30	6.02	0.31	5.21	30	5.99	0.34	5.69	30	5.95	0.31	5.15	30	6.00	0.41	6.79	30	5.98	0.39	6.60
C	24	7.21	0.40	5.57	25	7.20	0.40	5.50	23	7.16	0.30	4.22	24	7.14	0.41	5.69	27	7.21	0.53	7.36	28	7.17	0.52	7.19
M1	29	11.34	0.64	5.63	32	11.36	0.57	5.02	31	11.30	0.56	4.99	31	11.30	0.57	5.02	29	11.29	0.71	6.26	31	11.32	0.67	5.90
M2	12	11.00	0.45	4.11	12	11.32	0.57	5.01	2	10.89	0.08	0.71	4	10.92	0.52	4.76	12	10.90	0.96	8.79	12	10.97	1.03	9.38

Table 5-18. Comparison of buccolingual (BL) dimensions in the primary and permanent dentitions of Australian male twins.

	MZ Males								DZSS Males								DZOS Males							
	Right				Left				Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																								
Maxillary																								
i1	25	5.14	0.28	5.51	27	5.19	0.23	4.48	30	5.02	0.30	6.04	29	5.09	0.35	6.81	29	5.06	0.38	7.51	30	5.09	0.38	7.42
c	33	6.24	0.33	5.30	33	6.23	0.32	5.10	34	6.16	0.51	8.33	34	6.10	0.51	8.35	35	6.20	0.41	6.61	34	6.22	0.42	6.79
m1	33	8.90	0.38	4.30	34	8.87	0.32	3.66	34	8.70	0.42	4.79	34	8.66	0.44	5.06	35	8.77	0.47	5.34	35	8.74	0.46	5.26
m2	34	10.09	0.44	4.36	34	10.02	0.44	4.35	33	9.92	0.44	4.48	34	9.91	0.44	4.44	35	9.97	0.53	5.35	35	9.94	0.43	4.36
Mandibular																								
i1	16	3.90	0.27	7.00	15	3.87	0.20	5.21	21	3.78	0.25	6.55	23	3.77	0.24	6.31	16	3.97	0.35	8.78	17	3.88	0.28	7.30
i2	27	4.42	0.28	6.27	28	4.39	0.27	6.20	31	4.33	0.33	7.61	32	4.34	0.30	6.98	29	4.44	0.37	8.35	31	4.39	0.34	7.79
c	34	5.70	0.32	5.65	34	5.69	0.30	5.27	34	5.62	0.41	7.23	33	5.59	0.40	7.07	33	5.63	0.36	6.33	33	5.66	0.38	6.62
m1	32	7.09	0.31	4.41	33	7.22	0.34	4.75	33	7.07	0.44	6.26	34	7.13	0.41	5.82	34	7.10	0.37	5.26	34	7.16	0.35	4.93
m2	34	8.77	0.39	4.41	33	8.81	0.38	4.26	34	8.72	0.39	4.53	33	8.67	0.39	4.50	35	8.67	0.36	4.19	35	8.68	0.37	4.21
Permanent																								
Maxillary																								
I1	33	7.24	0.52	7.12	32	7.25	0.54	7.45	33	7.23	0.52	7.13	33	7.21	0.49	6.85	30	7.37	0.65	8.85	30	7.42	0.61	8.26
C	16	8.37	0.55	6.53	20	8.50	0.47	5.55	19	8.23	0.49	5.98	18	8.24	0.57	6.90	25	8.36	0.63	7.49	22	8.46	0.75	8.81
M1	33	11.91	0.57	4.78	33	11.82	0.54	4.59	30	11.76	0.45	3.85	31	11.70	0.43	3.71	35	11.71	0.64	5.46	35	11.69	0.62	5.33
M2	13	12.06	0.62	5.11	10	12.24	0.64	5.24	3	11.93	0.56	4.66	5	11.95	0.42	3.53	12	11.85	0.85	7.15	13	11.98	1.09	9.14
Mandibular																								
I1	29	6.22	0.45	7.28	31	6.10	0.44	7.14	33	6.12	0.41	6.69	34	6.04	0.48	7.89	32	6.22	0.51	8.27	32	6.24	0.60	9.62
I2	26	6.53	0.40	6.15	27	6.53	0.38	5.83	32	6.36	0.55	8.61	32	6.32	0.52	8.21	29	6.53	0.61	9.36	31	6.39	0.68	10.58
C	20	7.85	0.67	8.49	24	7.83	0.65	8.29	21	7.53	0.71	9.39	22	7.51	0.72	9.52	26	7.61	0.58	7.62	27	7.62	0.57	7.49
M1	32	10.54	0.50	4.70	33	10.59	0.51	4.83	32	10.58	0.39	3.71	31	10.63	0.37	3.48	32	10.50	0.53	5.03	33	10.47	0.58	5.53
M2	13	10.78	0.53	4.92	12	10.78	0.46	4.24	4	10.62	0.19	1.76	6	10.53	0.56	5.34	14	10.65	0.70	6.56	12	10.56	0.76	7.24

Table 5-19 shows the comparison of median values of Carabelli trait (CT) scores of m2 and M1 of Australian male twins. There was no significant difference observed among zygosities at $p < 0.05$ based on Kruskal-Wallis test. Median values of CT scores of males were consistently equal in all zygosities.

Table 5-19. Comparison of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian male twins.

	Male Twins							
	Right				Left			
	Median				Median			
	MZ	DZSS	DZOS	p-value	MZ	DZSS	DZOS	p-value
m2	3.00	3.00	3.00	0.37	3.00	3.00	3.00	0.87
M1	5.00	5.00	5.00	0.79	5.00	3.00	5.00	0.61

Table 5-20 is a table that shows the frequency of occurrence of CT scores in both m2 and M1 of all Australian male twins per zygosity. It also shows that CT scores assigned were not normally distributed in all zygosity.

Table 5-20. Frequency of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian male twins.

	MZ Males				DZSS Males				DZOS Males			
	Right		Left		Right		Left		Right		Left	
Score	m2	M1	m2	M1	m2	M1	m2	M1	m2	M1	m2	M1
0	0	4	0	4	1	3	3	5	1	4	1	6
1	5	1	5	2	1	4	1	1	1	2	2	3
2	6	5	3	0	3	4	3	4	7	2	4	0
3	15	0	15	0	16	1	15	1	14	0	14	0
4	8	3	10	2	11	0	12	0	10	6	12	5
5	NA	11	NA	9	NA	5	NA	7	NA	9	NA	7
6	NA	6	NA	12	NA	4	NA	5	NA	10	NA	11
7	NA	4	NA	4	NA	9	NA	8	NA	2	NA	3
Total	34	34	33	33	32	30	34	31	33	35	33	35

5.7 Female twins

Shown in Table 5-21 is the comparison of mean values, SDs and CVs of mesiodistal (MD) measurements of primary and permanent teeth of Australian female twins. Highlighted in yellow are the mean values with significant differences between DZOS and MZ females at $p < 0.05$. Highlighted in blue are the mean values with significant differences between DZOS and DZSS females at $p < 0.05$. Highlighted in green are the mean values with significant differences among zygosities at $p < 0.05$. Mean values of MD crown dimensions of DZOS females were consistently greater compared to MZ and DZSS females except for the few highlighted in red.

Presented in Table 5-22 is the comparison of mean values, SDs and CVs of buccolingual (BL) measurements of primary and permanent teeth of Australian female twins. Highlighted in yellow are the mean values with significant differences between DZOS and MZ females at $p < 0.05$. Highlighted in blue are the mean values with significant differences between DZOS and DZSS females at $p < 0.05$. Highlighted in green are the mean values with significant differences among zygosities at $p < 0.05$. Mean values of BL crown dimensions of DZOS females were consistently greater compared to MZ and DZSS females except for the few highlighted in red.

Table 5-21. Comparison of mesiodistal (MD) dimensions in the primary and permanent dentitions of Australian female twins.

	MZ Females								DZSS Females								DZOS Females							
	Right				Left				Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																								
Maxillary																								
i1	34	6.21	0.36	5.85	35	6.21	0.33	5.36	28	6.24	0.41	6.60	29	6.22	0.45	7.20	24	6.25	0.40	6.46	28	6.21	0.47	7.57
c	42	6.63	0.44	6.61	43	6.64	0.39	5.92	34	6.76	0.37	5.41	33	6.73	0.36	5.42	35	6.72	0.34	5.11	35	6.73	0.34	5.11
m1	42	6.78	0.33	4.83	43	6.84	0.36	5.19	34	6.91	0.49	7.04	33	6.96	0.46	6.66	34	6.82	0.33	4.79	33	6.91	0.39	5.62
m2	43	8.53	0.35	4.12	43	8.55	0.35	4.13	34	8.71	0.44	5.02	31	8.68	0.47	5.36	34	8.66	0.41	4.74	34	8.70	0.40	4.63
Mandibular																								
i1	23	3.88	0.27	6.92	21	3.83	0.26	6.68	24	3.93	0.27	7.00	23	3.90	0.27	6.87	14	3.96	0.27	6.72	16	4.00	0.32	8.01
i2	36	4.45	0.31	6.98	33	4.39	0.30	6.82	31	4.49	0.37	8.24	29	4.49	0.31	6.90	24	4.58	0.23	4.95	25	4.63	0.30	6.49
c	42	5.74	0.26	4.56	42	5.71	0.29	5.01	34	5.71	0.35	6.11	34	5.72	0.35	6.08	34	5.74	0.29	5.11	34	5.80	0.34	5.82
m1	42	7.60	0.33	4.35	40	7.60	0.35	4.64	33	7.66	0.32	4.24	34	7.64	0.39	5.04	34	7.76	0.48	6.14	33	7.73	0.46	5.94
m2	42	9.71	0.33	3.40	42	9.71	0.34	3.52	34	9.80	0.46	4.67	34	9.77	0.48	4.91	35	9.93	0.41	4.15	34	9.86	0.42	4.25
Permanent																								
Maxillary																								
I1	43	8.42	0.53	6.24	42	8.40	0.48	5.75	33	8.36	0.49	5.82	32	8.38	0.41	4.92	34	8.50	0.57	6.72	34	8.50	0.53	6.27
C	29	7.54	0.33	4.36	28	7.54	0.35	4.67	20	7.79	0.61	7.83	22	7.66	0.43	5.57	21	7.87	0.40	5.05	24	7.78	0.43	5.46
M1	41	10.01	0.46	4.62	42	10.06	0.43	4.23	31	9.98	0.50	5.03	33	10.01	0.49	4.93	33	10.29	0.53	5.11	33	10.26	0.51	4.99
M2	8	9.62	0.53	5.52	7	9.67	0.38	3.97	6	9.71	0.67	6.90	10	9.76	0.67	6.85	14	10.05	0.43	4.23	9	9.98	0.55	5.56
Mandibular																								
I1	41	5.27	0.30	5.67	40	5.34	0.29	5.38	32	5.26	0.34	6.48	29	5.18	0.32	6.09	29	5.40	0.34	6.30	31	5.33	0.37	6.90
I2	40	5.81	0.39	6.66	41	5.76	0.35	6.07	31	5.73	0.38	6.60	27	5.67	0.33	5.85	24	5.89	0.32	5.43	28	5.91	0.41	6.91
C	33	6.54	0.36	5.52	33	6.56	0.34	5.11	24	6.67	0.40	6.04	24	6.65	0.49	7.44	25	6.81	0.42	6.23	25	6.77	0.39	5.82
M1	41	10.69	0.61	5.68	41	10.71	0.55	5.14	29	10.82	0.66	6.06	30	10.78	0.65	6.03	27	11.06	0.58	5.23	29	11.11	0.61	5.47
M2	15	10.12	0.41	4.06	14	10.24	0.51	4.99	11	10.34	0.64	6.17	11	10.47	0.65	6.25	7	10.20	0.70	6.85	10	10.61	0.87	8.24

Table 5-22. Comparison of buccolingual (BL) dimensions in the primary and permanent dentitions of Australian female twins.

	MZ Females								DZSS Females								DZOS Females							
	Right				Left				Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Primary																								
Maxillary																								
i1	37	4.91	0.31	6.31	35	4.97	0.28	5.70	28	4.89	0.39	8.02	29	4.92	0.40	8.09	26	4.97	0.34	6.86	28	4.99	0.41	8.20
c	43	6.10	0.41	6.76	43	6.09	0.41	6.68	34	6.00	0.34	5.71	33	5.97	0.33	5.56	35	6.19	0.39	6.35	35	6.17	0.37	5.98
m1	43	8.54	0.32	3.77	43	8.52	0.31	3.66	33	8.55	0.32	3.74	34	8.50	0.31	3.61	35	8.56	0.38	4.46	35	8.58	0.41	4.76
m2	43	9.69	0.38	3.94	43	9.58	0.37	3.89	34	9.61	0.41	4.29	33	9.57	0.39	4.05	35	9.73	0.41	4.20	35	9.77	0.39	3.95
Mandibular																								
i1	22	3.63	0.32	8.92	22	3.65	0.29	8.04	24	3.77	0.24	6.44	24	3.73	0.22	5.82	15	3.75	0.21	5.54	16	3.76	0.20	5.36
i2	36	4.28	0.28	6.60	34	4.24	0.28	6.63	30	4.21	0.28	6.70	29	4.23	0.28	6.51	24	4.38	0.28	6.47	26	4.42	0.26	5.79
c	42	5.58	0.39	6.99	42	5.59	0.39	6.94	34	5.46	0.33	6.04	34	5.51	0.32	5.80	34	5.69	0.40	7.08	34	5.64	0.33	5.83
m1	42	6.81	0.40	5.90	41	6.97	0.36	5.23	33	6.82	0.33	4.78	34	6.83	0.34	4.99	34	6.96	0.44	6.32	34	7.01	0.38	5.45
m2	42	8.22	0.41	4.96	42	8.36	0.38	4.60	34	8.35	0.34	4.08	34	8.33	0.34	4.09	34	8.61	0.36	4.16	34	8.53	0.35	4.06
Permanent																								
Maxillary																								
I1	39	7.10	0.43	6.06	39	7.06	0.51	7.23	31	6.85	0.64	9.34	26	6.84	0.57	8.28	32	7.16	0.54	7.54	32	7.17	0.58	8.06
C	27	7.72	0.39	5.11	28	7.84	0.41	5.20	19	7.94	0.60	7.59	20	8.10	0.60	7.37	18	8.17	0.57	6.97	23	8.04	0.65	8.14
M1	42	11.11	0.48	4.30	42	11.03	0.46	4.15	30	11.11	0.53	4.73	33	11.10	0.46	4.11	34	11.46	0.54	4.70	34	11.39	0.53	4.62
M2	10	11.01	0.42	3.81	10	10.92	0.39	3.57	10	11.06	0.62	5.57	12	11.00	0.51	4.64	14	11.40	0.85	7.47	12	11.28	0.80	7.13
Mandibular																								
I1	39	5.90	0.40	6.75	37	5.96	0.38	6.33	31	5.86	0.47	8.01	29	5.83	0.44	7.48	28	6.05	0.52	8.54	29	6.13	0.45	7.39
I2	41	6.21	0.46	7.41	38	6.26	0.45	7.13	30	6.11	0.58	9.45	29	6.13	0.50	8.13	27	6.47	0.51	7.83	28	6.45	0.42	6.57
C	32	7.23	0.49	6.81	33	7.34	0.50	6.78	23	7.17	0.50	6.94	24	7.11	0.65	9.15	23	7.17	0.46	6.35	24	7.39	0.54	7.37
M1	42	9.89	0.47	4.79	41	9.96	0.45	4.50	31	9.89	0.47	4.71	33	10.02	0.49	4.88	30	10.24	0.41	3.99	29	10.28	0.46	4.46
M2	21	9.84	0.55	5.60	21	9.91	0.54	5.44	13	10.07	0.57	5.69	12	10.16	0.57	5.62	12	10.26	0.71	6.87	13	10.23	0.60	5.90

Table 5-23 shows the comparison of median values of Carabelli trait (CT) scores of m2 and M1 of Australian female twins. Highlighted in yellow are the significant p-values based on Kruskal-Wallis test, where CT scores are significantly different among zygosities. CT scores of DZOS females (highlighted in blue) were consistently and significantly greater than MZ and DZSS females in both m2 and M1.

Table 5-23. Comparison of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian female twins.

	Female Twins							
	Right				Left			
	Median				Median			
	MZ	DZSS	DZOS	p-value	MZ	DZSS	DZOS	p-value
m2	2.00	1.00	3.00	0.00	2.00	1.00	3.00	0.00
M1	1.00	1.00	6.00	0.02	1.00	1.00	5.50	0.02

Table 5-24 shows the frequency of occurrence of CT scores in both m2 and M1 of all Australian male twins per zygosity. It also shows that CT scores assigned were not normally distributed in all zygosity, and there were higher scores in DZOS females than MZ and DZSS females.

Table 5-24. Frequency of Carabelli trait (CT) scores of primary second molars (m2) and permanent first molars (M1) of Australian female twins.

	MZ Females				DZSS Females				DZOS Females			
	Right		Left		Right		Left		Right		Left	
Score	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**	**m2**	**M1**
0	3	15	6	20	4	11	7	14	0	8	2	7
1	13	7	13	4	17	6	13	4	3	1	3	1
2	11	2	8	1	6	5	6	5	2	0	2	2
3	6	0	8	2	5	3	5	1	20	0	22	0
4	9	2	7	2	2	0	2	0	8	5	4	3
5	NA	9	NA	4	NA	1	NA	2	NA	3	NA	4
6	NA	2	NA	5	NA	2	NA	4	NA	11	NA	11
7	NA	5	NA	5	NA	4	NA	4	NA	7	NA	6
Total	42	42	42	43	34	32	33	34	33	35	33	34

5.8 Correlations

Pearson's coefficients (r) between dental dimensions MD and BL are presented in Table 5-25. Highlighted in yellow are the statistically significant correlations at $p < 0.05$. Overall, the correlations between MD and BL are statistically significant and medium to high in magnitude.

Table 5-25. Pearson correlation coefficients of mesiodistal (MD) and BL (buccolingual) dimensions.

	Males		Females	
	Right	**Left**	**Right**	**Left**
		Primary		
		Maxillary		
i1	0.53	0.40	0.62	0.37
c	0.63	0.53	0.48	0.49
m1	0.46	0.45	0.54	0.56
m2	0.75	0.70	0.64	0.65
		Mandibular		
i1	0.56	0.58	0.54	0.60
i2	0.55	0.55	0.54	0.66
c	0.53	0.53	0.32	0.43
m1	0.31	0.46	0.34	0.29
m2	0.57	0.62	0.51	0.51
		Permanent		
		Maxillary		
I1	0.44	0.45	0.38	0.31
C	0.51	0.56	0.46	0.54
M1	0.62	0.65	0.68	0.63
M2	0.56	0.71	0.66	0.57
		Mandibular		
I1	0.42	0.44	0.31	0.29
I2	0.29	0.45	0.31	0.35
C	0.27	0.34	0.43	0.22
M1	0.61	0.50	0.53	0.46
M2	0.71	0.85	0.60	0.71

Shown in Table 5-26 are Spearman's correlation coefficients (r) between the Carabelli trait (CT) scores and measurements of mesiodistal (MD) and buccolingual (BL) dimensions. Highlighted in yellow are the statistically significant correlations at $p < 0.05$. Only MD and BL measurements of M1 are statistically significant to CT scores but they are low in magnitude.

Table 5-26. Spearman correlation coefficients of Carabelli trait (CT) scores and mesiodistal (MD) and BL (buccolingual) measurements.

		Males		Females	
		Right	**Left**	**Right**	**Left**
	m2	-0.12	0.02	-0.01	-0.06
MD	**M1**	0.17	0.03	0.19	0.19
	m2	-0.05	0.06	0.09	0.12
BL	**M1**	0.24	0.19	0.32	0.22

Presented in Table 5-27 are Pearson's correlation coefficients (r) between left and right sides. Highlighted in yellow are the statistically significant correlations at $p < 0.05$. Overall, the correlations between sides are statistically significant and high in magnitude in all tooth types and dental dimensions.

Table 5-27. Pearson correlation coefficients of left and right sides in all tooth types and dental dimensions.

	Males		Females	
	MD	**BL**	**MD**	**BL**
	Primary			
	Maxillary			
i1	0.79	0.87	0.85	0.85
c	0.90	0.91	0.72	0.91
m1	0.84	0.91	0.89	0.87
m2	0.84	0.85	0.86	0.87
	Mandibular			
i1	0.92	0.72	0.69	0.89
i2	0.73	0.66	0.79	0.80
c	0.86	0.84	0.64	0.81
m1	0.79	0.80	0.83	0.84
m2	0.89	0.82	0.90	0.86
	Permanent			
	Maxillary			
I1	0.83	0.85	0.88	0.80
C	0.79	0.79	0.71	0.77
M1	0.81	0.93	0.87	0.88
M2	0.71	0.77	0.65	0.85
	Mandibular			
I1	0.82	0.74	0.74	0.79
I2	0.81	0.78	0.74	0.71
C	0.81	0.66	0.69	0.74
M1	0.90	0.89	0.86	0.86
M2	0.83	0.81	0.72	0.87

Pearson's coefficients (r) between maxillary and mandibular measurements are presented in Table 5-28. Highlighted in yellow are the statistically significant correlations at $p < 0.05$. Overall, the correlations between maxillary and mandibular were statistically significant and medium in magnitude.

Table 5-28. Pearson correlation coefficients of maxillary and mandibular teeth.

	Males				Females			
	Right		Left		Right		Left	
	MD	BL	MD	BL	MD	BL	MD	BL
	Primary							
i1	0.51	0.46	0.55	0.48	0.61	0.48	0.55	0.50
c	0.79	0.77	0.75	0.77	0.57	0.70	0.66	0.78
m1	0.51	0.59	0.60	0.60	0.65	0.54	0.61	0.51
m2	0.55	0.70	0.63	0.66	0.59	0.68	0.64	0.68
	Permanent							
I1	0.65	0.57	0.59	0.60	0.66	0.58	0.61	0.61
C	0.66	0.41	0.64	0.50	0.63	0.50	0.61	0.54
M1	0.56	0.77	0.56	0.72	0.65	0.75	0.67	0.73
M2	0.48	0.62	0.64	0.66	0.37	0.55	0.50	0.56

5.9 Associations

Tables 5-29 and 5-30 gives Differences of Marginal Means for each model (post-hoc comparisons). Highlighted in yellow are the statistically significant models at $p < 0.05$. For Model 4 (permanent teeth), there is a statistically significant difference in mean MD between twin types (global p-value=0.01). DZOS females have mean MD 0.20 units less than DZOS males and MZ females have mean MD 0.52 units less than MZ males at 95% confidence interval.

For Models 5 (primary teeth) and 6 (permanent teeth), there is a statistically significant difference in mean MD between sexes. Females have mean MD 0.11 and 0.23 units less than males at global p-value=0.0047.

For Models 7 (primary teeth) and 8 (permanent teeth), there is a statistically significant difference in mean MD between the upper and lower teeth. Mandibular or lower teeth have mean MD 0.16 and 1.11 units less than maxillary or upper teeth.

For Models 11 (primary teeth) and 12 (permanent teeth), there is a statistically significant difference in mean MD among tooth types. For the primary teeth, the first incisors have mean MD 0.51 units more than the second incisors, and the first molars have mean MD 1.96 units less than the second molars. For the permanent teeth, the first incisors have mean MD 1.11 units more than the second incisors, and the first molars have mean MD 0.26 units more than the second molars.

For Model 16 (permanent teeth), there is a statistically significant difference in mean BL between twin types (global p-value=0.01). DZOS females have mean BL 0.20 units less than DZOS males, and MZ females have mean BL 0.61 units less than MZ males at 95% confidence interval.

For Models 17 (primary teeth) and 18 (permanent teeth), there is a statistically significant difference in mean BL between sexes. Females have mean BL 0.09 and 0.21 units less than males.

For Models 19 (primary teeth) and 20 (permanent teeth), there is a statistically significant difference in mean BL between the upper and lower teeth. Mandibular or lower teeth have mean BL 1.02 and 1.03 units less than maxillary or upper teeth.

For Models 23 (primary teeth) and 24 (permanent teeth), there is a statistically significant difference in mean BL between tooth types. For the primary teeth, the first incisors have mean BL 0.04 units less than the second incisors, and the first molars have mean BL 1.34 units less than the second molars. For the permanent teeth, the first incisors have mean BL 0.26 units more than the second incisors, and the first molars have mean BL 0.06 units more than the second molars.

In Table 5-30, for Models 29 (primary teeth) and 30 (permanent teeth), there is a statistically significant interaction between tooth type and sex, for outcome MD (interaction p-value=0.04). For the primary teeth, females have mean MD value 0.16 units less than males in canines, 0.13 units less in the first incisors, 0.22 units less in the first molars, and 0.23 units less in the second molars. It can also be observed that in females, canines have a mean MD value 0.92 units greater than the first incisors, 1.38 units more than the second incisors, 1.04 units less than the first molars, and 3.00 units less than the second molars. For the permanent teeth, females have mean MD value 0.49 units less than males in canines, 0.15 units less in the first incisors, 0.43 units less in the first molars, and 0.61 units less in the second molars. It can also be observed that in females, canines have a mean MD value 0.21 units greater than the first incisors, 1.34 units more than the second incisors, 3.32 units less than the first molars, and 2.97 units less than the second molars.

In Model 32 (permanent teeth), there is a statistically significant interaction between tooth position (upper or lower) and sex, for outcome BL (interaction p-value=0.0033). Mandibular or lower teeth of females have mean BL 0.20 less than males, and 0.28 less in maxillary or upper teeth.

For Models 35 (primary teeth) and 36 (permanent teeth), there is a statistically significant interaction between tooth type and sex, for outcome BL (interaction p-value=0.0024). For the primary teeth, females have mean BL value 0.08 units less than males in canines, 0.16 units less in the first incisors, 0.06 units less in the second incisors, 0.23 units less in the first molars, and 0.32 units less in the second molars. It can also be observed that in females, canines have a mean BL value 1.39 units greater than the first incisors, 1.30 units more than the second incisors, 1.90 units less than the first molars, and 3.19 units less than the second molars. For the permanent teeth, females have mean BL value 0.38 units less than males in canines, 0.21 units less in the first incisors, 0.15 units less in the second incisors, 0.45 units less in the first molars, and 0.71 units less in the second molars. It can also be observed that in females, canines have a mean BL value 1.07 units greater than the first incisors, 1.29 units more than the second incisors, 3.11 units less than the first molars, and 2.97 units less than the second molars.

Table 5-29. Linear mixed-effects models.

Model	Type	Outcome	Predictor	Comparison value	Reference value	Estimate	Lower 95%	Upper 95%	p- value	Global p
1	Primary	MD	TTT	DZOS Females	MZ and DZSS Females	0.13	-0.17	0.42	0.39	0.39
2	Permanent	MD	TTT	DZOS Females	MZ and DZSS Females	0.27	-0.11	0.65	0.16	0.16
3	Primary	MD	Twin_type	DZOS Females	DZOS Males	-0.10	-0.18	-0.02	0.01	0.12
3	Primary	MD	Twin_type	DZOS Females	DZSS Females	0.06	-0.29	0.41	0.73	0.12
3	Primary	MD	Twin_type	DZOS Females	DZSS Males	-0.06	-0.42	0.29	0.72	0.12
3	Primary	MD	Twin_type	DZOS Females	MZ Females	0.07	-0.27	0.40	0.68	0.12
3	Primary	MD	Twin_type	DZOS Females	MZ Males	-0.18	-0.54	0.18	0.32	0.12
3	Primary	MD	Twin_type	DZOS Males	DZSS Females	0.16	-0.19	0.52	0.37	0.12
3	Primary	MD	Twin_type	DZOS Males	DZSS Males	0.04	-0.31	0.39	0.83	0.12
3	Primary	MD	Twin_type	DZOS Males	MZ Females	0.17	-0.16	0.51	0.32	0.12
3	Primary	MD	Twin_type	DZOS Males	MZ Males	-0.08	-0.43	0.28	0.67	0.12
3	Primary	MD	Twin_type	DZSS Females	DZSS Males	-0.13	-0.48	0.23	0.49	0.12
3	Primary	MD	Twin_type	DZSS Females	MZ Females	0.01	-0.33	0.35	0.96	0.12
3	Primary	MD	Twin_type	DZSS Females	MZ Males	-0.24	-0.60	0.12	0.19	0.12
3	Primary	MD	Twin_type	DZSS Males	MZ Females	0.13	-0.20	0.47	0.44	0.12
3	Primary	MD	Twin_type	DZSS Males	MZ Males	-0.12	-0.47	0.24	0.52	0.12
3	Primary	MD	Twin_type	MZ Females	MZ Males	-0.25	-0.59	0.09	0.15	0.12
4	Permanent	MD	Twin_type	DZOS Females	DZOS Males	-0.20	-0.34	-0.05	0.01	0.01
4	Permanent	MD	Twin_type	DZOS Females	DZSS Females	0.27	-0.19	0.72	0.25	0.01
4	Permanent	MD	Twin_type	DZOS Females	DZSS Males	0.04	-0.42	0.49	0.88	0.01
4	Permanent	MD	Twin_type	DZOS Females	MZ Females	0.29	-0.13	0.71	0.18	0.01
4	Permanent	MD	Twin_type	DZOS Females	MZ Males	-0.23	-0.68	0.22	0.31	0.01
4	Permanent	MD	Twin_type	DZOS Males	DZSS Females	0.46	0.01	0.91	0.04	0.01
4	Permanent	MD	Twin_type	DZOS Males	DZSS Males	0.23	-0.22	0.69	0.32	0.01
4	Permanent	MD	Twin_type	DZOS Males	MZ Females	0.48	0.06	0.90	0.02	0.01
4	Permanent	MD	Twin_type	DZOS Males	MZ Males	-0.04	-0.48	0.41	0.88	0.01
4	Permanent	MD	Twin_type	DZSS Females	DZSS Males	-0.23	-0.70	0.24	0.33	0.01
4	Permanent	MD	Twin_type	DZSS Females	MZ Females	0.02	-0.41	0.46	0.92	0.01
4	Permanent	MD	Twin_type	DZSS Females	MZ Males	-0.50	-0.96	-0.04	0.03	0.01
4	Permanent	MD	Twin_type	DZSS Males	MZ Females	0.25	-0.19	0.69	0.26	0.01
4	Permanent	MD	Twin_type	DZSS Males	MZ Males	-0.27	-0.73	0.20	0.26	0.01
4	Permanent	MD	Twin_type	MZ Females	MZ Males	-0.52	-0.95	-0.09	0.02	0.01
5	Primary	MD	Sex	Female	Male	-0.11	-0.19	-0.03	0.00	0.00
6	Permanent	MD	Sex	Female	Male	-0.23	-0.36	-0.10	0.00	0.00
7	Primary	MD	Tooth_Position	Lower	Upper	-0.16	-0.21	-0.12	<.0001	<.0001

Continuation of Table 5-29

8	Permanent	MD	Tooth_Position	Lower	Upper	-1.11	-1.19	-1.03	<.0001	<.0001
9	Primary	MD	Tooth_Side	Left	Right	0.01	-0.04	0.05	0.76	0.76
10	Permanent	MD	Tooth_Side	Left	Right	0.01	-0.07	0.10	0.76	0.76
11	Primary	MD	Tooth_Type	C	I1	0.93	0.85	1.02	<.0001	<.0001
11	Primary	MD	Tooth_Type	C	I2	1.44	1.36	1.52	<.0001	<.0001
11	Primary	MD	Tooth_Type	C	M1	-1.07	-1.15	-1.00	<.0001	<.0001
11	Primary	MD	Tooth_Type	C	M2	-3.03	-3.11	-2.96	<.0001	<.0001
11	Primary	MD	Tooth_Type	I1	I2	0.51	0.42	0.59	<.0001	<.0001
11	Primary	MD	Tooth_Type	I1	M1	-2.01	-2.09	-1.92	<.0001	<.0001
11	Primary	MD	Tooth_Type	I1	M2	-3.97	-4.05	-3.88	<.0001	<.0001
11	Primary	MD	Tooth_Type	I2	M1	-2.51	-2.59	-2.44	<.0001	<.0001
11	Primary	MD	Tooth_Type	I2	M2	-4.47	-4.55	-4.39	<.0001	<.0001
11	Primary	MD	Tooth_Type	M1	M2	-1.96	-2.03	-1.88	<.0001	<.0001
12	Permanent	MD	Tooth_Type	C	I1	0.37	0.26	0.48	<.0001	<.0001
12	Permanent	MD	Tooth_Type	C	I2	1.48	1.34	1.61	<.0001	<.0001
12	Permanent	MD	Tooth_Type	C	M1	-3.29	-3.40	-3.18	<.0001	<.0001
12	Permanent	MD	Tooth_Type	C	M2	-3.03	-3.19	-2.87	<.0001	<.0001
12	Permanent	MD	Tooth_Type	I1	I2	1.11	0.98	1.24	<.0001	<.0001
12	Permanent	MD	Tooth_Type	I1	M1	-3.66	-3.77	-3.56	<.0001	<.0001
12	Permanent	MD	Tooth_Type	I1	M2	-3.40	-3.55	-3.24	<.0001	<.0001
12	Permanent	MD	Tooth_Type	I2	M1	-4.77	-4.90	-4.64	<.0001	<.0001
12	Permanent	MD	Tooth_Type	I2	M2	-4.50	-4.68	-4.33	<.0001	<.0001
12	Permanent	MD	Tooth_Type	M1	M2	0.26	0.11	0.42	0.00	<.0001
13	Primary	BL	TTT	DZOS Females	MZ and DZSS Females	0.19	-0.15	0.52	0.28	0.28
14	Permanent	BL	TTT	DZOS Females	MZ and DZSS Females	0.35	-0.04	0.74	0.08	0.08
15	Primary	BL	Twin_type	DZOS Females	DZOS Males	-0.08	-0.16	-0.01	0.03	0.13
15	Primary	BL	Twin_type	DZOS Females	DZSS Females	0.18	-0.22	0.58	0.38	0.13
15	Primary	BL	Twin_type	DZOS Females	DZSS Males	0.00	-0.40	0.40	1.00	0.13
15	Primary	BL	Twin_type	DZOS Females	MZ Females	0.07	-0.31	0.45	0.70	0.13
15	Primary	BL	Twin_type	DZOS Females	MZ Males	-0.21	-0.61	0.20	0.31	0.13
15	Primary	BL	Twin_type	DZOS Males	DZSS Females	0.26	-0.14	0.66	0.20	0.13
15	Primary	BL	Twin_type	DZOS Males	DZSS Males	0.08	-0.32	0.48	0.69	0.13
15	Primary	BL	Twin_type	DZOS Males	MZ Females	0.16	-0.22	0.54	0.41	0.13
15	Primary	BL	Twin_type	DZOS Males	MZ Males	-0.12	-0.53	0.28	0.55	0.13
15	Primary	BL	Twin_type	DZSS Females	DZSS Males	-0.18	-0.58	0.22	0.38	0.13
15	Primary	BL	Twin_type	DZSS Females	MZ Females	-0.10	-0.49	0.28	0.60	0.13
15	Primary	BL	Twin_type	DZSS Females	MZ Males	-0.39	-0.79	0.02	0.06	0.13

Continuation of Table 5-29

15	Primary	BL	Twin_type	DZSS Males	MZ Females	0.08	-0.31	0.46	0.70	0.13
15	Primary	BL	Twin_type	DZSS Males	MZ Males	-0.21	-0.61	0.20	0.32	0.13
15	Primary	BL	Twin_type	MZ Females	MZ Males	-0.28	-0.67	0.10	0.15	0.13
16	Permanent	BL	Twin_type	DZOS Females	DZOS Males	-0.20	-0.28	-0.11	<.0001	<.0001
16	Permanent	BL	Twin_type	DZOS Females	DZSS Females	0.39	-0.08	0.87	0.10	<.0001
16	Permanent	BL	Twin_type	DZOS Females	DZSS Males	0.17	-0.31	0.65	0.48	<.0001
16	Permanent	BL	Twin_type	DZOS Females	MZ Females	0.36	-0.08	0.81	0.11	<.0001
16	Permanent	BL	Twin_type	DZOS Females	MZ Males	-0.25	-0.72	0.23	0.30	<.0001
16	Permanent	BL	Twin_type	DZOS Males	DZSS Females	0.59	0.12	1.07	0.01	<.0001
16	Permanent	BL	Twin_type	DZOS Males	DZSS Males	0.37	-0.11	0.85	0.13	<.0001
16	Permanent	BL	Twin_type	DZOS Males	MZ Females	0.56	0.12	1.00	0.01	<.0001
16	Permanent	BL	Twin_type	DZOS Males	MZ Males	-0.05	-0.53	0.42	0.83	<.0001
16	Permanent	BL	Twin_type	DZSS Females	DZSS Males	-0.22	-0.71	0.27	0.38	<.0001
16	Permanent	BL	Twin_type	DZSS Females	MZ Females	-0.03	-0.48	0.42	0.89	<.0001
16	Permanent	BL	Twin_type	DZSS Females	MZ Males	-0.64	-1.13	-0.16	0.01	<.0001
16	Permanent	BL	Twin_type	DZSS Males	MZ Females	0.19	-0.27	0.65	0.42	<.0001
16	Permanent	BL	Twin_type	DZSS Males	MZ Males	-0.42	-0.91	0.07	0.09	<.0001
16	Permanent	BL	Twin_type	MZ Females	MZ Males	-0.61	-1.07	-0.16	0.01	<.0001
17	Primary	BL	Sex	Female	Male	-0.09	-0.17	-0.02	0.01	0.01
18	Permanent	BL	Sex	Female	Male	-0.21	-0.29	-0.13	<.0001	<.0001
19	Primary	BL	Tooth_Position	Lower	Upper	-1.02	-1.04	-1.00	<.0001	<.0001
20	Permanent	BL	Tooth_Position	Lower	Upper	-1.03	-1.06	-1.00	<.0001	<.0001
21	Primary	BL	Tooth_Side	Left	Right	0.00	-0.04	0.04	0.90	0.90
22	Permanent	BL	Tooth_Side	Left	Right	0.01	-0.03	0.06	0.58	0.58
23	Primary	BL	Tooth_Type	C	I1	1.35	1.27	1.42	<.0001	<.0001
23	Primary	BL	Tooth_Type	C	I2	1.31	1.23	1.38	<.0001	<.0001
23	Primary	BL	Tooth_Type	C	M1	-1.97	-2.03	-1.90	<.0001	<.0001
23	Primary	BL	Tooth_Type	C	M2	-3.31	-3.38	-3.24	<.0001	<.0001
23	Primary	BL	Tooth_Type	I1	I2	-0.04	-0.12	0.04	0.31	<.0001
23	Primary	BL	Tooth_Type	I1	M1	-3.31	-3.39	-3.24	<.0001	<.0001
23	Primary	BL	Tooth_Type	I1	M2	-4.65	-4.73	-4.58	<.0001	<.0001
23	Primary	BL	Tooth_Type	I2	M1	-3.27	-3.34	-3.20	<.0001	<.0001
23	Primary	BL	Tooth_Type	I2	M2	-4.61	-4.68	-4.54	<.0001	<.0001
23	Primary	BL	Tooth_Type	M1	M2	-1.34	-1.41	-1.27	<.0001	<.0001
24	Permanent	BL	Tooth_Type	C	I1	1.14	1.02	1.26	<.0001	<.0001
24	Permanent	BL	Tooth_Type	C	I2	1.40	1.27	1.53	<.0001	<.0001
24	Permanent	BL	Tooth_Type	C	M1	-3.15	-3.27	-3.03	<.0001	<.0001

Continuation of Table 5-29

24	Permanent	BL	Tooth_Type	C	M2	-3.09	-3.25	-2.94	<.0001	<.0001
24	Permanent	BL	Tooth_Type	I1	I2	0.26	0.13	0.38	<.0001	<.0001
24	Permanent	BL	Tooth_Type	I1	M1	-4.29	-4.40	-4.18	<.0001	<.0001
24	Permanent	BL	Tooth_Type	I1	M2	-4.23	-4.38	-4.09	<.0001	<.0001
24	Permanent	BL	Tooth_Type	I2	M1	-4.55	-4.67	-4.42	<.0001	<.0001
24	Permanent	BL	Tooth_Type	I2	M2	-4.49	-4.64	-4.34	<.0001	<.0001
24	Permanent	BL	Tooth_Type	M1	M2	0.06	-0.09	0.20	0.45	<.0001

Table 5-30. Linear mixed-effects models with interactions.

Model	Type	Outcome	Interaction	Comparison 1	Reference 1	Comparison 2	Reference 2	Estimate	Lower 95%	Upper 95%	p- value	Global p
25	Primary	MD	Tooth_Position*Sex	Lower	Lower	Female	Male	-0.14	-0.23	-0.06	0.00	0.16
25	Primary	MD	Tooth_Position*Sex	Lower	Upper	Female	Female	-0.20	-0.26	-0.13	<.0001	0.16
25	Primary	MD	Tooth_Position*Sex	Lower	Upper	Male	Male	-0.13	-0.20	-0.07	<.0001	0.16
25	Primary	MD	Tooth_Position*Sex	Upper	Upper	Female	Male	-0.08	-0.17	0.01	0.07	0.16
26	Permanent	MD	Tooth_Position*Sex	Lower	Lower	Female	Male	-0.25	-0.39	-0.12	0.00	0.82
26	Permanent	MD	Tooth_Position*Sex	Lower	Upper	Female	Female	-1.10	-1.21	-1.00	<.0001	0.82
26	Permanent	MD	Tooth_Position*Sex	Lower	Upper	Male	Male	-1.12	-1.23	-1.01	<.0001	0.82
26	Permanent	MD	Tooth_Position*Sex	Upper	Upper	Female	Male	-0.27	-0.42	-0.13	0.00	0.82
27	Primary	MD	Tooth_Side*Sex	Left	Left	Female	Male	-0.11	-0.20	-0.02	0.02	0.94
27	Primary	MD	Tooth_Side*Sex	Left	Right	Female	Female	0.01	-0.05	0.07	0.78	0.94
27	Primary	MD	Tooth_Side*Sex	Left	Right	Male	Male	0.01	-0.06	0.07	0.87	0.94
27	Primary	MD	Tooth_Side*Sex	Right	Right	Female	Male	-0.11	-0.20	-0.02	0.01	0.94
28	Permanent	MD	Tooth_Side*Sex	Left	Left	Female	Male	-0.24	-0.39	-0.08	0.00	0.90
28	Permanent	MD	Tooth_Side*Sex	Left	Right	Female	Female	0.01	-0.11	0.12	0.90	0.90
28	Permanent	MD	Tooth_Side*Sex	Left	Right	Male	Male	0.02	-0.10	0.14	0.76	0.90
28	Permanent	MD	Tooth_Side*Sex	Right	Right	Female	Male	-0.22	-0.38	-0.07	0.01	0.90
29	Primary	MD	Tooth_Type*Sex	C	C	Female	Male	-0.16	-0.26	-0.06	0.00	0.04
29	Primary	MD	Tooth_Type*Sex	C	I1	Female	Female	0.92	0.81	1.03	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	C	I2	Female	Female	1.38	1.27	1.48	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	C	M1	Female	Female	-1.04	-1.14	-0.94	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	C	M2	Female	Female	-3.00	-3.09	-2.90	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	C	I1	Male	Male	0.95	0.83	1.06	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	C	I2	Male	Male	1.51	1.40	1.62	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	C	M1	Male	Male	-1.11	-1.21	-1.00	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	C	M2	Male	Male	-3.07	-3.18	-2.97	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I1	I1	Female	Male	-0.13	-0.25	-0.01	0.03	0.04
29	Primary	MD	Tooth_Type*Sex	I1	I2	Female	Female	0.45	0.34	0.57	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I1	M1	Female	Female	-1.96	-2.07	-1.85	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I1	M2	Female	Female	-3.92	-4.03	-3.81	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I1	I2	Male	Male	0.56	0.44	0.68	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I1	M1	Male	Male	-2.06	-2.17	-1.94	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I1	M2	Male	Male	-4.02	-4.13	-3.90	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I2	I2	Female	Male	-0.02	-0.13	0.08	0.67	0.04
29	Primary	MD	Tooth_Type*Sex	I2	M1	Female	Female	-2.42	-2.52	-2.31	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I2	M2	Female	Female	-4.37	-4.47	-4.27	<.0001	0.04

Continuation of Table 5-30

29	Primary	MD	Tooth_Type*Sex	I2	M1	Male	Male	-2.62	-2.73	-2.51	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	I2	M2	Male	Male	-4.58	-4.69	-4.48	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	M1	M1	Female	Male	-0.22	-0.32	-0.12	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	M1	M2	Female	Female	-1.96	-2.05	-1.86	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	M1	M2	Male	Male	-1.96	-2.07	-1.86	<.0001	0.04
29	Primary	MD	Tooth_Type*Sex	M2	M2	Female	Male	-0.23	-0.33	-0.13	<.0001	0.04
30	Permanent	MD	Tooth_Type*Sex	C	C	Female	Male	-0.49	-0.65	-0.32	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	C	I1	Female	Female	0.21	0.06	0.37	0.01	0.00
30	Permanent	MD	Tooth_Type*Sex	C	I2	Female	Female	1.34	1.16	1.53	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	C	M1	Female	Female	-3.32	-3.47	-3.17	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	C	M2	Female	Female	-2.97	-3.18	-2.75	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	C	I1	Male	Male	0.55	0.39	0.71	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	C	I2	Male	Male	1.63	1.43	1.82	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	C	M1	Male	Male	-3.26	-3.42	-3.10	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	C	M2	Male	Male	-3.09	-3.32	-2.86	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I1	I1	Female	Male	-0.15	-0.29	-0.01	0.04	0.00
30	Permanent	MD	Tooth_Type*Sex	I1	I2	Female	Female	1.13	0.95	1.31	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I1	M1	Female	Female	-3.53	-3.67	-3.39	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I1	M2	Female	Female	-3.18	-3.39	-2.97	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I1	I2	Male	Male	1.08	0.90	1.26	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I1	M1	Male	Male	-3.81	-3.95	-3.66	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I1	M2	Male	Male	-3.64	-3.86	-3.42	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I2	I2	Female	Male	-0.20	-0.41	0.01	0.06	0.00
30	Permanent	MD	Tooth_Type*Sex	I2	M1	Female	Female	-4.66	-4.84	-4.48	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I2	M2	Female	Female	-4.31	-4.55	-4.08	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I2	M1	Male	Male	-4.89	-5.07	-4.70	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	I2	M2	Male	Male	-4.72	-4.97	-4.47	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	M1	M1	Female	Male	-0.43	-0.57	-0.28	<.0001	0.00
30	Permanent	MD	Tooth_Type*Sex	M1	M2	Female	Female	0.35	0.14	0.56	0.00	0.00
30	Permanent	MD	Tooth_Type*Sex	M1	M2	Male	Male	0.17	-0.05	0.39	0.14	0.00
30	Permanent	MD	Tooth_Type*Sex	M2	M2	Female	Male	-0.61	-0.88	-0.34	<.0001	0.00
31	Primary	BL	Tooth_Position*Sex	Lower	Lower	Female	Male	-0.09	-0.14	-0.05	<.0001	0.93
31	Primary	BL	Tooth_Position*Sex	Lower	Upper	Female	Female	-1.02	-1.05	-0.99	<.0001	0.93
31	Primary	BL	Tooth_Position*Sex	Lower	Upper	Male	Male	-1.02	-1.05	-0.99	<.0001	0.93
31	Primary	BL	Tooth_Position*Sex	Upper	Upper	Female	Male	-0.09	-0.14	-0.05	<.0001	0.93
32	Permanent	BL	Tooth_Position*Sex	Lower	Lower	Female	Male	-0.20	-0.25	-0.15	<.0001	0.00
32	Permanent	BL	Tooth_Position*Sex	Lower	Upper	Female	Female	-0.99	-1.03	-0.96	<.0001	0.00

Continuation of Table 5-30

32	Permanent	BL	Tooth_Position*Sex	Lower	Upper	Male	Male	-1.07	-1.11	-1.04	<.0001	0.00
32	Permanent	BL	Tooth_Position*Sex	Upper	Upper	Female	Male	-0.28	-0.33	-0.23	<.0001	0.00
33	Primary	BL	Tooth_Side*Sex	Left	Left	Female	Male	-0.09	-0.17	0.00	0.04	0.80
33	Primary	BL	Tooth_Side*Sex	Left	Right	Female	Female	0.01	-0.05	0.07	0.79	0.80
33	Primary	BL	Tooth_Side*Sex	Left	Right	Male	Male	0.00	-0.06	0.06	0.93	0.80
33	Primary	BL	Tooth_Side*Sex	Right	Right	Female	Male	-0.10	-0.18	-0.01	0.02	0.80
34	Permanent	BL	Tooth_Side*Sex	Left	Left	Female	Male	-0.20	-0.29	-0.10	<.0001	0.59
34	Permanent	BL	Tooth_Side*Sex	Left	Right	Female	Female	0.03	-0.04	0.09	0.44	0.59
34	Permanent	BL	Tooth_Side*Sex	Left	Right	Male	Male	0.00	-0.07	0.07	1.00	0.59
34	Permanent	BL	Tooth_Side*Sex	Right	Right	Female	Male	-0.22	-0.32	-0.13	<.0001	0.59
35	Primary	BL	Tooth_Type*Sex	C	C	Female	Male	-0.08	-0.18	0.01	0.03	0.00
35	Primary	BL	Tooth_Type*Sex	C	I1	Female	Female	1.39	1.29	1.49	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	C	I2	Female	Female	1.30	1.20	1.39	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	C	M1	Female	Female	-1.90	-1.99	-1.81	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	C	M2	Female	Female	-3.19	-3.29	-3.10	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	C	I1	Male	Male	1.31	1.20	1.41	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	C	I2	Male	Male	1.32	1.22	1.42	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	C	M1	Male	Male	-2.04	-2.13	-1.95	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	C	M2	Male	Male	-3.43	-3.52	-3.33	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I1	I1	Female	Male	-0.16	-0.27	-0.05	0.00	0.00
35	Primary	BL	Tooth_Type*Sex	I1	I2	Female	Female	-0.09	-0.19	0.01	0.08	0.00
35	Primary	BL	Tooth_Type*Sex	I1	M1	Female	Female	-3.28	-3.38	-3.18	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I1	M2	Female	Female	-4.58	-4.68	-4.48	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I1	I2	Male	Male	0.01	-0.10	0.12	0.83	0.00
35	Primary	BL	Tooth_Type*Sex	I1	M1	Male	Male	-3.35	-3.45	-3.24	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I1	M2	Male	Male	-4.73	-4.84	-4.63	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I2	I2	Female	Male	-0.06	-0.16	0.04	0.22	0.00
35	Primary	BL	Tooth_Type*Sex	I2	M1	Female	Female	-3.19	-3.29	-3.10	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I2	M2	Female	Female	-4.49	-4.58	-4.40	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I2	M1	Male	Male	-3.36	-3.46	-3.26	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	I2	M2	Male	Male	-4.75	-4.84	-4.65	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	M1	M1	Female	Male	-0.23	-0.32	-0.14	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	M1	M2	Female	Female	-1.30	-1.39	-1.21	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	M1	M2	Male	Male	-1.39	-1.48	-1.29	<.0001	0.00
35	Primary	BL	Tooth_Type*Sex	M2	M2	Female	Male	-0.32	-0.41	-0.23	<.0001	0.00
36	Permanent	BL	Tooth_Type*Sex	C	C	Female	Male	-0.38	-0.51	-0.24	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	C	I1	Female	Female	1.07	0.93	1.20	<.0001	<.0001

Continuation of Table 5-30

36	Permanent	BL	Tooth_Type*Sex	C	I2	Female	Female	1.29	1.14	1.45	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	C	M1	Female	Female	-3.11	-3.24	-2.97	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	C	M2	Female	Female	-2.97	-3.14	-2.80	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	C	I1	Male	Male	1.24	1.09	1.38	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	C	I2	Male	Male	1.52	1.36	1.68	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	C	M1	Male	Male	-3.18	-3.32	-3.03	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	C	M2	Male	Male	-3.31	-3.50	-3.11	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I1	I1	Female	Male	-0.21	-0.32	-0.09	0.00	<.0001
36	Permanent	BL	Tooth_Type*Sex	I1	I2	Female	Female	0.23	0.08	0.37	0.00	<.0001
36	Permanent	BL	Tooth_Type*Sex	I1	M1	Female	Female	-4.17	-4.30	-4.05	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I1	M2	Female	Female	-4.04	-4.20	-3.87	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I1	I2	Male	Male	0.28	0.13	0.43	0.00	<.0001
36	Permanent	BL	Tooth_Type*Sex	I1	M1	Male	Male	-4.41	-4.54	-4.28	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I1	M2	Male	Male	-4.55	-4.73	-4.36	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I2	I2	Female	Male	-0.15	-0.30	0.00	0.05	<.0001
36	Permanent	BL	Tooth_Type*Sex	I2	M1	Female	Female	-4.40	-4.55	-4.26	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I2	M2	Female	Female	-4.27	-4.44	-4.09	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I2	M1	Male	Male	-4.70	-4.85	-4.55	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	I2	M2	Male	Male	-4.83	-5.03	-4.63	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	M1	M1	Female	Male	-0.45	-0.56	-0.33	<.0001	<.0001
36	Permanent	BL	Tooth_Type*Sex	M1	M2	Female	Female	0.14	-0.03	0.30	0.10	<.0001
36	Permanent	BL	Tooth_Type*Sex	M1	M2	Male	Male	-0.13	-0.31	0.05	0.16	<.0001
36	Permanent	BL	Tooth_Type*Sex	M2	M2	Female	Male	-0.71	-0.90	-0.52	<.0001	<.0001

The Carabelli trait (CT) scores were observed to be zero-inflated data, which was why the association between outcome CT binary (0, >0) and various predictors was investigated. Llogistic generalized estimating equations (GEE) models were performed, adjusting for clustering on tooth nested within subject (Tables 5-31 and 5-32). Highlighted in yellow are the statistically significant models at $p < 0.05$.

For Models 37 (primary teeth) and 38 (permanent teeth), there was a statistically significant association between CT binary (0 versus >0) and TTT (global p-value=0.0002 and 0.05 respectively). DZOS Females have odds of having CT > 0 2.86 and 1.94 times respectively that of MZ and DZSS females (95% confidence interval).

For Models 39 (primary teeth) and 40 (permanent teeth), there was a statistically significant association between CT binary and twin type: DZOS females have odds of having CT > 0 3.16 and 0.95 times less than DZOS males, DZSS females have odds of CT > 0 0.44 and 0.29 less than DZSS males, and MZ females have odds of CT > 0 0.44 and 0.28 less than MZ males.

For Model 42 (permanent teeth), there was a statistically significant association between CT binary and sex (global P value=0.0004). Females have odds of CT > 0 56% less than males (odds ratio=0.44, 95% confidence interval).

For Models 45 (primary teeth) and 46 (permanent teeth), there was a statistically significant association between CT and TTT (global p-value<0.0001 and =0.0035

respectively). DZOS Females have odds of having a high CT value 2.84 and 2.50 times respectively that of MZ and DZSS females (95% confidence interval).

For Models 47 (primary teeth) and 48 (permanent teeth), there was a statistically significant association between CT and twin type: DZOS females have odds of having a high CT value 1.60 and 1.22 times less than DZOS males, DZSS females have odds of having a high CT value 0.31 and 0.25 less than DZSS males, and MZ females have odds of having a high CT value 0.50 and 0.33 times less than MZ males.

For Models 49 (primary teeth) and 50 (permanent teeth), there was a statistically significant association between CT and sex (global P value=0.0016). Females have odds of having a high CT value 37% and 51% less than males (odds ratio=0.63 and 0.49, 95% confidence interval).

In Models 53 and 55 (both primary teeth), there is a statistically significant interaction between tooth side and sex, for outcomes CT binary (interaction p-value=0.03) and CT (interaction p-value=0.01). The females' left molars have odds of having a high CT value 40% and 26% less than the right side. The males' left molars have odds of having a high CT value 20% and 7% less than the right side.

Table 5-31. Ordinal logistic Generalized Estimating Equations (GEE) models with predictors.

Model	Type	Outcome	Predictor	Comparison value	Reference value	Odds Ratio	Lower 95%	Upper 95%	p- value	Global p
37	Primary	CT binary	TTT	DZOS Females	MZ and DZSS Females	2.86	1.63	5.02	0.00	0.00
38	Permanent	CT binary	TTT	DZOS Females	MZ and DZSS Females	1.94	1.00	3.77	0.05	0.05
39	Primary	CT binary	Twin_type	DZOS Females	DZOS Males	3.16	2.09	4.78	<.0001	<.0001
39	Primary	CT binary	Twin_type	DZOS Females	DZSS Females	3.56	1.84	6.90	0.00	<.0001
39	Primary	CT binary	Twin_type	DZOS Females	DZSS Males	1.56	0.79	3.08	0.20	<.0001
39	Primary	CT binary	Twin_type	DZOS Females	MZ Females	2.41	1.30	4.46	0.01	<.0001
39	Primary	CT binary	Twin_type	DZOS Females	MZ Males	1.05	0.52	2.10	0.89	<.0001
39	Primary	CT binary	Twin_type	DZOS Males	DZSS Females	1.13	0.59	2.16	0.72	<.0001
39	Primary	CT binary	Twin_type	DZOS Males	DZSS Males	0.49	0.25	0.96	0.04	<.0001
39	Primary	CT binary	Twin_type	DZOS Males	MZ Females	0.76	0.42	1.39	0.38	<.0001
39	Primary	CT binary	Twin_type	DZOS Males	MZ Males	0.33	0.17	0.66	0.00	<.0001
39	Primary	CT binary	Twin_type	DZSS Females	DZSS Males	0.44	0.23	0.85	0.01	<.0001
39	Primary	CT binary	Twin_type	DZSS Females	MZ Females	0.68	0.37	1.23	0.20	<.0001
39	Primary	CT binary	Twin_type	DZSS Females	MZ Males	0.29	0.15	0.58	0.00	<.0001
39	Primary	CT binary	Twin_type	DZSS Males	MZ Females	1.55	0.83	2.87	0.17	<.0001
39	Primary	CT binary	Twin_type	DZSS Males	MZ Males	0.67	0.33	1.35	0.27	<.0001
39	Primary	CT binary	Twin_type	MZ Females	MZ Males	0.44	0.23	0.82	0.01	<.0001
40	Permanent	CT binary	Twin_type	DZOS Females	DZOS Males	0.95	0.49	1.84	0.88	0.00
40	Permanent	CT binary	Twin_type	DZOS Females	DZSS Females	1.74	0.80	3.79	0.16	0.00
40	Permanent	CT binary	Twin_type	DZOS Females	DZSS Males	0.51	0.20	1.31	0.16	0.00
40	Permanent	CT binary	Twin_type	DZOS Females	MZ Females	2.12	1.01	4.44	0.05	0.00
40	Permanent	CT binary	Twin_type	DZOS Females	MZ Males	0.59	0.25	1.38	0.22	0.00
40	Permanent	CT binary	Twin_type	DZOS Males	DZSS Females	1.83	0.83	4.05	0.14	0.00
40	Permanent	CT binary	Twin_type	DZOS Males	DZSS Males	0.54	0.21	1.40	0.20	0.00
40	Permanent	CT binary	Twin_type	DZOS Males	MZ Females	2.22	1.04	4.75	0.04	0.00
40	Permanent	CT binary	Twin_type	DZOS Males	MZ Males	0.62	0.26	1.47	0.28	0.00
40	Permanent	CT binary	Twin_type	DZSS Females	DZSS Males	0.29	0.12	0.75	0.01	0.00
40	Permanent	CT binary	Twin_type	DZSS Females	MZ Females	1.22	0.59	2.53	0.60	0.00
40	Permanent	CT binary	Twin_type	DZSS Females	MZ Males	0.34	0.15	0.79	0.01	0.00
40	Permanent	CT binary	Twin_type	DZSS Males	MZ Females	4.15	1.68	10.24	0.00	0.00
40	Permanent	CT binary	Twin_type	DZSS Males	MZ Males	1.15	0.43	3.13	0.78	0.00
40	Permanent	CT binary	Twin_type	MZ Females	MZ Males	0.28	0.12	0.62	0.00	0.00
41	Primary	CT binary	Sex	Female	Male	0.84	0.60	1.18	0.32	0.32
42	Permanent	CT binary	Sex	Female	Male	0.44	0.28	0.69	0.00	0.00

Continuation of Table 5-31

43	Primary	CT binary	Tooth_Side	Left	Right	0.69	0.60	0.78	<.0001	<.0001
44	Permanent	CT binary	Tooth_Side	Left	Right	0.72	0.59	0.88	0.00	0.00
45	Primary	CT	TTT	DZOS Females	MZ and DZSS Females	2.84	1.72	4.67	<.0001	<.0001
46	Permanent	CT	TTT	DZOS Females	MZ and DZSS Females	2.50	1.35	4.62	0.00	0.00
47	Primary	CT	Twin_type	DZOS Females	DZOS Males	1.60	1.23	2.07	0.00	<.0001
47	Primary	CT	Twin_type	DZOS Females	DZSS Females	3.21	1.86	5.55	<.0001	<.0001
47	Primary	CT	Twin_type	DZOS Females	DZSS Males	0.99	0.56	1.76	0.98	<.0001
47	Primary	CT	Twin_type	DZOS Females	MZ Females	2.06	1.23	3.45	0.01	<.0001
47	Primary	CT	Twin_type	DZOS Females	MZ Males	1.03	0.60	1.74	0.92	<.0001
47	Primary	CT	Twin_type	DZOS Males	DZSS Females	2.01	1.07	3.78	0.03	<.0001
47	Primary	CT	Twin_type	DZOS Males	DZSS Males	0.62	0.32	1.20	0.16	<.0001
47	Primary	CT	Twin_type	DZOS Males	MZ Females	1.29	0.71	2.35	0.41	<.0001
47	Primary	CT	Twin_type	DZOS Males	MZ Males	0.64	0.35	1.19	0.16	<.0001
47	Primary	CT	Twin_type	DZSS Females	DZSS Males	0.31	0.17	0.57	0.00	<.0001
47	Primary	CT	Twin_type	DZSS Females	MZ Females	0.64	0.37	1.11	0.11	<.0001
47	Primary	CT	Twin_type	DZSS Females	MZ Males	0.32	0.18	0.56	<.0001	<.0001
47	Primary	CT	Twin_type	DZSS Males	MZ Females	2.07	1.16	3.69	0.01	<.0001
47	Primary	CT	Twin_type	DZSS Males	MZ Males	1.03	0.57	1.87	0.91	<.0001
47	Primary	CT	Twin_type	MZ Females	MZ Males	0.50	0.29	0.85	0.01	<.0001
48	Permanent	CT	Twin_type	DZOS Females	DZOS Males	1.22	0.76	1.96	0.42	0.00
48	Permanent	CT	Twin_type	DZOS Females	DZSS Females	2.60	1.27	5.32	0.01	0.00
48	Permanent	CT	Twin_type	DZOS Females	DZSS Males	0.65	0.30	1.41	0.28	0.00
48	Permanent	CT	Twin_type	DZOS Females	MZ Females	2.71	1.33	5.54	0.01	0.00
48	Permanent	CT	Twin_type	DZOS Females	MZ Males	0.90	0.47	1.75	0.77	0.00
48	Permanent	CT	Twin_type	DZOS Males	DZSS Females	2.14	1.08	4.21	0.03	0.00
48	Permanent	CT	Twin_type	DZOS Males	DZSS Males	0.54	0.26	1.12	0.10	0.00
48	Permanent	CT	Twin_type	DZOS Males	MZ Females	2.23	1.13	4.38	0.02	0.00
48	Permanent	CT	Twin_type	DZOS Males	MZ Males	0.74	0.40	1.39	0.35	0.00
48	Permanent	CT	Twin_type	DZSS Females	DZSS Males	0.25	0.12	0.54	0.00	0.00
48	Permanent	CT	Twin_type	DZSS Females	MZ Females	1.04	0.52	2.08	0.90	0.00
48	Permanent	CT	Twin_type	DZSS Females	MZ Males	0.35	0.18	0.68	0.00	0.00
48	Permanent	CT	Twin_type	DZSS Males	MZ Females	4.15	1.92	8.95	0.00	0.00
48	Permanent	CT	Twin_type	DZSS Males	MZ Males	1.38	0.67	2.84	0.38	0.00
48	Permanent	CT	Twin_type	MZ Females	MZ Males	0.33	0.17	0.65	0.00	0.00
49	Primary	CT	Sex	Female	Male	0.63	0.47	0.84	0.00	0.00
50	Permanent	CT	Sex	Female	Male	0.49	0.34	0.71	0.00	0.00

Continuation of Table 5-31

51	Primary	CT	Tooth_Side	Left	Right	0.82	0.76	0.89	<.0001	<.0001
52	Permanent	CT	Tooth_Side	Left	Right	0.95	0.84	1.08	0.44	0.44

Table 5-32. Logistic Generalized Estimating Equations (GEE) models with interactions.

Model	Type	Outcome	Interaction	Comparison 1	Reference 1	Comparison 2	Reference 2	Odd Ratio	Lower 95%	Upper 95%	p- value	Global p
53	Primary	CT binary	Tooth_Side*Sex	Left	Left	Female	Male	0.73	0.51	1.04	0.08	0.03
53	Primary	CT binary	Tooth_Side*Sex	Left	Right	Female	Female	0.60	0.49	0.73	<.0001	0.03
53	Primary	CT binary	Tooth_Side*Sex	Left	Right	Male	Male	0.80	0.68	0.94	0.01	0.03
53	Primary	CT binary	Tooth_Side*Sex	Right	Right	Female	Male	0.98	0.67	1.43	0.90	0.03
54	Permanent	CT binary	Tooth_Side*Sex	Left	Left	Female	Male	0.42	0.26	0.69	0.00	0.69
54	Permanent	CT binary	Tooth_Side*Sex	Left	Right	Female	Female	0.69	0.52	0.90	0.01	0.69
54	Permanent	CT binary	Tooth_Side*Sex	Left	Right	Male	Male	0.75	0.54	1.03	0.07	0.69
54	Permanent	CT binary	Tooth_Side*Sex	Right	Right	Female	Male	0.46	0.27	0.77	0.00	0.69
55	Primary	CT	Tooth_Side*Sex	Left	Left	Female	Male	0.56	0.41	0.76	0.00	0.01
55	Primary	CT	Tooth_Side*Sex	Left	Right	Female	Female	0.74	0.65	0.84	<.0001	0.01
55	Primary	CT	Tooth_Side*Sex	Left	Right	Male	Male	0.93	0.84	1.02	0.13	0.01
55	Primary	CT	Tooth_Side*Sex	Right	Right	Female	Male	0.70	0.53	0.94	0.02	0.01
56	Permanent	CT	Tooth_Side*Sex	Left	Left	Female	Male	0.43	0.28	0.65	<.0001	0.06
56	Permanent	CT	Tooth_Side*Sex	Left	Right	Female	Female	0.83	0.69	1.00	0.05	0.06
56	Permanent	CT	Tooth_Side*Sex	Left	Right	Male	Male	1.09	0.89	1.33	0.40	0.06
56	Permanent	CT	Tooth_Side*Sex	Right	Right	Female	Male	0.56	0.38	0.81	0.00	0.06

5.10 Principal components analysis (PCA)

Principal components analysis (PCA) was undertaken to explore patterns of covariation within the data. Analysis was conducted on primary and permanent tooth size data. Carabelli trait was excluded from the dental data due to it being scored on a different scale and due to the complexity of the zero-inflated data.

For primary tooth size data (mesiodistal and buccolingual dimensions), missing data were assumed to be missing completely at random (MCAR). The SAS MI procedure was used to impute missing values using a Markov Chain Monte Carlo approach. Left and right sides were imputed separately due to convergence issues stemming from significant collinearity between antimeric pairs. The same approach was used for permanent tooth size data.

The SAS PRINCOMP procedure was used to run the PCA on the datasets.

5.10.1 Primary tooth size

The percentages of variation accounted for by the first five principal components were as follows:

PC1 48.8%

PC2 9.4%

PC3 6.6%

PC4 3.5%

PC5 3.2%

Patterns in all four arcades were broadly similar; PC4 was a minor exception (see Figures 5-1 to 5-4). PC1 accounted for 48.8 % and indicated that the overall size of all tooth size variables (MD and BL) were positively correlated. PC2 (9.4%) indicated that anterior BL dimensions were positively correlated with each other and negatively correlated with MD of both central incisors and posterior teeth. PC3 (6.6%) showed that anterior dimensions were negatively correlated with posterior dimensions and that there was a minor antero-posterior trend. PC4 (3.5%) specified that the BL dimension of the maxillary second incisor was negatively correlated with MD of maxillary canine. PC5 revealed a modest correlation of mid-arcade dimensions.

There was no obvious clustering observed in the primary dentition. Males tended to be more positive for PC1 than females; DZOS females were slightly less variable for PC2 and PC3 than other females (see Figures 5-5 to 5-7).

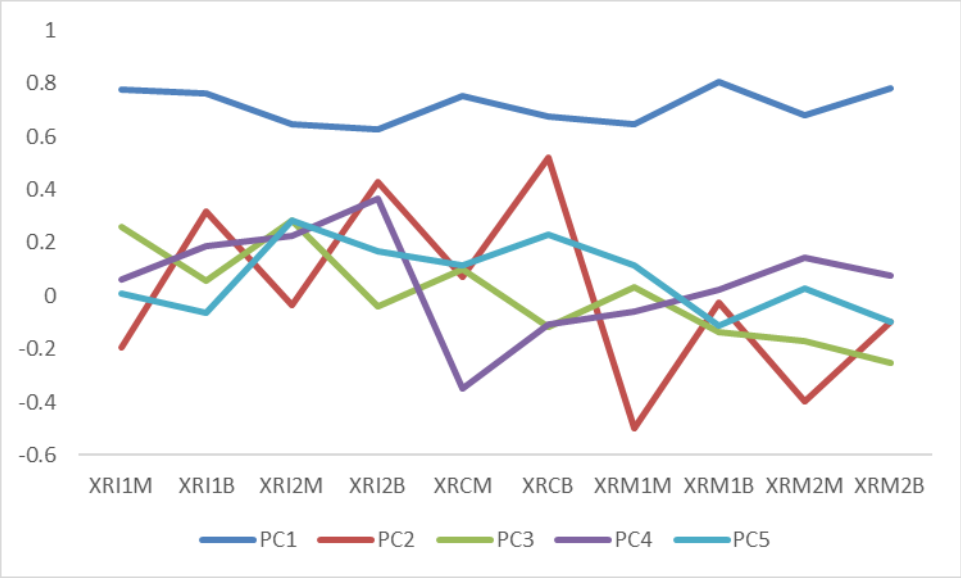

Figure 5-1. PCA graph for primary maxillary right teeth.
Legend: X- maxillary; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

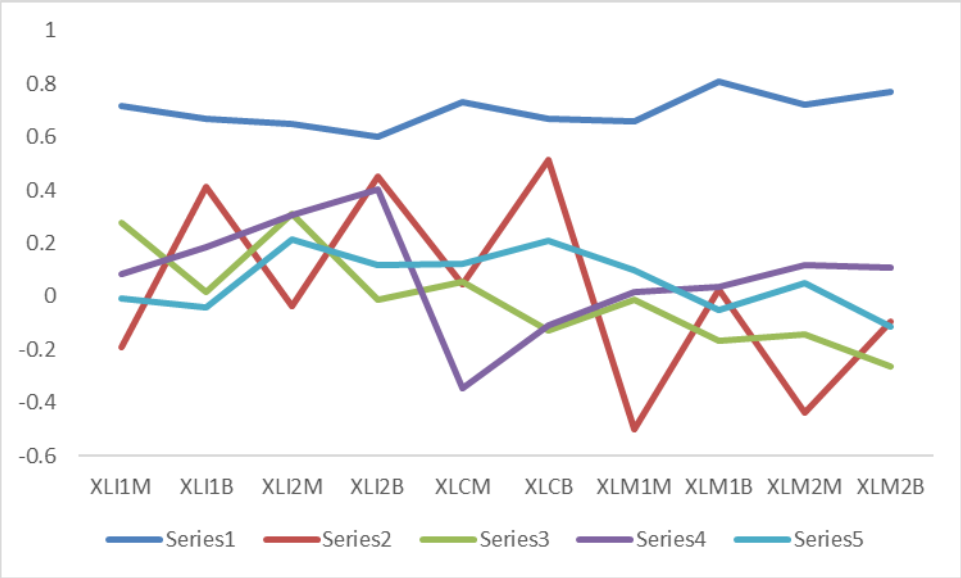

Figure 5-2. PCA graph for primary maxillary left teeth.
Legend: X- maxillary; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

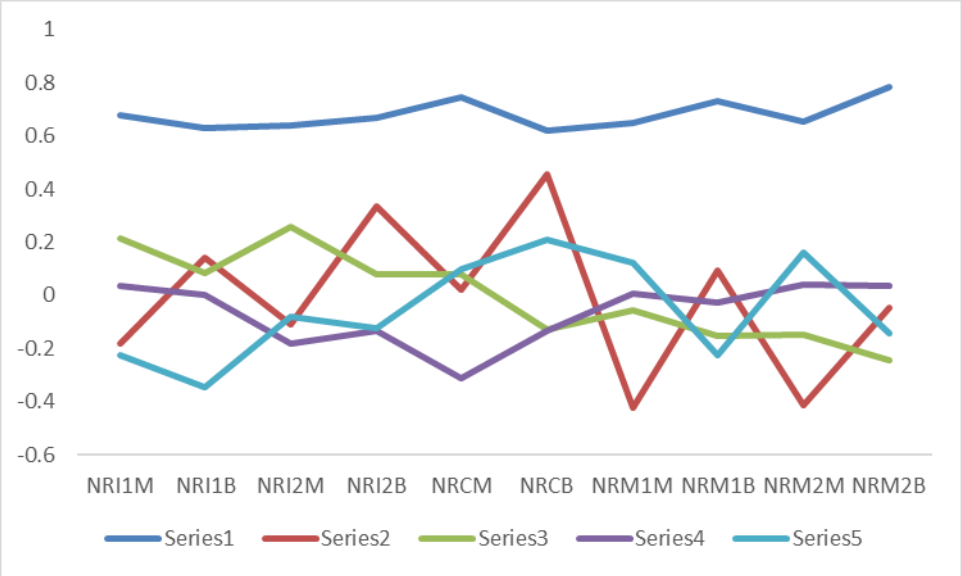

Figure 5-3. PCA graph for primary mandibular right teeth.
Legend: N- mandibular; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

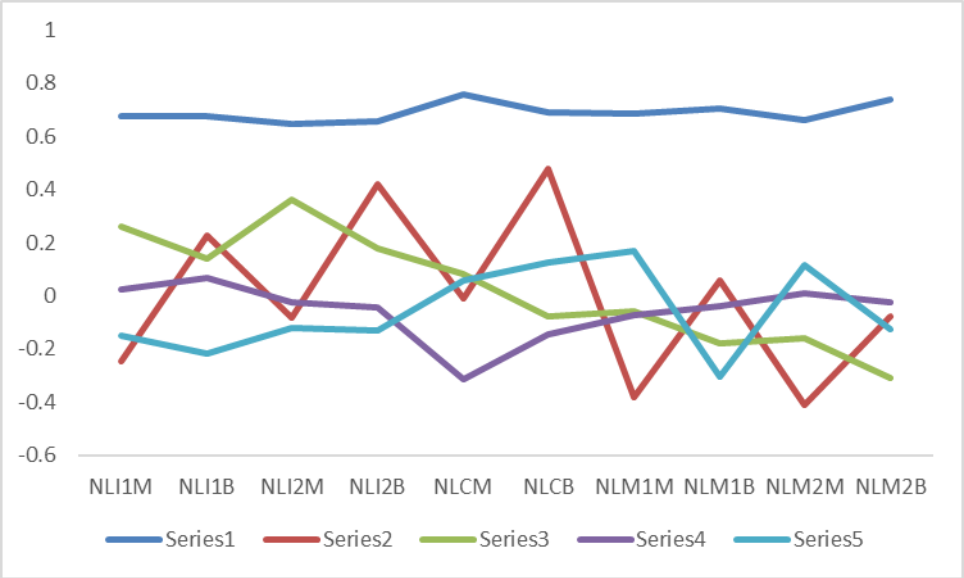

Figure 5-4. PCA graph for primary mandibular left teeth.
Legend: N- mandibular; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

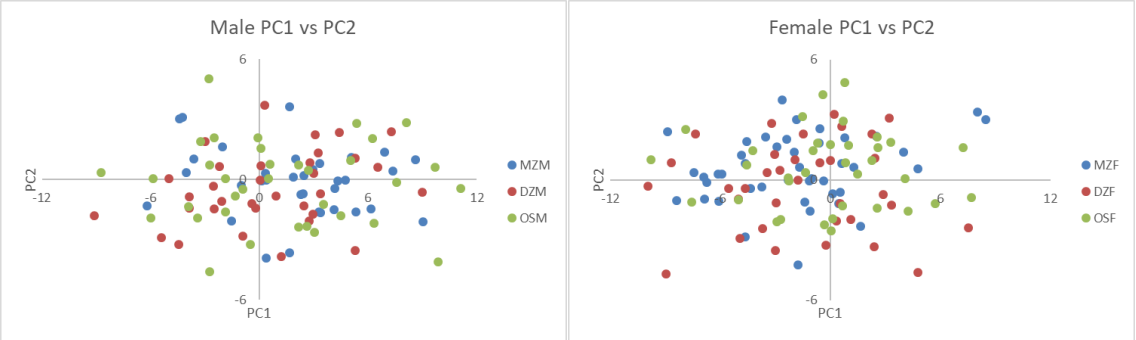

Figure 5-5. Sex and zygosity comparisons of PC1 and PC2 of the primary teeth.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

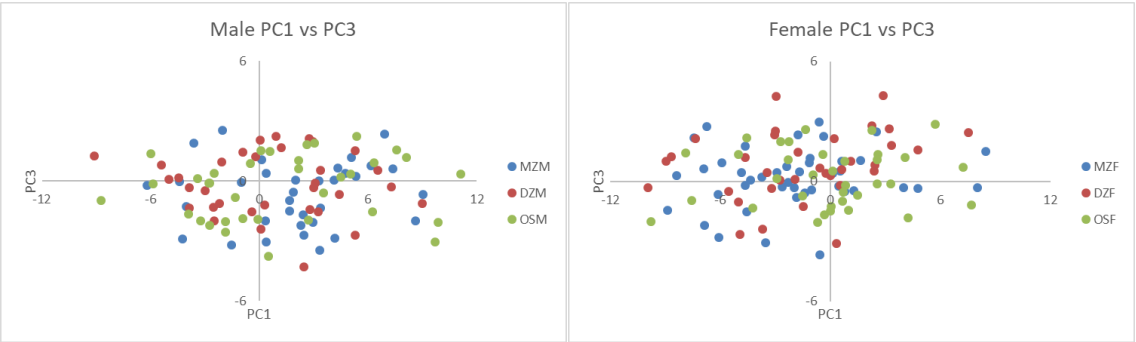

Figure 5-6. Sex and zygosity comparisons of PC1 and PC3 of the primary teeth.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

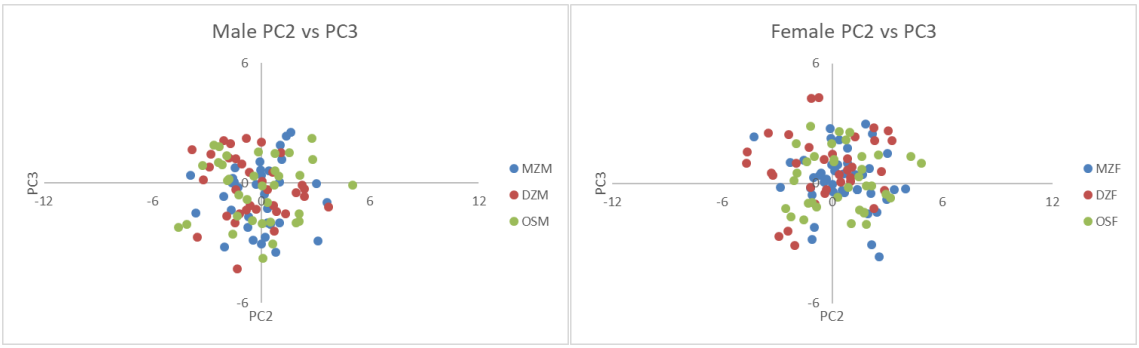

Figure 5-7. Sex and zygosity comparisons of PC2 and PC3 of the primary teeth.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

5.10.2 Permanent tooth size

The percentages of variation accounted for by the first five principal components were as follows:

PC1 53.5%

PC2 8.6%

PC3 6.9%

PC4 3.5%

PC5 3.1%

In permanent tooth size, broadly similar patterns to primary tooth size were observed in PC1 to PC3. PC4 showed a negative correlation, especially on the MD of the canine, and this could be a distinct phenotype in the permanent dentition. PC5 showed that incisor dimensions were negatively correlated with the MD dimension of the second molar in the maxilla only (see Figures 5-8 to 5-11).

Sex difference for PC1 was more pronounced in permanent tooth size than primary tooth size (see Figures 5-12 to 5-14).

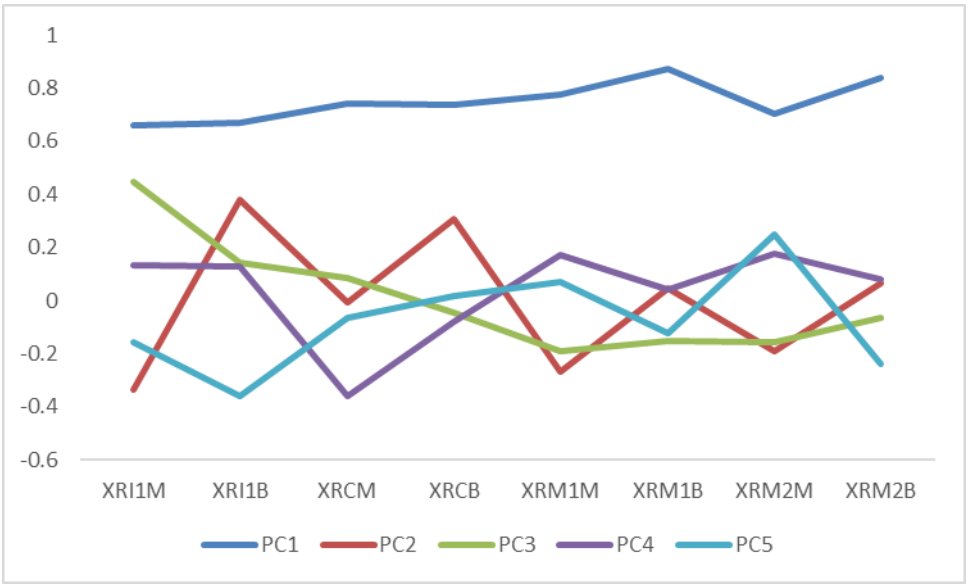

Figure 5-8. PCA graph for permanent maxillary right teeth.
Legend: X- maxillary; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

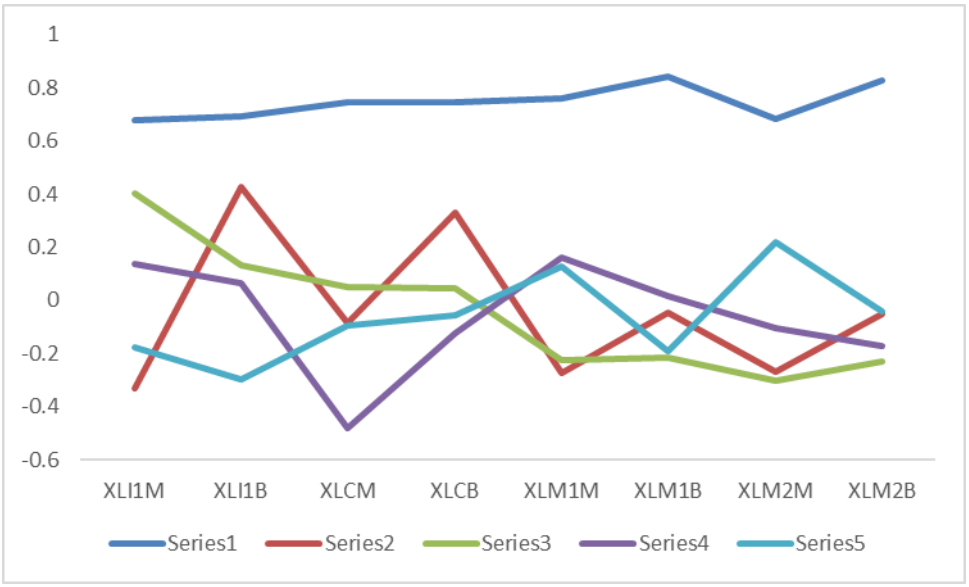

Figure 5-9. PCA graph for permanent maxillary left teeth.
Legend: X- maxillary; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

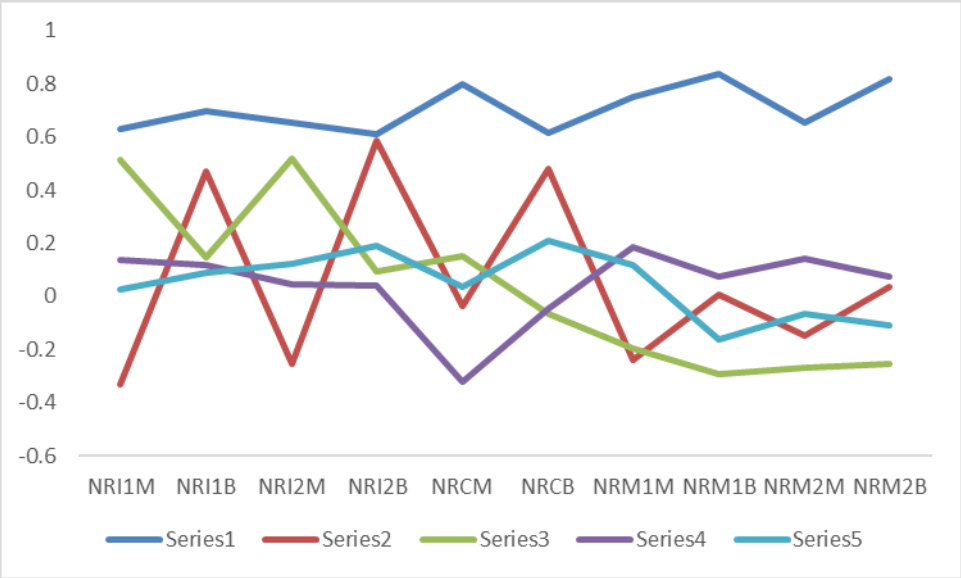

Figure 5-10. PCA graph for primary mandibular right teeth.
Legend: N- mandibular; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

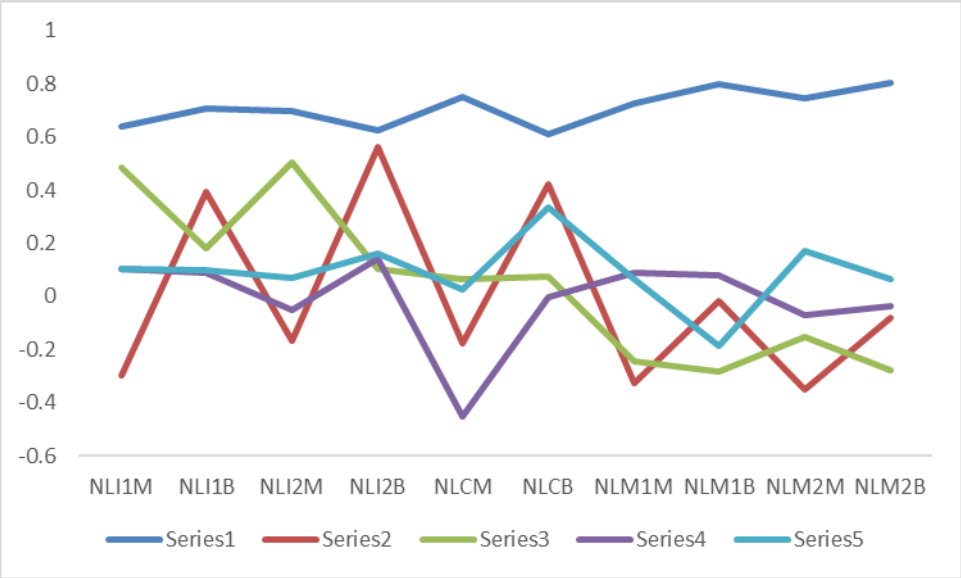

Figure 5-11. PCA graph for primary mandibular left teeth.
Legend: N- mandibular; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

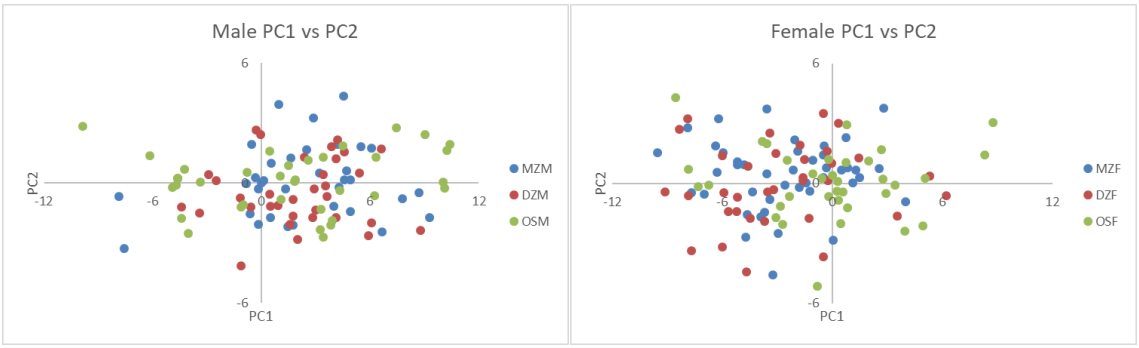

Figure 5-12. Sex and zygosity comparisons of PC1 and PC2 of the permanent teeth.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

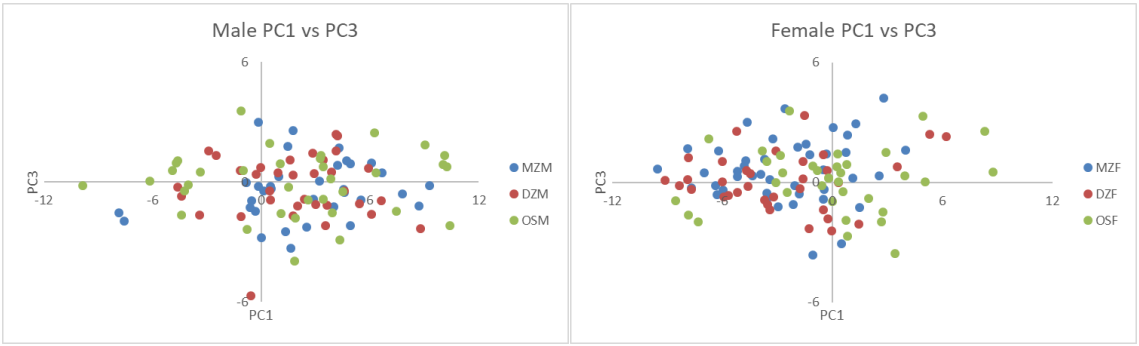

Figure 5-13. Sex and zygosity comparisons of PC1 and PC3 of the permanent teeth.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

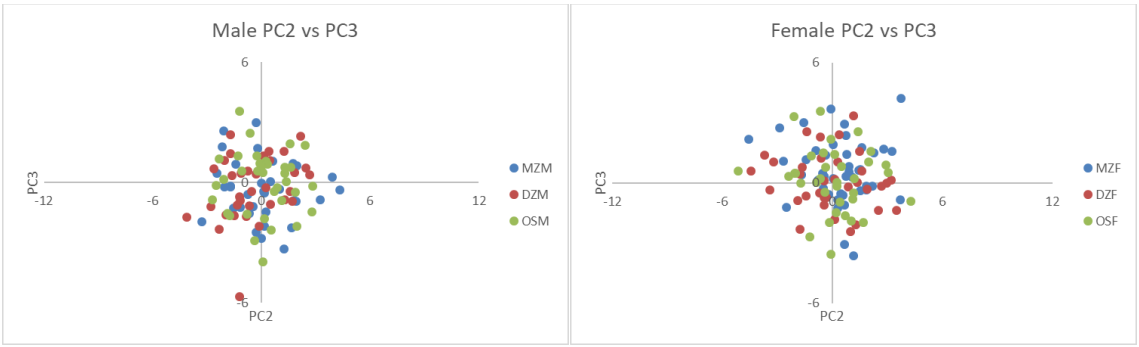

Figure 5-14. Sex and zygosity comparisons of PC2 and PC3 of the permanent teeth.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

Chapter 6 Results of statistical analysis of dermatoglyphic variables

6.1 Introduction

Fingerprints are distinct physical characteristics that remain unchanged throughout an individual's lifetime. Comparing fingerprint characteristics within and between individuals can provide a way to analyse genetic, epigenetic and environmental influences on dermatoglyphic variation.

This chapter describes the different dermatoglyphic variables (fingerprint pattern, FP; ridge count, RC; white lines count, WLC) in terms of means, medians, standard deviations (SD) and coefficients of variation (CV) for sexes, zygosities and fingers. It also aims to determine the magnitude and pattern of sexual dimorphism for each dermatoglyphic phenotype of MZ, DZSS and DZOS twins, consisting of the same individuals.

Associations were also quantified between the different dermatoglyphic variables using Spearman's and Pearson's coefficient. Correlation coefficients among fingers from right and left sides, as well as correlations among fingers from the same side were calculated for all variables in both sexes and zygosities. Another correlation calculated was the correlations among all variables in the same finger, also making associations with the timing of formation of each phenotype studied.

6.2 Sexual dimorphism

Shown in Table 6-1 is the frequency of each fingerprint pattern (arch, loop, and whorl) in all fingers of both sexes. There are more loop pattern in all fingers of both sexes, and arch pattern was observed to be the least in occurrence.

Table 6-1. Frequency distribution of fingerprint patterns (FP) of Australian male and female twins.

Males							Females						
	Right							Right					Total
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	
Arch	1	17	10	3	3	34	Arch	1	13	10	4	4	32
Loop	60	53	73	56	76	318	Loop	69	62	86	67	90	374
Whorl	42	33	20	44	24	163	Whorl	42	37	16	41	18	154
	Left							Left					Total
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	
Arch	3	13	12	1	3	32	Arch	3	14	13	3	2	35
Loop	70	61	76	70	81	358	Loop	73	63	80	76	96	388
Whorl	30	29	15	32	19	125	Whorl	36	35	19	33	14	137
	Both							Both					Total
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	
Arch	4	30	22	4	6	66	Arch	4	27	23	7	6	67
Loop	130	114	149	126	157	676	Loop	142	125	166	143	186	762
Whorl	72	62	35	76	43	288	Whorl	78	72	35	74	32	291
Total	206	206	206	206	206	1030	Total	224	224	224	224	224	1120

Presented in Table 6-2 are the mean values, SDs and CVs of ridge count (RC) of fingerprints of Australian twins. There was no observed sexual dimorphism because finger ridge counts in both sexes had insignificant differences. Highlighted in blue are the significant left-right differences (i.e. directional asymmetry) based on paired t-tests.

Table 6-2. Descriptive statistics for ridge count (RC) of fingerprints of Australian male and female twins.

	Males								Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Thumb	103	19.64	4.28	21.80	103	17.87	4.45	24.89	112	19.69	4.56	23.15	112	18.00	4.10	22.78
Index	103	21.62	4.20	19.41	103	21.05	4.59	21.79	112	21.26	4.20	19.74	112	21.04	4.33	20.57
Middle	103	23.72	3.14	13.26	103	22.81	3.73	16.34	112	23.03	4.05	17.59	112	22.93	4.26	18.59
Ring	103	22.01	4.05	18.41	103	22.41	4.62	20.61	112	21.88	3.66	16.75	112	22.80	4.12	18.08
Little	103	22.86	4.72	20.62	103	22.25	4.75	21.33	112	22.63	4.35	19.20	112	22.93	3.95	17.25

Table 6-3 shows the median values of white lines count (WLC) of fingerprints of Australian twins. Highlighted in yellow is the p-value of the right little finger, where WLC different between sexes at $p < 0.05$. There were no significant left-right differences observed in all fingers based on Wilcoxon signed-rank test.

Table 6-3. Descriptive statistics for white lines count (WLC) of fingerprints of Australian male and female twins.

	Australian Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
Thumb	0.00	0.00	0.71	0.00	0.00	0.95
Index	0.00	0.00	0.13	0.00	0.00	0.72
Middle	0.00	0.00	0.67	0.00	0.00	0.62
Ring	0.00	0.00	0.23	0.00	0.00	0.74
Little	0.00	0.00	0.04	0.00	0.00	0.41

6.3 MZ twins

Shown in Table 6-4 is the frequency of each fingerprint pattern (arch, loop, and whorl) in all fingers of Australian male and female MZ twins. There are more loop pattern in all fingers of both sexes, and arch pattern was observed to be the least in occurrence.

Table 6-4. Frequency distribution of fingerprint patterns (FP) of Australian male and female monozygotic (MZ) twins.

MZ Males							MZ Females						
	Right							Right					
Pattern	**Thumb**	**Index**	**Middle**	**Ring**	**Little**	**Total**	**Pattern**	**Thumb**	**Index**	**Middle**	**Ring**	**Little**	**Total**
Arch	0	8	6	3	2	19	**Arch**	1	8	5	2	2	18
Loop	22	13	20	18	23	96	**Loop**	24	17	27	23	36	127
Whorl	12	13	8	13	9	55	**Whorl**	18	18	11	18	5	70
	Left							**Left**					
Pattern	**Thumb**	**Index**	**Middle**	**Ring**	**Little**	**Total**	**Pattern**	**Thumb**	**Index**	**Middle**	**Ring**	**Little**	**Total**
Arch	1	8	5	1	2	17	**Arch**	1	6	8	2	0	17
Loop	22	14	24	23	25	108	**Loop**	30	24	25	27	36	142
Whorl	11	12	5	10	7	45	**Whorl**	12	13	10	14	7	56
	Both							**Both**					
Pattern	**Thumb**	**Index**	**Middle**	**Ring**	**Little**	**Total**	**Pattern**	**Thumb**	**Index**	**Middle**	**Ring**	**Little**	**Total**
Arch	1	16	11	4	4	36	**Arch**	2	14	13	4	2	35
Loop	44	27	44	41	48	204	**Loop**	54	41	52	50	72	269
Whorl	23	25	13	23	16	100	**Whorl**	30	31	21	32	12	126
Total	68	68	68	68	68	340	**Total**	86	86	86	86	86	430

Presented in Table 6-5 are the mean values, SDs and CVs of ridge count (RC) of fingerprints of Australian MZ twins. There was no observed sexual dimorphism because finger ridge counts in both sexes had insignificant differences. Highlighted in blue are the significant left-right differences (i.e. directional asymmetry) based on paired t-tests, which was observed in the thumb of both male and female MZ twins.

Table 6-5. Descriptive statistics for fingerprint ridge count (RC) of Australian male and female monozygotic (MZ) twins.

	MZ Males								MZ Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Thumb	34	20.94	4.10	19.56	34	18.82	3.66	19.42	43	20.42	3.95	19.36	43	18.40	3.86	20.96
Index	34	21.97	4.00	18.22	34	20.74	4.93	23.75	43	21.84	3.76	17.22	43	20.95	3.32	15.86
Middle	34	23.21	3.40	14.65	34	22.41	3.01	13.41	43	23.37	2.87	12.28	43	23.26	3.78	16.25
Ring	34	22.18	4.74	21.37	34	21.62	5.39	24.95	43	22.21	3.30	14.85	43	23.28	3.74	16.05
Little	34	22.03	4.65	21.10	34	22.09	5.42	24.53	43	23.00	3.62	15.73	43	23.74	3.33	14.03

Table 6-6 shows the median values of white lines count (WLC) of fingerprints of Australian MZ twins. There was no observed sexual dimorphism because the number of white creases in both sexes had insignificant difference. There were no significant left-right differences (i.e. directional asymmetry) observed in any finger based on Wilcoxon signed-rank test.

Table 6-6. Descriptive statistics for fingerprint white lines count (WLC) of Australian male and female monozygotic (MZ) twins.

	MZ Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
Thumb	0.00	0.00	0.08	0.00	0.00	0.86
Index	0.00	0.00	0.70	0.00	0.00	0.36
Middle	0.00	0.00	0.52	0.00	0.00	0.42
Ring	0.00	0.00	0.88	0.00	0.00	0.65
Little	0.00	0.00	0.08	0.00	0.00	0.16

6.4 DZSS twins

Shown in Table 6-7 is the frequency of each fingerprint pattern (arch, loop, and whorl) in all fingers of Australian male and female DZSS twins. There are more loop pattern in all fingers of both sexes, and arch pattern was observed to be the least in occurrence.

Table 6-7. Frequency distribution of fingerprint patterns (FP) of Australian male and female dizygotic same sex (DZSS) twins.

DZSS Males							DZSS Females						
	Right							Right					Total
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	
Arch	1	7	3	0	1	12	Arch	0	1	4	1	1	7
Loop	21	20	26	19	27	113	Loop	23	19	26	22	28	118
Whorl	12	7	5	15	6	45	Whorl	11	14	4	11	5	45
	Left							Left					Total
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	
Arch	1	4	5	0	0	10	Arch	0	4	3	0	1	8
Loop	24	22	24	25	29	124	Loop	26	17	27	25	28	123
Whorl	9	8	5	9	5	36	Whorl	8	13	4	9	5	39
	Both							Both					Total
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	
Arch	2	11	8	0	1	22	Arch	0	5	7	1	2	15
Loop	45	42	50	44	56	237	Loop	49	36	53	47	56	241
Whorl	21	15	10	24	11	81	Whorl	19	27	8	20	10	84
Total	68	68	68	68	68	340	Total	68	68	68	68	68	340

Presented in Table 6-8 are the mean values, SDs and CVs of ridge count (RC) of fingerprints of Australian DZSS twins. There was no observed sexual dimorphism and left-right variation because finger ridge counts in both sexes and sides had insignificant differences.

Table 6-8. Descriptive statistics for fingerprint ridge count (RC) of Australian male and female dizygotic same sex (DZSS) twins.

	DZSS Males								DZSS Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Thumb	34	18.97	3.77	19.87	34	17.32	4.33	24.97	34	19.29	4.95	25.63	34	17.97	4.26	23.71
Index	34	21.50	3.99	18.58	34	21.09	4.45	21.09	34	20.53	4.59	22.38	34	21.12	3.98	18.83
Middle	34	23.59	3.11	13.17	34	22.15	4.45	20.07	34	22.29	5.14	23.04	34	23.21	4.73	20.40
Ring	34	21.71	3.53	16.26	34	22.62	3.61	15.96	34	21.47	4.32	20.13	34	21.97	4.34	19.78
Little	34	23.38	4.94	21.14	34	22.38	4.38	19.55	34	22.71	4.75	20.93	34	22.26	4.04	18.15

Table 6-9 shows the median values of white lines count (WLC) of fingerprints of Australian DZSS twins. The right index finger, left middle finger and left ring finger were found to be sexually dimorphic (highlighted in yellow) based on Mann-Whitney test. There was no observed directional asymmetry because white creases in both sides had insignificant differences based on Wilcoxon signed-rank test.

Table 6-9. Descriptive statistics for fingerprint white lines count (WLC) of Australian male and female dizygotic same sex (DZSS) twins.

	DZSS Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
Thumb	0.00	0.50	0.41	0.00	0.50	0.23
Index	0.00	0.00	0.04	0.00	0.00	0.53
Middle	0.00	0.00	0.92	0.00	0.50	0.04
Ring	0.00	1.00	0.06	0.00	1.00	0.03
Little	0.00	0.00	0.84	0.00	0.00	0.67

6.5 DZOS twins

Shown in Table 6-10 is the frequency of each fingerprint pattern in all fingers of Australian male and female DZOS twins. There are more loop pattern in all fingers of both sexes, and arch pattern was observed to be the least in occurrence.

Table 6-10. Frequency distribution of fingerprint patterns (FP) of Australian male and female dizygotic opposite sex (DZOS) twins.

DZOS Males							DZOS Females						
	Right							Right					
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total
Arch	0	2	1	0	0	3	Arch	0	4	1	1	1	7
Loop	17	20	27	19	26	109	Loop	22	26	33	22	26	129
Whorl	18	13	7	16	9	63	Whorl	13	5	1	12	8	39
	Left							Left					
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total
Arch	1	1	2	0	1	5	Arch	2	4	2	1	1	10
Loop	24	25	28	22	27	126	Loop	17	22	28	24	32	123
Whorl	10	9	5	13	7	44	Whorl	16	9	5	10	2	42
	Both							Both					
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total
Arch	1	3	3	0	1	8	Arch	2	8	3	2	2	17
Loop	41	45	55	41	53	235	Loop	39	48	61	46	58	252
Whorl	28	22	12	29	16	107	Whorl	29	14	6	22	10	81
Total	70	70	70	70	70	350	Total	70	70	70	70	70	350

Presented in Table 6-11 are the mean values, SDs and CVs of ridge count (RC) of fingerprints of Australian DZOS twins. There was no observed sexual dimorphism and left-right differences because finger ridge counts in both sexes and sides had insignificant differences.

Table 6-11. Descriptive statistics for fingerprint ridge count (RC) of Australian male and female dizygotic opposite sex (DZOS) twins.

	DZOS Males								DZOS Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Thumb	35	19.03	4.73	24.86	35	17.49	5.19	29.66	35	19.17	4.87	25.38	35	17.54	4.30	24.51
Index	35	21.40	4.65	21.72	35	21.31	4.49	21.07	35	21.26	4.31	20.29	35	21.09	5.67	26.91
Middle	35	24.34	2.90	11.91	35	23.83	3.47	14.55	35	23.31	4.12	17.68	35	22.26	4.39	19.72
Ring	35	22.14	3.90	17.63	35	22.97	4.70	20.46	35	21.86	3.46	15.82	35	23.03	4.35	18.88
Little	35	23.17	4.58	19.76	35	22.29	4.52	20.29	35	22.11	4.81	21.74	35	22.57	4.48	19.85

Table 6-12 shows the median values of white lines count (WLC) of fingerprints of Australian DZOS twins. There was no observed sexual differences and directional

asymmetry because white creases in both sexes and sides had insignificant differences.

Table 6-12. Descriptive statistics for fingerprint white lines count (WLC) of Australian male and female dizygotic opposite sex (DZOS) twins.

	DZOS Twins					
	Right			Left		
	Median		p-value	Median		p-value
	Males	Females		Males	Females	
Thumb	0.00	0.00	0.64	1.00	0.00	0.23
Index	0.00	0.00	0.33	0.00	0.00	0.62
Middle	0.00	0.00	0.88	1.00	1.00	0.65
Ring	0.00	0.00	0.87	1.00	0.00	0.37
Little	0.00	0.00	0.15	0.00	0.00	0.80

6.6 Male twins

Table 6-13 shows the comparison of frequency percentage of FP of Australian male twins. Highlighted in yellow are the greatest frequency percentage of FP per finger and side. Frequency percentage of arch fingerprint was consistently greatest in MZ twins, loop fingerprint was steadily greatest in DZSS twins, and whorl fingerprint was greatest in DZOS, except in the left.

Shown in Table 6-14 is the comparison of mean values, SDs and CVs of RC of Australian male twins. There was no observed significant difference of mean values among zygosities at $p < 0.05$. Highlighted in yellow are the greatest mean value per finger and side. There was no consistency in which zygosity had greater mean values: MZ males were the highest in right and left thumb, right index finger, and right ring finger; DZSS males had the highest count in both right and left little fingers; and DZOS males were highest in left index finger, right and left middle finger, and left ring finger.

Presented in Table 6-15 is the comparison of median values of WLC of Australian male twins. There was no observed significant difference among zygosities at $p < 0.05$ based on Kruskall-Wallis test.

Table 6-13. Frequency percentage distribution of fingerprint patterns (FP) of Australian male twins.

	MZ Males							DZSS Males							DZOS Males						
	Right							Right							Right						
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	
Arch	0.00	2.35	1.76	0.88	0.59	5.59	Arch	0.29	2.06	0.88	0.00	0.29	3.53	Arch	0.00	0.57	0.29	0.00	0.00	0.86	
Loop	6.47	3.82	5.88	5.29	6.76	28.24	Loop	6.18	5.88	7.65	5.59	7.94	33.24	Loop	4.86	5.71	7.71	5.43	7.43	31.14	
Whorl	3.53	3.82	2.35	3.82	2.65	16.18	Whorl	3.53	2.06	1.47	4.41	1.76	13.24	Whorl	5.14	3.71	2.00	4.57	2.57	18.00	
	Left							Left							Left						
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	
Arch	0.29	2.35	1.47	0.29	0.59	5.00	Arch	0.29	1.18	1.47	0.00	0.00	2.94	Arch	0.29	0.29	0.57	0.00	0.29	1.43	
Loop	6.47	4.12	7.06	6.76	7.35	31.76	Loop	7.06	6.47	7.06	7.35	8.53	36.47	Loop	6.86	7.14	8.00	6.29	7.71	36.00	
Whorl	3.24	3.53	1.47	2.94	2.06	13.24	Whorl	2.65	2.35	1.47	2.65	1.47	10.59	Whorl	2.86	2.57	1.43	3.71	2.00	12.57	
	Both							Both							Both						
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	
Arch	0.29	4.71	3.24	1.18	1.18	10.59	Arch	0.59	3.24	2.35	0.00	0.29	6.47	Arch	0.29	0.86	0.86	0.00	0.29	2.29	
Loop	12.94	7.94	12.94	12.06	14.12	60.00	Loop	13.24	12.35	14.71	12.94	16.47	69.71	Loop	11.71	12.86	15.71	11.71	15.14	67.14	
Whorl	6.76	7.35	3.82	6.76	4.71	29.41	Whorl	6.18	4.41	2.94	7.06	3.24	23.82	Whorl	8.00	6.29	3.43	8.29	4.57	30.57	
Total %	20	20	20	20	20	100	Total %	20	20	20	20	20	100	Total %	20	20	20	20	20	100	

Table 6-14. Comparison of fingerprint ridge count (RC) of Australian male twins.

	MZ Males								DZSS Males								DZOS Males							
	Right				Left				Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Thumb	34	20.94	4.10	19.56	34	18.82	3.66	19.42	34	18.97	3.77	19.87	34	17.32	4.33	24.97	35	19.03	4.73	24.86	35	17.49	5.19	29.66
Index	34	21.97	4.00	18.22	34	20.74	4.93	23.75	34	21.50	3.99	18.58	34	21.09	4.45	21.09	35	21.40	4.65	21.72	35	21.31	4.49	21.07
Middle	34	23.21	3.40	14.65	34	22.41	3.01	13.41	34	23.59	3.11	13.17	34	22.15	4.45	20.07	35	24.34	2.90	11.91	35	23.83	3.47	14.55
Ring	34	22.18	4.74	21.37	34	21.62	5.39	24.95	34	21.71	3.53	16.26	34	22.62	3.61	15.96	35	22.14	3.90	17.63	35	22.97	4.70	20.46
Little	34	22.03	4.65	21.10	34	22.09	5.42	24.53	34	23.38	4.94	21.14	34	22.38	4.38	19.55	35	23.17	4.58	19.76	35	22.29	4.52	20.29

Table 6-15. Comparison of fingerprint white lines count (WLC) of Australian male twins.

	Males							
	Right				Left			
	Median				Median			
	MZ	DZSS	DZOS	p-value	MZ	DZSS	DZOS	p-value
Thumb	0.00	0.00	0.00	0.66	0.00	0.00	1.00	0.37
Index	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.19
Middle	0.00	0.00	0.00	0.55	0.00	0.00	1.00	0.06
Ring	0.00	0.00	0.00	0.35	0.00	0.00	1.00	0.06
Little	0.00	0.00	0.00	0.75	0.00	0.00	0.00	0.61

6.7 Female twins

Table 6-16 shows the comparison of frequency percentage of FP of Australian female twins. Highlighted in yellow are the greatest frequency percentage of FP per finger and side. Frequency percentage of arch and whorl fingerprints were consistently greatest in MZ twins, loop fingerprint was greatest in DZSS twins on the left, and in DZOS twins on the right and when pooled together.

Shown in Table 6-17 is the comparison of mean values, SDs and CVs of RC of Australian male twins. There was no observed significant difference of mean values among zygosities at $p < 0.05$. Highlighted in yellow are the greatest mean value per finger and side. Mean values of RC of MZ females were consistently greater compared to DZSS and DZOS females, except for the left index finger.

Presented in Table 6-18 is the comparison of median values of WLC of Australian male twins. There was no observed significant difference among zygosities at $p < 0.05$ based on Kruskall-Wallis test.

Table 6-16. Frequency distribution of fingerprint patterns (FP) of Australian female twins.

	MZ Females							DZSS Females							DZOS Females						
	Right							Right							Right						
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	
Arch	0.23	1.86	1.16	0.47	0.47	4.19	Arch	0.00	0.29	1.18	0.29	0.29	2.06	Arch	0.00	1.14	0.29	0.29	0.29	2.00	
Loop	5.58	3.95	6.28	5.35	8.37	29.53	Loop	6.76	5.59	7.65	6.47	8.24	34.71	Loop	6.29	7.43	9.43	6.29	7.43	36.86	
Whorl	4.19	4.19	2.56	4.19	1.16	16.28	Whorl	3.24	4.12	1.18	3.24	1.47	13.24	Whorl	3.71	1.43	0.29	3.43	2.29	11.14	
	Left							Left							Left						
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	
Arch	0.23	1.40	1.86	0.47	0.00	3.95	Arch	0.00	1.18	0.88	0.00	0.29	2.35	Arch	0.57	1.14	0.57	0.29	0.29	2.86	
Loop	6.98	5.58	5.81	6.28	8.37	33.02	Loop	7.65	5.00	7.94	7.35	8.24	36.18	Loop	4.86	6.29	8.00	6.86	9.14	35.14	
Whorl	2.79	3.02	2.33	3.26	1.63	13.02	Whorl	2.35	3.82	1.18	2.65	1.47	11.47	Whorl	4.57	2.57	1.43	2.86	0.57	12.00	
	Both							Both							Both						
Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	Pattern	Thumb	Index	Middle	Ring	Little	Total	
Arch	0.47	3.26	3.02	0.93	0.47	8.14	Arch	0.00	1.47	2.06	0.29	0.59	4.41	Arch	0.57	2.29	0.86	0.57	0.57	4.86	
Loop	12.56	9.53	12.09	11.63	16.74	62.56	Loop	14.41	10.59	15.59	13.82	16.47	70.88	Loop	11.14	13.71	17.43	13.14	16.57	72.00	
Whorl	6.98	7.21	4.88	7.44	2.79	29.30	Whorl	5.59	7.94	2.35	5.88	2.94	24.71	Whorl	8.29	4.00	1.71	6.29	2.86	23.14	
Total %	20	20	20	20	20	100	Total %	20	20	20	20	20	100	Total %	20	20	20	20	20	100	

Table 6-17. Comparison of fingerprint ridge count (RC) of Australian female twins.

	MZ Females								DZSS Females								DZOS Females							
	Right				Left				Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
Thumb	43	20.42	3.95	19.36	43	18.40	3.86	20.96	34	19.29	4.95	25.63	34	17.97	4.26	23.71	35	19.17	4.87	25.38	35	17.54	4.30	24.51
Index	43	21.84	3.76	17.22	43	20.95	3.32	15.86	34	20.53	4.59	22.38	34	21.12	3.98	18.83	35	21.26	4.31	20.29	35	21.09	5.67	26.91
Middle	43	23.37	2.87	12.28	43	23.26	3.78	16.25	34	22.29	5.14	23.04	34	23.21	4.73	20.40	35	23.31	4.12	17.68	35	22.26	4.39	19.72
Ring	43	22.21	3.30	14.85	43	23.28	3.74	16.05	34	21.47	4.32	20.13	34	21.97	4.34	19.78	35	21.86	3.46	15.82	35	23.03	4.35	18.88
Little	43	23.00	3.62	15.73	43	23.74	3.33	14.03	34	22.71	4.75	20.93	34	22.26	4.04	18.15	35	22.11	4.81	21.74	35	22.57	4.48	19.85

Table 6-18. Comparison of fingerprint white lines count (WLC) of Australian male twins.

	Females							
	Right				Left			
	Median				Median			
	MZ	DZSS	DZOS	p-value	MZ	DZSS	DZOS	p-value
Thumb	0.00	0.50	0.00	0.15	0.00	0.50	0.00	0.70
Index	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.91
Middle	0.00	0.00	0.00	0.48	0.00	0.50	1.00	0.34
Ring	0.00	1.00	0.00	0.11	0.00	1.00	0.00	0.22
Little	0.00	0.00	0.00	0.46	0.00	0.00	0.00	0.11

6.8 Correlations

Pearson's coefficients (r) between dermatoglyphic variables RC and WLC are presented in Table 6-19. The correlations between them were observed to be statistically insignificant in all fingers.

Table 6-19. Pearson correlation coefficients of ridge count (RC) and white lines count (WLC).

	Males		Females	
	Right	Left	Right	Left
Thumb	-0.02	-0.04	-0.05	0.06
Index	0.09	0.17	-0.09	0.06
Middle	-0.20	0.15	-0.17	0.11
Ring	-0.04	-0.02	0.01	-0.08
Little	0.13	0.11	0.00	0.02

Shown in Table 6-20 are Spearman's correlation coefficients between the fingerprint pattern (FP) and totals of ridge count (RC) and white lines count (WLC). Highlighted in yellow are the statistically significant correlations at $p < 0.05$. Only RC of index finger and ring finger were observed to be statistically significant but low in magnitude.

Table 6-20. Spearman correlation coefficients of Fingerprint pattern (FP) and Ridge Count (RC) and White Lines Count (WLC).

	Males				Females			
	Right		Left		Right		Left	
	RC	WLC	RC	WLC	RC	WLC	RC	WLC
Thumb	-0.11	-0.10	0.04	0.10	-0.15	-0.04	-0.05	-0.09
Index	-0.31	0.00	-0.27	-0.13	-0.24	-0.08	-0.26	-0.02
Middle	-0.06	-0.03	-0.02	-0.02	0.02	-0.11	-0.08	0.06
Ring	-0.25	0.09	-0.35	-0.04	-0.40	-0.09	-0.23	-0.08
Little	-0.11	0.11	-0.04	0.04	-0.15	-0.11	-0.12	0.15

Presented in Table 6-21 are the correlation coefficients between left and right sides. Highlighted in yellow are the statistically significant correlation at $p < 0.05$. Overall, the correlations between sides in all fingers are statistically significant and high in magnitude in FP, medium in magnitude in WLC, and low in magnitude in RC.

Table 6-21.Correlation coefficients of left and right sides in all fingers and fingerprint variables.

	Males			Females		
	FP	RC	WLC	FP	RC	WLC
Thumb	0.57	0.30	0.58	0.51	0.26	0.40
Index	0.68	0.57	0.66	0.64	0.37	0.55
Middle	0.64	0.37	0.54	0.69	0.27	0.44
Ring	0.66	0.31	0.73	0.72	0.32	0.32
Little	0.75	0.43	0.61	0.60	0.26	0.45

6.9 Associations

Table 6-22 gives Differences of Marginal Means for each model (post-hoc comparisons). Highlighted in yellow are the statistically significant models at $p < 0.05$. For Model number 5, there is a statistically significant difference in mean RC between fingers (global P value<0.0001). The index finger has mean RC 1.43 units less than the little finger, 1.04 units less than the ring finger, 1.87 units less than the middle finger, and 2.44 units more than the thumb, all at 95% confidence interval. These

comparisons are significant (comparison P value<0.0001). There are many other significant post-hoc comparisons for this model (refer to Table 6-22).

In Table 6-23, for Model 11, there is a statistically significant interaction between hand and finger, which means that fingers are mostly significantly different from each other.

Table 6-22. Linear mixed-effects models.

Model	Outcome	Predictor	Comparison value	Reference value	Estimate	Lower 95%	Upper 95%	p- value	Global p
1	RC	TTT	DZOS Females	MZ and DZSS Females	-0.29	-1.03	0.45	0.44	0.44
2	RC	Twin_type	DZOS Females	DZOS Males	-0.38	-0.70	-0.05	0.02	0.12
2	RC	Twin_type	DZOS Females	DZSS Females	0.14	-0.73	1.01	0.76	0.12
2	RC	Twin_type	DZOS Females	DZSS Males	-0.05	-0.92	0.82	0.91	0.12
2	RC	Twin_type	DZOS Females	MZ Females	-0.63	-1.45	0.19	0.13	0.12
2	RC	Twin_type	DZOS Females	MZ Males	-0.18	-1.05	0.69	0.68	0.12
2	RC	Twin_type	DZOS Males	DZSS Females	0.51	-0.35	1.38	0.25	0.12
2	RC	Twin_type	DZOS Males	DZSS Males	0.33	-0.54	1.20	0.46	0.12
2	RC	Twin_type	DZOS Males	MZ Females	-0.25	-1.07	0.57	0.55	0.12
2	RC	Twin_type	DZOS Males	MZ Males	0.20	-0.67	1.07	0.66	0.12
2	RC	Twin_type	DZSS Females	DZSS Males	-0.19	-1.06	0.69	0.67	0.12
2	RC	Twin_type	DZSS Females	MZ Females	-0.76	-1.59	0.06	0.07	0.12
2	RC	Twin_type	DZSS Females	MZ Males	-0.32	-1.19	0.56	0.48	0.12
2	RC	Twin_type	DZSS Males	MZ Females	-0.58	-1.40	0.25	0.17	0.12
2	RC	Twin_type	DZSS Males	MZ Males	-0.13	-1.00	0.75	0.77	0.12
2	RC	Twin_type	MZ Females	MZ Males	0.45	-0.38	1.27	0.29	0.12
3	RC	Sex	Female	Male	-0.25	-0.54	0.04	0.09	0.09
4	RC	Hand	Left	Right	-0.43	-0.96	0.11	0.12	0.12
5	RC	Finger	Index	Little	-1.43	-1.70	-1.17	<.0001	<.0001
5	RC	Finger	Index	Middle	-1.87	-2.14	-1.61	<.0001	<.0001
5	RC	Finger	Index	Ring	-1.04	-1.31	-0.77	<.0001	<.0001
5	RC	Finger	Index	Thumb	2.44	2.17	2.71	<.0001	<.0001
5	RC	Finger	Little	Middle	-0.44	-0.71	-0.17	0.00	<.0001
5	RC	Finger	Little	Ring	0.40	0.13	0.67	0.00	<.0001
5	RC	Finger	Little	Thumb	3.87	3.60	4.14	<.0001	<.0001
5	RC	Finger	Middle	Ring	0.84	0.57	1.11	<.0001	<.0001
5	RC	Finger	Middle	Thumb	4.31	4.04	4.58	<.0001	<.0001
5	RC	Finger	Ring	Thumb	3.47	3.21	3.74	<.0001	<.0001

Table 6-23. Linear mixed-effects models with interactions.

Model	Outcome	Interaction	Comparison 1	Reference 1	Comparison 2	Reference 2	Estimate	Lower 95%	Upper 95%	p- value	Global p
6	RC	Hand*Sex	Left	Left	Female	Male	-0.10	-0.50	0.31	0.64	0.29
6	RC	Hand*Sex	Left	Right	Female	Female	-0.28	-0.88	0.32	0.36	0.29
6	RC	Hand*Sex	Left	Right	Male	Male	-0.59	-1.20	0.02	0.06	0.29
6	RC	Hand*Sex	Right	Right	Female	Male	-0.41	-0.81	0.00	0.05	0.29
7	RC	Finger*Sex	Index	Index	Female	Male	-0.45	-0.88	-0.02	0.04	0.28
7	RC	Finger*Sex	Index	Little	Female	Female	-1.63	-2.00	-1.26	<.0001	0.28
7	RC	Finger*Sex	Index	Middle	Female	Female	-1.83	-2.20	-1.45	<.0001	0.28
7	RC	Finger*Sex	Index	Ring	Female	Female	-1.19	-1.56	-0.82	<.0001	0.28
7	RC	Finger*Sex	Index	Thumb	Female	Female	2.31	1.94	2.68	<.0001	0.28
7	RC	Finger*Sex	Index	Little	Male	Male	-1.22	-1.61	-0.84	<.0001	0.28
7	RC	Finger*Sex	Index	Middle	Male	Male	-1.93	-2.31	-1.54	<.0001	0.28
7	RC	Finger*Sex	Index	Ring	Male	Male	-0.87	-1.26	-0.49	<.0001	0.28
7	RC	Finger*Sex	Index	Thumb	Male	Male	2.58	2.19	2.96	<.0001	0.28
7	RC	Finger*Sex	Little	Little	Female	Male	-0.04	-0.47	0.39	0.85	0.28
7	RC	Finger*Sex	Little	Middle	Female	Female	-0.20	-0.57	0.17	0.30	0.28
7	RC	Finger*Sex	Little	Ring	Female	Female	0.44	0.07	0.81	0.02	0.28
7	RC	Finger*Sex	Little	Thumb	Female	Female	3.94	3.57	4.31	<.0001	0.28
7	RC	Finger*Sex	Little	Middle	Male	Male	-0.70	-1.09	-0.32	0.00	0.28
7	RC	Finger*Sex	Little	Ring	Male	Male	0.35	-0.04	0.74	0.08	0.28
7	RC	Finger*Sex	Little	Thumb	Male	Male	3.80	3.41	4.19	<.0001	0.28
7	RC	Finger*Sex	Middle	Middle	Female	Male	-0.55	-0.98	-0.12	0.01	0.28
7	RC	Finger*Sex	Middle	Ring	Female	Female	0.64	0.27	1.01	0.00	0.28
7	RC	Finger*Sex	Middle	Thumb	Female	Female	4.13	3.76	4.51	<.0001	0.28
7	RC	Finger*Sex	Middle	Ring	Male	Male	1.05	0.67	1.44	<.0001	0.28
7	RC	Finger*Sex	Middle	Thumb	Male	Male	4.50	4.12	4.89	<.0001	0.28
7	RC	Finger*Sex	Ring	Ring	Female	Male	-0.13	-0.56	0.30	0.55	0.28
7	RC	Finger*Sex	Ring	Thumb	Female	Female	3.50	3.12	3.87	<.0001	0.28
7	RC	Finger*Sex	Ring	Thumb	Male	Male	3.45	3.06	3.84	<.0001	0.28
7	RC	Finger*Sex	Thumb	Thumb	Female	Male	-0.18	-0.61	0.25	0.42	0.28
8	RC	Finger*Twin_type	Index	Index	DZOS Females	DZOS Males	-0.19	-1.41	1.04	0.77	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Females	DZSS Females	0.35	-1.07	1.76	0.63	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Females	DZSS Males	-0.12	-1.54	1.29	0.86	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Females	MZ Females	-0.22	-1.56	1.11	0.74	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Females	MZ Males	-0.18	-1.60	1.23	0.80	0.44
8	RC	Finger*Twin_type	Index	Little	DZOS Females	DZOS Females	-1.17	-2.40	0.05	0.06	0.44

Continuation of Table 6-23

8	RC	Finger*Twin_type	Index	Middle	DZOS Females	DZOS Females	-1.61	-2.84	-0.39	0.01	0.44
8	RC	Finger*Twin_type	Index	Ring	DZOS Females	DZOS Females	-1.27	-2.50	-0.05	0.04	0.44
8	RC	Finger*Twin_type	Index	Thumb	DZOS Females	DZOS Females	2.81	1.59	4.04	<.0001	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Males	DZSS Females	0.53	-0.88	1.95	0.46	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Males	DZSS Males	0.06	-1.35	1.48	0.93	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Males	MZ Females	-0.04	-1.37	1.30	0.96	0.44
8	RC	Finger*Twin_type	Index	Index	DZOS Males	MZ Males	0.00	-1.41	1.42	1.00	0.44
8	RC	Finger*Twin_type	Index	Little	DZOS Males	DZOS Males	-1.37	-2.60	-0.15	0.03	0.44
8	RC	Finger*Twin_type	Index	Middle	DZOS Males	DZOS Males	-2.73	-3.95	-1.50	<.0001	0.44
8	RC	Finger*Twin_type	Index	Ring	DZOS Males	DZOS Males	-1.20	-2.43	0.03	0.06	0.44
8	RC	Finger*Twin_type	Index	Thumb	DZOS Males	DZOS Males	3.10	1.87	4.33	<.0001	0.44
8	RC	Finger*Twin_type	Index	Index	DZSS Females	DZSS Males	-0.47	-1.89	0.95	0.52	0.44
8	RC	Finger*Twin_type	Index	Index	DZSS Females	MZ Females	-0.57	-1.92	0.78	0.41	0.44
8	RC	Finger*Twin_type	Index	Index	DZSS Females	MZ Males	-0.53	-1.95	0.89	0.47	0.44
8	RC	Finger*Twin_type	Index	Little	DZSS Females	DZSS Females	-1.66	-2.91	-0.42	0.01	0.44
8	RC	Finger*Twin_type	Index	Middle	DZSS Females	DZSS Females	-1.93	-3.17	-0.68	0.00	0.44
8	RC	Finger*Twin_type	Index	Ring	DZSS Females	DZSS Females	-0.90	-2.14	0.35	0.16	0.44
8	RC	Finger*Twin_type	Index	Thumb	DZSS Females	DZSS Females	2.19	0.95	3.44	0.00	0.44
8	RC	Finger*Twin_type	Index	Index	DZSS Males	MZ Females	-0.10	-1.45	1.25	0.88	0.44
8	RC	Finger*Twin_type	Index	Index	DZSS Males	MZ Males	-0.06	-1.48	1.36	0.94	0.44
8	RC	Finger*Twin_type	Index	Little	DZSS Males	DZSS Males	-1.59	-2.83	-0.34	0.01	0.44
8	RC	Finger*Twin_type	Index	Middle	DZSS Males	DZSS Males	-1.57	-2.82	-0.33	0.01	0.44
8	RC	Finger*Twin_type	Index	Ring	DZSS Males	DZSS Males	-0.87	-2.11	0.38	0.17	0.44
8	RC	Finger*Twin_type	Index	Thumb	DZSS Males	DZSS Males	3.15	1.90	4.39	<.0001	0.44
8	RC	Finger*Twin_type	Index	Index	MZ Females	MZ Males	0.04	-1.30	1.39	0.95	0.44
8	RC	Finger*Twin_type	Index	Little	MZ Females	MZ Females	-1.98	-3.08	-0.87	0.00	0.44
8	RC	Finger*Twin_type	Index	Middle	MZ Females	MZ Females	-1.92	-3.02	-0.81	0.00	0.44
8	RC	Finger*Twin_type	Index	Ring	MZ Females	MZ Females	-1.35	-2.46	-0.24	0.02	0.44
8	RC	Finger*Twin_type	Index	Thumb	MZ Females	MZ Females	1.99	0.88	3.09	0.00	0.44
8	RC	Finger*Twin_type	Index	Little	MZ Males	MZ Males	-0.71	-1.95	0.54	0.27	0.44
8	RC	Finger*Twin_type	Index	Middle	MZ Males	MZ Males	-1.46	-2.70	-0.21	0.02	0.44
8	RC	Finger*Twin_type	Index	Ring	MZ Males	MZ Males	-0.54	-1.79	0.70	0.39	0.44
8	RC	Finger*Twin_type	Index	Thumb	MZ Males	MZ Males	1.47	0.23	2.71	0.02	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Females	DZOS Males	-0.39	-1.61	0.84	0.54	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Females	DZSS Females	-0.14	-1.56	1.27	0.84	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Females	DZSS Males	-0.54	-1.95	0.87	0.45	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Females	MZ Females	-1.03	-2.37	0.31	0.13	0.44

Continuation of Table 6-23

8	RC	Finger*Twin_type	Little	Little	DZOS Females	MZ Males	0.28	-1.13	1.70	0.69	0.44
8	RC	Finger*Twin_type	Little	Middle	DZOS Females	DZOS Females	-0.44	-1.67	0.78	0.48	0.44
8	RC	Finger*Twin_type	Little	Ring	DZOS Females	DZOS Females	-0.10	-1.33	1.13	0.87	0.44
8	RC	Finger*Twin_type	Little	Thumb	DZOS Females	DZOS Females	3.99	2.76	5.21	<.0001	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Males	DZSS Females	0.24	-1.17	1.66	0.74	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Males	DZSS Males	-0.15	-1.57	1.26	0.83	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Males	MZ Females	-0.64	-1.98	0.69	0.35	0.44
8	RC	Finger*Twin_type	Little	Little	DZOS Males	MZ Males	0.67	-0.74	2.08	0.35	0.44
8	RC	Finger*Twin_type	Little	Middle	DZOS Males	DZOS Males	-1.36	-2.58	-0.13	0.03	0.44
8	RC	Finger*Twin_type	Little	Ring	DZOS Males	DZOS Males	0.17	-1.05	1.40	0.78	0.44
8	RC	Finger*Twin_type	Little	Thumb	DZOS Males	DZOS Males	4.47	3.25	5.70	<.0001	0.44
8	RC	Finger*Twin_type	Little	Little	DZSS Females	DZSS Males	-0.40	-1.82	1.03	0.58	0.44
8	RC	Finger*Twin_type	Little	Little	DZSS Females	MZ Females	-0.89	-2.23	0.46	0.20	0.44
8	RC	Finger*Twin_type	Little	Little	DZSS Females	MZ Males	0.43	-1.00	1.85	0.56	0.44
8	RC	Finger*Twin_type	Little	Middle	DZSS Females	DZSS Females	-0.26	-1.51	0.98	0.68	0.44
8	RC	Finger*Twin_type	Little	Ring	DZSS Females	DZSS Females	0.76	-0.48	2.01	0.23	0.44
8	RC	Finger*Twin_type	Little	Thumb	DZSS Females	DZSS Females	3.85	2.61	5.10	<.0001	0.44
8	RC	Finger*Twin_type	Little	Little	DZSS Males	MZ Females	-0.49	-1.84	0.86	0.48	0.44
8	RC	Finger*Twin_type	Little	Little	DZSS Males	MZ Males	0.82	-0.60	2.25	0.26	0.44
8	RC	Finger*Twin_type	Little	Middle	DZSS Males	DZSS Males	0.01	-1.23	1.26	0.98	0.44
8	RC	Finger*Twin_type	Little	Ring	DZSS Males	DZSS Males	0.72	-0.52	1.96	0.26	0.44
8	RC	Finger*Twin_type	Little	Thumb	DZSS Males	DZSS Males	4.74	3.49	5.98	<.0001	0.44
8	RC	Finger*Twin_type	Little	Little	MZ Females	MZ Males	1.31	-0.03	2.66	0.06	0.44
8	RC	Finger*Twin_type	Little	Middle	MZ Females	MZ Females	0.06	-1.05	1.16	0.92	0.44
8	RC	Finger*Twin_type	Little	Ring	MZ Females	MZ Females	0.63	-0.48	1.73	0.27	0.44
8	RC	Finger*Twin_type	Little	Thumb	MZ Females	MZ Females	3.97	2.86	5.07	<.0001	0.44
8	RC	Finger*Twin_type	Little	Middle	MZ Males	MZ Males	-0.75	-1.99	0.49	0.24	0.44
8	RC	Finger*Twin_type	Little	Ring	MZ Males	MZ Males	0.16	-1.08	1.41	0.80	0.44
8	RC	Finger*Twin_type	Little	Thumb	MZ Males	MZ Males	2.18	0.93	3.42	0.00	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Females	DZOS Males	-1.30	-2.53	-0.07	0.04	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Females	DZSS Females	0.04	-1.38	1.45	0.96	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Females	DZSS Males	-0.08	-1.50	1.33	0.91	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Females	MZ Females	-0.53	-1.86	0.81	0.44	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Females	MZ Males	-0.02	-1.44	1.39	0.97	0.44
8	RC	Finger*Twin_type	Middle	Ring	DZOS Females	DZOS Females	0.34	-0.88	1.57	0.58	0.44
8	RC	Finger*Twin_type	Middle	Thumb	DZOS Females	DZOS Females	4.43	3.20	5.65	<.0001	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Males	DZSS Females	1.34	-0.08	2.75	0.06	0.44

Continuation of Table 6-23

8	RC	Finger*Twin_type	Middle	Middle	DZOS Males	DZSS Males	1.22	-0.20	2.63	0.09	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Males	MZ Females	0.77	-0.56	2.11	0.26	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZOS Males	MZ Males	1.28	-0.14	2.69	0.08	0.44
8	RC	Finger*Twin_type	Middle	Ring	DZOS Males	DZOS Males	1.53	0.30	2.75	0.01	0.44
8	RC	Finger*Twin_type	Middle	Thumb	DZOS Males	DZOS Males	5.83	4.60	7.05	<.0001	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZSS Females	DZSS Males	-0.12	-1.54	1.31	0.87	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZSS Females	MZ Females	-0.56	-1.91	0.78	0.41	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZSS Females	MZ Males	-0.06	-1.48	1.36	0.94	0.44
8	RC	Finger*Twin_type	Middle	Ring	DZSS Females	DZSS Females	1.03	-0.21	2.27	0.10	0.44
8	RC	Finger*Twin_type	Middle	Thumb	DZSS Females	DZSS Females	4.12	2.87	5.36	<.0001	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZSS Males	MZ Females	-0.45	-1.79	0.90	0.52	0.44
8	RC	Finger*Twin_type	Middle	Middle	DZSS Males	MZ Males	0.06	-1.36	1.48	0.94	0.44
8	RC	Finger*Twin_type	Middle	Ring	DZSS Males	DZSS Males	0.71	-0.54	1.95	0.27	0.44
8	RC	Finger*Twin_type	Middle	Thumb	DZSS Males	DZSS Males	4.72	3.48	5.96	<.0001	0.44
8	RC	Finger*Twin_type	Middle	Middle	MZ Females	MZ Males	0.51	-0.84	1.85	0.46	0.44
8	RC	Finger*Twin_type	Middle	Ring	MZ Females	MZ Females	0.57	-0.54	1.68	0.31	0.44
8	RC	Finger*Twin_type	Middle	Thumb	MZ Females	MZ Females	3.91	2.80	5.01	<.0001	0.44
8	RC	Finger*Twin_type	Middle	Ring	MZ Males	MZ Males	0.91	-0.33	2.16	0.15	0.44
8	RC	Finger*Twin_type	Middle	Thumb	MZ Males	MZ Males	2.93	1.68	4.17	<.0001	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Females	DZOS Males	-0.11	-1.34	1.11	0.86	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Females	DZSS Females	0.72	-0.69	2.14	0.32	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Females	DZSS Males	0.28	-1.13	1.69	0.70	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Females	MZ Females	-0.30	-1.64	1.04	0.66	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Females	MZ Males	0.55	-0.87	1.96	0.45	0.44
8	RC	Finger*Twin_type	Ring	Thumb	DZOS Females	DZOS Females	4.09	2.86	5.31	<.0001	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Males	DZSS Females	0.84	-0.58	2.25	0.25	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Males	DZSS Males	0.40	-1.02	1.81	0.58	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Males	MZ Females	-0.19	-1.52	1.15	0.78	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZOS Males	MZ Males	0.66	-0.75	2.07	0.36	0.44
8	RC	Finger*Twin_type	Ring	Thumb	DZOS Males	DZOS Males	4.30	3.07	5.53	<.0001	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZSS Females	DZSS Males	-0.44	-1.86	0.98	0.54	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZSS Females	MZ Females	-1.02	-2.37	0.32	0.14	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZSS Females	MZ Males	-0.18	-1.60	1.25	0.81	0.44
8	RC	Finger*Twin_type	Ring	Thumb	DZSS Females	DZSS Females	3.09	1.84	4.33	<.0001	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZSS Males	MZ Females	-0.58	-1.93	0.76	0.40	0.44
8	RC	Finger*Twin_type	Ring	Ring	DZSS Males	MZ Males	0.26	-1.16	1.69	0.72	0.44
8	RC	Finger*Twin_type	Ring	Thumb	DZSS Males	DZSS Males	4.01	2.77	5.26	<.0001	0.44

Continuation of Table 6-23

8	RC	Finger*Twin_type	Ring	Ring	MZ Females	MZ Males	0.85	-0.50	2.19	0.22	0.44
8	RC	Finger*Twin_type	Ring	Thumb	MZ Females	MZ Females	3.34	2.23	4.44	<.0001	0.44
8	RC	Finger*Twin_type	Ring	Thumb	MZ Males	MZ Males	2.01	0.77	3.26	0.00	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Females	DZOS Males	0.10	-1.13	1.33	0.87	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Females	DZSS Females	-0.28	-1.69	1.14	0.70	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Females	DZSS Males	0.21	-1.20	1.62	0.77	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Females	MZ Females	-1.05	-2.39	0.29	0.12	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Females	MZ Males	-1.53	-2.94	-0.11	0.03	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Males	DZSS Females	-0.38	-1.79	1.04	0.60	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Males	DZSS Males	0.11	-1.30	1.52	0.88	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Males	MZ Females	-1.15	-2.49	0.19	0.09	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZOS Males	MZ Males	-1.63	-3.04	-0.21	0.02	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZSS Females	DZSS Males	0.49	-0.94	1.91	0.50	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZSS Females	MZ Females	-0.77	-2.12	0.57	0.26	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZSS Females	MZ Males	-1.25	-2.67	0.17	0.09	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZSS Males	MZ Females	-1.26	-2.61	0.09	0.07	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	DZSS Males	MZ Males	-1.74	-3.16	-0.31	0.02	0.44
8	RC	Finger*Twin_type	Thumb	Thumb	MZ Females	MZ Males	-0.48	-1.82	0.87	0.49	0.44
9	RC	Hand*Twin_type	Left	Left	DZOS Females	DZOS Males	-0.28	-1.13	0.57	0.52	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Females	DZSS Females	-0.01	-1.26	1.25	0.99	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Females	DZSS Males	0.19	-1.07	1.44	0.77	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Females	MZ Females	-0.63	-1.82	0.56	0.30	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Females	MZ Males	0.16	-1.09	1.42	0.80	0.90
9	RC	Hand*Twin_type	Left	Right	DZOS Females	DZOS Females	-0.25	-1.49	1.00	0.70	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Males	DZSS Females	0.27	-0.98	1.53	0.67	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Males	DZSS Males	0.47	-0.79	1.72	0.47	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Males	MZ Females	-0.35	-1.54	0.84	0.57	0.90
9	RC	Hand*Twin_type	Left	Left	DZOS Males	MZ Males	0.44	-0.81	1.70	0.49	0.90
9	RC	Hand*Twin_type	Left	Right	DZOS Males	DZOS Males	-0.44	-1.69	0.81	0.49	0.90
9	RC	Hand*Twin_type	Left	Left	DZSS Females	DZSS Males	0.19	-1.07	1.46	0.76	0.90
9	RC	Hand*Twin_type	Left	Left	DZSS Females	MZ Females	-0.62	-1.82	0.58	0.31	0.90
9	RC	Hand*Twin_type	Left	Left	DZSS Females	MZ Males	0.17	-1.09	1.44	0.79	0.90
9	RC	Hand*Twin_type	Left	Right	DZSS Females	DZSS Females	0.05	-1.22	1.31	0.94	0.90
9	RC	Hand*Twin_type	Left	Left	DZSS Males	MZ Females	-0.81	-2.01	0.38	0.18	0.90
9	RC	Hand*Twin_type	Left	Left	DZSS Males	MZ Males	-0.02	-1.29	1.24	0.97	0.90
9	RC	Hand*Twin_type	Left	Right	DZSS Males	DZSS Males	-0.72	-1.98	0.55	0.27	0.90
9	RC	Hand*Twin_type	Left	Left	MZ Females	MZ Males	0.79	-0.41	1.99	0.20	0.90

Continuation of Table 6-23

9	RC	Hand*Twin_type	Left	Right	MZ Females	MZ Females	-0.24	-1.37	0.88	0.67	0.90
9	RC	Hand*Twin_type	Left	Right	MZ Males	MZ Males	-0.93	-2.19	0.34	0.15	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Females	DZOS Males	-0.47	-1.33	0.38	0.28	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Females	DZSS Females	0.28	-0.97	1.54	0.66	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Females	DZSS Males	-0.29	-1.54	0.97	0.65	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Females	MZ Females	-0.62	-1.81	0.56	0.30	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Females	MZ Males	-0.52	-1.78	0.73	0.42	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Males	DZSS Females	0.76	-0.50	2.01	0.24	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Males	DZSS Males	0.19	-1.07	1.44	0.77	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Males	MZ Females	-0.15	-1.34	1.04	0.80	0.90
9	RC	Hand*Twin_type	Right	Right	DZOS Males	MZ Males	-0.05	-1.30	1.21	0.94	0.90
9	RC	Hand*Twin_type	Right	Right	DZSS Females	DZSS Males	-0.57	-1.84	0.69	0.38	0.90
9	RC	Hand*Twin_type	Right	Right	DZSS Females	MZ Females	-0.91	-2.11	0.29	0.14	0.90
9	RC	Hand*Twin_type	Right	Right	DZSS Females	MZ Males	-0.81	-2.07	0.46	0.21	0.90
9	RC	Hand*Twin_type	Right	Right	DZSS Males	MZ Females	-0.34	-1.54	0.86	0.58	0.90
9	RC	Hand*Twin_type	Right	Right	DZSS Males	MZ Males	-0.24	-1.50	1.03	0.72	0.90
9	RC	Hand*Twin_type	Right	Right	MZ Females	MZ Males	0.10	-1.09	1.30	0.87	0.90
10	RC	Sex*Twin_type	Female	Female	DZOS Females	DZSS Females	0.14	-0.75	1.02	0.76	.
10	RC	Sex*Twin_type	Female	Female	DZOS Females	MZ Females	-0.63	-1.46	0.21	0.14	.
10	RC	Sex*Twin_type	Female	Female	DZSS Females	MZ Females	-0.76	-1.61	0.08	0.08	.
10	RC	Sex*Twin_type	Male	Male	DZOS Males	DZSS Males	0.33	-0.56	1.21	0.47	.
10	RC	Sex*Twin_type	Male	Male	DZOS Males	MZ Males	0.20	-0.69	1.08	0.66	.
10	RC	Sex*Twin_type	Male	Male	DZSS Males	MZ Males	-0.13	-1.02	0.76	0.78	.
11	RC	Hand*Finger	Left	Left	Index	Little	-1.56	-2.25	-0.86	<.0001	<.0001
11	RC	Hand*Finger	Left	Left	Index	Middle	-1.82	-2.52	-1.13	<.0001	<.0001
11	RC	Hand*Finger	Left	Left	Index	Ring	-1.57	-2.26	-0.87	<.0001	<.0001
11	RC	Hand*Finger	Left	Left	Index	Thumb	3.11	2.41	3.80	<.0001	<.0001
11	RC	Hand*Finger	Left	Right	Index	Index	-0.40	-1.21	0.42	0.34	<.0001
11	RC	Hand*Finger	Left	Left	Little	Middle	-0.27	-0.96	0.43	0.46	<.0001
11	RC	Hand*Finger	Left	Left	Little	Ring	-0.01	-0.71	0.69	0.98	<.0001
11	RC	Hand*Finger	Left	Left	Little	Thumb	4.67	3.97	5.36	<.0001	<.0001
11	RC	Hand*Finger	Left	Right	Little	Little	-0.15	-0.97	0.67	0.72	<.0001
11	RC	Hand*Finger	Left	Left	Middle	Ring	0.26	-0.44	0.95	0.47	<.0001
11	RC	Hand*Finger	Left	Left	Middle	Thumb	4.93	4.23	5.63	<.0001	<.0001
11	RC	Hand*Finger	Left	Right	Middle	Middle	-0.50	-1.32	0.32	0.23	<.0001
11	RC	Hand*Finger	Left	Left	Ring	Thumb	4.67	3.98	5.37	<.0001	<.0001
11	RC	Hand*Finger	Left	Right	Ring	Ring	0.66	-0.15	1.48	0.11	<.0001

Continuation of Table 6-23

11	RC	Hand*Finger	Left	Right	Thumb	Thumb	-1.74	-2.55	-0.92	<.0001	<.0001
11	RC	Hand*Finger	Right	Right	Index	Little	-1.31	-2.01	-0.62	0.00	<.0001
11	RC	Hand*Finger	Right	Right	Index	Middle	-1.93	-2.62	-1.23	<.0001	<.0001
11	RC	Hand*Finger	Right	Right	Index	Ring	-0.51	-1.20	0.19	0.15	<.0001
11	RC	Hand*Finger	Right	Right	Index	Thumb	1.77	1.07	2.46	<.0001	<.0001
11	RC	Hand*Finger	Right	Right	Little	Middle	-0.61	-1.31	0.08	0.08	<.0001
11	RC	Hand*Finger	Right	Right	Little	Ring	0.80	0.11	1.50	0.02	<.0001
11	RC	Hand*Finger	Right	Right	Little	Thumb	3.08	2.38	3.78	<.0001	<.0001
11	RC	Hand*Finger	Right	Right	Middle	Ring	1.42	0.72	2.11	<.0001	<.0001
11	RC	Hand*Finger	Right	Right	Middle	Thumb	3.69	3.00	4.39	<.0001	<.0001
11	RC	Hand*Finger	Right	Right	Ring	Thumb	2.27	1.58	2.97	<.0001	<.0001

To investigate the associations between outcome WLC and various predictors, ordinal logistic generalized estimating equations (GEE) models were performed, adjusting for clustering on hand nested within subject (Table 6-24), and also with interaction of predictor and sex (Table 6-25). Highlighted in yellow are the statistically significant models at $p < 0.05$. For Model 13, there is a statistically significant association between WLC and twin type (global p-value=0.0074). DZSS females have odds of a high WLC value 1.90 times that of DZSS males.

For Model 16, there are significant differences in fingers when it comes to WLC. The little finger has mean WLC 0.79 units more than the ring finger, 0.69 units more than the middle finger, and 0.73 units more than the thumb, all at 95% confidence interval.

For Model 18, there is a statistically significant interaction between finger and sex for outcome WLC (interaction p-value=0.0018). The little finger of females has odds of a a high WLC value 0.61 times than males

For Model 19, there is a statistically significant interaction between finger and twin type for outcome WLC (interaction P value=0.05). The little finger of MZ females has odds of a high WLC value 0.34 times that of MZ males, the ring finger of DZSS females has odds of a high WLC value 3.31 times that of DZSS males

Table 6-24. Ordinal Logistic GEE models.

Model	Outcome	Predictor	Comparison value	Reference value	Odds Ratio	Lower 95%	Upper 95%	p- value	Global p
12	WLC	TTT	DZOS Females	MZ and DZSS Females	1.33	0.89	1.97	0.16	0.16
13	WLC	Twin_type	DZOS Females	DZOS Males	0.85	0.56	1.29	0.44	0.01
13	WLC	Twin_type	DZOS Females	DZSS Females	0.97	0.61	1.56	0.92	0.01
13	WLC	Twin_type	DZOS Females	DZSS Males	1.86	1.10	3.14	0.02	0.01
13	WLC	Twin_type	DZOS Females	MZ Females	1.75	1.09	2.81	0.02	0.01
13	WLC	Twin_type	DZOS Females	MZ Males	1.16	0.70	1.90	0.56	0.01
13	WLC	Twin_type	DZOS Males	DZSS Females	1.15	0.71	1.85	0.56	0.01
13	WLC	Twin_type	DZOS Males	DZSS Males	2.19	1.29	3.73	0.00	0.01
13	WLC	Twin_type	DZOS Males	MZ Females	2.06	1.27	3.34	0.00	0.01
13	WLC	Twin_type	DZOS Males	MZ Males	1.37	0.83	2.26	0.22	0.01
13	WLC	Twin_type	DZSS Females	DZSS Males	1.90	1.17	3.10	0.01	0.01
13	WLC	Twin_type	DZSS Females	MZ Females	1.79	1.16	2.76	0.01	0.01
13	WLC	Twin_type	DZSS Females	MZ Males	1.19	0.75	1.87	0.46	0.01
13	WLC	Twin_type	DZSS Males	MZ Females	0.94	0.58	1.54	0.81	0.01
13	WLC	Twin_type	DZSS Males	MZ Males	0.62	0.37	1.04	0.07	0.01
13	WLC	Twin_type	MZ Females	MZ Males	0.66	0.42	1.05	0.08	0.01
14	WLC	Gender	Female	Male	0.99	0.76	1.28	0.92	0.92
15	WLC	Hand	Left	Right	1.04	0.77	1.40	0.82	0.82
16	WLC	Finger	Index	Little	1.15	0.93	1.41	0.20	0.00
16	WLC	Finger	Index	Middle	0.79	0.66	0.96	0.02	0.00
16	WLC	Finger	Index	Ring	0.91	0.74	1.12	0.36	0.00
16	WLC	Finger	Index	Thumb	0.84	0.68	1.04	0.11	0.00
16	WLC	Finger	Little	Middle	0.69	0.57	0.84	0.00	0.00
16	WLC	Finger	Little	Ring	0.79	0.65	0.97	0.02	0.00
16	WLC	Finger	Little	Thumb	0.73	0.59	0.91	0.00	0.00
16	WLC	Finger	Middle	Ring	1.15	0.95	1.39	0.16	0.00
16	WLC	Finger	Middle	Thumb	1.06	0.88	1.27	0.53	0.00
16	WLC	Finger	Ring	Thumb	0.93	0.76	1.13	0.45	0.00

Table 6-25. Ordinal Logistic GEE models with interactions.

Model	Outcome	Interaction	Comparison 1	Reference 1	Comparison 2	Reference 2	Odd Ratio	Lower 95%	Upper 95%	p- value	Global p
17	WLC	Hand*Sex	Left	Left	Female	Male	0.98	0.67	1.43	0.92	0.96
17	WLC	Hand*Sex	Left	Right	Female	Female	1.03	0.71	1.50	0.88	0.96
17	WLC	Hand*Sex	Left	Right	Female	Male	1.02	0.69	1.51	0.91	0.96
17	WLC	Hand*Sex	Left	Right	Male	Female	1.05	0.70	1.58	0.82	0.96
17	WLC	Hand*Sex	Left	Right	Male	Male	1.04	0.68	1.59	0.85	0.96
17	WLC	Hand*Sex	Right	Right	Female	Male	0.99	0.69	1.42	0.97	0.96
18	WLC	Finger*Sex	Index	Index	Female	Male	1.20	0.84	1.72	0.32	0.00
18	WLC	Finger*Sex	Index	Little	Female	Female	1.61	1.19	2.18	0.00	0.00
18	WLC	Finger*Sex	Index	Little	Female	Male	0.98	0.68	1.41	0.91	0.00
18	WLC	Finger*Sex	Index	Middle	Female	Female	0.86	0.65	1.13	0.27	0.00
18	WLC	Finger*Sex	Index	Middle	Female	Male	0.87	0.61	1.23	0.43	0.00
18	WLC	Finger*Sex	Index	Ring	Female	Female	0.89	0.67	1.18	0.41	0.00
18	WLC	Finger*Sex	Index	Ring	Female	Male	1.13	0.77	1.66	0.52	0.00
18	WLC	Finger*Sex	Index	Thumb	Female	Female	0.93	0.70	1.24	0.63	0.00
18	WLC	Finger*Sex	Index	Thumb	Female	Male	0.90	0.63	1.29	0.55	0.00
18	WLC	Finger*Sex	Index	Little	Male	Female	1.34	0.92	1.95	0.13	0.00
18	WLC	Finger*Sex	Index	Little	Male	Male	0.81	0.62	1.08	0.15	0.00
18	WLC	Finger*Sex	Index	Middle	Male	Female	0.72	0.50	1.03	0.07	0.00
18	WLC	Finger*Sex	Index	Middle	Male	Male	0.72	0.57	0.92	0.01	0.00
18	WLC	Finger*Sex	Index	Ring	Male	Female	0.74	0.52	1.06	0.10	0.00
18	WLC	Finger*Sex	Index	Ring	Male	Male	0.94	0.71	1.25	0.69	0.00
18	WLC	Finger*Sex	Index	Thumb	Male	Female	0.78	0.54	1.11	0.16	0.00
18	WLC	Finger*Sex	Index	Thumb	Male	Male	0.75	0.56	1.01	0.05	0.00
18	WLC	Finger*Sex	Little	Little	Female	Male	0.61	0.42	0.88	0.01	0.00
18	WLC	Finger*Sex	Little	Middle	Female	Female	0.53	0.39	0.73	<.0001	0.00
18	WLC	Finger*Sex	Little	Middle	Female	Male	0.54	0.37	0.78	0.00	0.00
18	WLC	Finger*Sex	Little	Ring	Female	Female	0.55	0.41	0.73	<.0001	0.00
18	WLC	Finger*Sex	Little	Ring	Female	Male	0.70	0.47	1.05	0.09	0.00
18	WLC	Finger*Sex	Little	Thumb	Female	Female	0.58	0.43	0.79	0.00	0.00
18	WLC	Finger*Sex	Little	Thumb	Female	Male	0.56	0.38	0.82	0.00	0.00
18	WLC	Finger*Sex	Little	Middle	Male	Female	0.88	0.62	1.24	0.46	0.00
18	WLC	Finger*Sex	Little	Middle	Male	Male	0.89	0.68	1.15	0.36	0.00
18	WLC	Finger*Sex	Little	Ring	Male	Female	0.91	0.64	1.29	0.58	0.00
18	WLC	Finger*Sex	Little	Ring	Male	Male	1.16	0.89	1.51	0.28	0.00
18	WLC	Finger*Sex	Little	Thumb	Male	Female	0.95	0.67	1.35	0.79	0.00

Continuation of Table 6-25

18	WLC	Finger*Sex	Little	Thumb	Male	Male	0.92	0.69	1.22	0.55	0.00
18	WLC	Finger*Sex	Middle	Middle	Female	Male	1.01	0.71	1.43	0.96	0.00
18	WLC	Finger*Sex	Middle	Ring	Female	Female	1.03	0.78	1.36	0.82	0.00
18	WLC	Finger*Sex	Middle	Ring	Female	Male	1.32	0.90	1.93	0.15	0.00
18	WLC	Finger*Sex	Middle	Thumb	Female	Female	1.09	0.86	1.38	0.50	0.00
18	WLC	Finger*Sex	Middle	Thumb	Female	Male	1.04	0.73	1.49	0.81	0.00
18	WLC	Finger*Sex	Middle	Ring	Male	Female	1.02	0.73	1.43	0.89	0.00
18	WLC	Finger*Sex	Middle	Ring	Male	Male	1.31	1.02	1.68	0.04	0.00
18	WLC	Finger*Sex	Middle	Thumb	Male	Female	1.08	0.77	1.51	0.67	0.00
18	WLC	Finger*Sex	Middle	Thumb	Male	Male	1.04	0.79	1.35	0.80	0.00
18	WLC	Finger*Sex	Ring	Ring	Female	Male	1.28	0.88	1.85	0.19	0.00
18	WLC	Finger*Sex	Ring	Thumb	Female	Female	1.05	0.81	1.37	0.71	0.00
18	WLC	Finger*Sex	Ring	Thumb	Female	Male	1.01	0.71	1.43	0.95	0.00
18	WLC	Finger*Sex	Ring	Thumb	Male	Female	0.82	0.57	1.20	0.31	0.00
18	WLC	Finger*Sex	Ring	Thumb	Male	Male	0.79	0.59	1.06	0.12	0.00
18	WLC	Finger*Sex	Thumb	Thumb	Female	Male	0.96	0.68	1.36	0.83	0.00
19	WLC	Finger*Twin_type	Index	Index	DZOS Females	DZOS Males	1.14	0.65	2.00	0.64	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Females	DZSS Females	1.18	0.62	2.28	0.61	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Females	DZSS Males	2.98	1.42	6.27	0.00	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Females	MZ Females	1.57	0.85	2.92	0.15	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Females	MZ Males	1.16	0.61	2.21	0.64	0.05
19	WLC	Finger*Twin_type	Index	Little	DZOS Females	DZOS Females	1.52	0.92	2.51	0.11	0.05
19	WLC	Finger*Twin_type	Index	Middle	DZOS Females	DZOS Females	0.82	0.53	1.26	0.37	0.05
19	WLC	Finger*Twin_type	Index	Ring	DZOS Females	DZOS Females	0.91	0.57	1.47	0.70	0.05
19	WLC	Finger*Twin_type	Index	Thumb	DZOS Females	DZOS Females	1.15	0.73	1.81	0.55	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Males	DZSS Females	1.04	0.54	2.00	0.91	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Males	DZSS Males	2.61	1.23	5.52	0.01	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Males	MZ Females	1.37	0.74	2.57	0.32	0.05
19	WLC	Finger*Twin_type	Index	Index	DZOS Males	MZ Males	1.02	0.53	1.94	0.96	0.05
19	WLC	Finger*Twin_type	Index	Little	DZOS Males	DZOS Males	0.83	0.52	1.32	0.42	0.05
19	WLC	Finger*Twin_type	Index	Middle	DZOS Males	DZOS Males	0.63	0.44	0.89	0.01	0.05
19	WLC	Finger*Twin_type	Index	Ring	DZOS Males	DZOS Males	0.65	0.43	0.99	0.04	0.05
19	WLC	Finger*Twin_type	Index	Thumb	DZOS Males	DZOS Males	0.83	0.54	1.30	0.42	0.05
19	WLC	Finger*Twin_type	Index	Index	DZSS Females	DZSS Males	2.51	1.18	5.34	0.02	0.05
19	WLC	Finger*Twin_type	Index	Index	DZSS Females	MZ Females	1.33	0.71	2.49	0.38	0.05
19	WLC	Finger*Twin_type	Index	Index	DZSS Females	MZ Males	0.98	0.51	1.88	0.96	0.05
19	WLC	Finger*Twin_type	Index	Little	DZSS Females	DZSS Females	1.21	0.72	2.03	0.47	0.05

19	WLC	Finger*Twin_type	Index	Middle	DZSS Females	DZSS Females	0.81	0.49	1.34	0.42	0.05
19	WLC	Finger*Twin_type	Index	Ring	DZSS Females	DZSS Females	0.67	0.38	1.18	0.16	0.05
19	WLC	Finger*Twin_type	Index	Thumb	DZSS Females	DZSS Females	0.76	0.46	1.24	0.27	0.05
19	WLC	Finger*Twin_type	Index	Index	DZSS Males	MZ Females	0.53	0.26	1.09	0.08	0.05
19	WLC	Finger*Twin_type	Index	Index	DZSS Males	MZ Males	0.39	0.19	0.82	0.01	0.05
19	WLC	Finger*Twin_type	Index	Little	DZSS Males	DZSS Males	0.50	0.27	0.93	0.03	0.05
19	WLC	Finger*Twin_type	Index	Middle	DZSS Males	DZSS Males	0.61	0.36	1.04	0.07	0.05
19	WLC	Finger*Twin_type	Index	Ring	DZSS Males	DZSS Males	0.89	0.46	1.70	0.72	0.05
19	WLC	Finger*Twin_type	Index	Thumb	DZSS Males	DZSS Males	0.51	0.26	1.01	0.05	0.05
19	WLC	Finger*Twin_type	Index	Index	MZ Females	MZ Males	0.74	0.40	1.37	0.34	0.05
19	WLC	Finger*Twin_type	Index	Little	MZ Females	MZ Females	2.50	1.37	4.58	0.00	0.05
19	WLC	Finger*Twin_type	Index	Middle	MZ Females	MZ Females	0.92	0.56	1.52	0.76	0.05
19	WLC	Finger*Twin_type	Index	Ring	MZ Females	MZ Females	1.15	0.71	1.85	0.57	0.05
19	WLC	Finger*Twin_type	Index	Thumb	MZ Females	MZ Females	0.98	0.57	1.68	0.93	0.05
19	WLC	Finger*Twin_type	Index	Little	MZ Males	MZ Males	1.14	0.75	1.74	0.54	0.05
19	WLC	Finger*Twin_type	Index	Middle	MZ Males	MZ Males	0.90	0.58	1.38	0.62	0.05
19	WLC	Finger*Twin_type	Index	Ring	MZ Males	MZ Males	1.44	0.89	2.34	0.14	0.05
19	WLC	Finger*Twin_type	Index	Thumb	MZ Males	MZ Males	0.86	0.52	1.40	0.54	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Females	DZOS Males	0.62	0.35	1.11	0.11	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Females	DZSS Females	0.95	0.48	1.87	0.87	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Females	DZSS Males	0.97	0.49	1.94	0.94	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Females	MZ Females	2.59	1.21	5.52	0.01	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Females	MZ Males	0.88	0.44	1.73	0.70	0.05
19	WLC	Finger*Twin_type	Little	Middle	DZOS Females	DZOS Females	0.54	0.34	0.87	0.01	0.05
19	WLC	Finger*Twin_type	Little	Ring	DZOS Females	DZOS Females	0.60	0.37	0.97	0.04	0.05
19	WLC	Finger*Twin_type	Little	Thumb	DZOS Females	DZOS Females	0.76	0.46	1.24	0.27	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Males	DZSS Females	1.52	0.79	2.90	0.21	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Males	DZSS Males	1.56	0.81	3.02	0.18	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Males	MZ Females	4.15	2.00	8.61	0.00	0.05
19	WLC	Finger*Twin_type	Little	Little	DZOS Males	MZ Males	1.41	0.73	2.69	0.30	0.05
19	WLC	Finger*Twin_type	Little	Middle	DZOS Males	DZOS Males	0.76	0.53	1.08	0.13	0.05
19	WLC	Finger*Twin_type	Little	Ring	DZOS Males	DZOS Males	0.78	0.53	1.16	0.22	0.05
19	WLC	Finger*Twin_type	Little	Thumb	DZOS Males	DZOS Males	1.01	0.65	1.57	0.97	0.05
19	WLC	Finger*Twin_type	Little	Little	DZSS Females	DZSS Males	1.03	0.53	2.00	0.93	0.05
19	WLC	Finger*Twin_type	Little	Little	DZSS Females	MZ Females	2.74	1.31	5.72	0.01	0.05
19	WLC	Finger*Twin_type	Little	Little	DZSS Females	MZ Males	0.93	0.48	1.79	0.82	0.05
19	WLC	Finger*Twin_type	Little	Middle	DZSS Females	DZSS Females	0.67	0.38	1.19	0.17	0.05

Continuation of Table 6-25

19	WLC	Finger*Twin_type	Little	Ring	DZSS Females	DZSS Females	0.56	0.36	0.86	0.01	0.05
19	WLC	Finger*Twin_type	Little	Thumb	DZSS Females	DZSS Females	0.62	0.38	1.02	0.06	0.05
19	WLC	Finger*Twin_type	Little	Little	DZSS Males	MZ Females	2.65	1.26	5.59	0.01	0.05
19	WLC	Finger*Twin_type	Little	Little	DZSS Males	MZ Males	0.90	0.46	1.75	0.75	0.05
19	WLC	Finger*Twin_type	Little	Middle	DZSS Males	DZSS Males	1.23	0.73	2.06	0.44	0.05
19	WLC	Finger*Twin_type	Little	Ring	DZSS Males	DZSS Males	1.79	0.99	3.23	0.06	0.05
19	WLC	Finger*Twin_type	Little	Thumb	DZSS Males	DZSS Males	1.03	0.63	1.69	0.90	0.05
19	WLC	Finger*Twin_type	Little	Little	MZ Females	MZ Males	0.34	0.16	0.71	0.00	0.05
19	WLC	Finger*Twin_type	Little	Middle	MZ Females	MZ Females	0.37	0.20	0.67	0.00	0.05
19	WLC	Finger*Twin_type	Little	Ring	MZ Females	MZ Females	0.46	0.24	0.87	0.02	0.05
19	WLC	Finger*Twin_type	Little	Thumb	MZ Females	MZ Females	0.39	0.21	0.74	0.00	0.05
19	WLC	Finger*Twin_type	Little	Middle	MZ Males	MZ Males	0.79	0.48	1.29	0.34	0.05
19	WLC	Finger*Twin_type	Little	Ring	MZ Males	MZ Males	1.26	0.81	1.97	0.31	0.05
19	WLC	Finger*Twin_type	Little	Thumb	MZ Males	MZ Males	0.75	0.44	1.29	0.30	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Females	DZOS Males	0.87	0.49	1.53	0.63	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Females	DZSS Females	1.17	0.62	2.22	0.62	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Females	DZSS Males	2.21	1.13	4.32	0.02	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Females	MZ Females	1.77	0.97	3.24	0.06	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Females	MZ Males	1.27	0.69	2.37	0.44	0.05
19	WLC	Finger*Twin_type	Middle	Ring	DZOS Females	DZOS Females	1.11	0.69	1.79	0.66	0.05
19	WLC	Finger*Twin_type	Middle	Thumb	DZOS Females	DZOS Females	1.40	0.94	2.09	0.10	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Males	DZSS Females	1.35	0.71	2.55	0.36	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Males	DZSS Males	2.54	1.30	4.96	0.01	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Males	MZ Females	2.03	1.11	3.71	0.02	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZOS Males	MZ Males	1.46	0.79	2.71	0.23	0.05
19	WLC	Finger*Twin_type	Middle	Ring	DZOS Males	DZOS Males	1.04	0.70	1.54	0.85	0.05
19	WLC	Finger*Twin_type	Middle	Thumb	DZOS Males	DZOS Males	1.33	0.86	2.07	0.20	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZSS Females	DZSS Males	1.88	0.95	3.72	0.07	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZSS Females	MZ Females	1.51	0.82	2.79	0.19	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZSS Females	MZ Males	1.09	0.58	2.04	0.80	0.05
19	WLC	Finger*Twin_type	Middle	Ring	DZSS Females	DZSS Females	0.83	0.48	1.43	0.50	0.05
19	WLC	Finger*Twin_type	Middle	Thumb	DZSS Females	DZSS Females	0.93	0.58	1.49	0.76	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZSS Males	MZ Females	0.80	0.42	1.53	0.50	0.05
19	WLC	Finger*Twin_type	Middle	Middle	DZSS Males	MZ Males	0.58	0.30	1.12	0.10	0.05
19	WLC	Finger*Twin_type	Middle	Ring	DZSS Males	DZSS Males	1.46	0.85	2.49	0.17	0.05
19	WLC	Finger*Twin_type	Middle	Thumb	DZSS Males	DZSS Males	0.84	0.50	1.43	0.52	0.05
19	WLC	Finger*Twin_type	Middle	Middle	MZ Females	MZ Males	0.72	0.40	1.31	0.28	0.05

Continuation of Table 6-25

19	WLC	Finger*Twin_type	Middle	Ring	MZ Females	MZ Females	1.24	0.82	1.89	0.31	0.05
19	WLC	Finger*Twin_type	Middle	Thumb	MZ Females	MZ Females	1.06	0.73	1.53	0.77	0.05
19	WLC	Finger*Twin_type	Middle	Ring	MZ Males	MZ Males	1.60	1.05	2.45	0.03	0.05
19	WLC	Finger*Twin_type	Middle	Thumb	MZ Males	MZ Males	0.95	0.60	1.52	0.84	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Females	DZOS Males	0.81	0.45	1.48	0.50	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Females	DZSS Females	0.87	0.47	1.61	0.67	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Females	DZSS Males	2.90	1.35	6.20	0.01	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Females	MZ Females	1.98	1.04	3.75	0.04	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Females	MZ Males	1.84	0.94	3.60	0.08	0.05
19	WLC	Finger*Twin_type	Ring	Thumb	DZOS Females	DZOS Females	1.26	0.82	1.93	0.30	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Males	DZSS Females	1.07	0.58	1.99	0.82	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Males	DZSS Males	3.56	1.65	7.68	0.00	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Males	MZ Females	2.43	1.28	4.64	0.01	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZOS Males	MZ Males	2.26	1.15	4.45	0.02	0.05
19	WLC	Finger*Twin_type	Ring	Thumb	DZOS Males	DZOS Males	1.29	0.80	2.06	0.30	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZSS Females	DZSS Males	3.31	1.61	6.83	0.00	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZSS Females	MZ Females	2.26	1.25	4.09	0.01	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZSS Females	MZ Males	2.10	1.12	3.94	0.02	0.05
19	WLC	Finger*Twin_type	Ring	Thumb	DZSS Females	DZSS Females	1.12	0.71	1.77	0.62	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZSS Males	MZ Females	0.68	0.33	1.44	0.32	0.05
19	WLC	Finger*Twin_type	Ring	Ring	DZSS Males	MZ Males	0.63	0.29	1.37	0.25	0.05
19	WLC	Finger*Twin_type	Ring	Thumb	DZSS Males	DZSS Males	0.58	0.31	1.07	0.08	0.05
19	WLC	Finger*Twin_type	Ring	Ring	MZ Females	MZ Males	0.93	0.48	1.79	0.83	0.05
19	WLC	Finger*Twin_type	Ring	Thumb	MZ Females	MZ Females	0.85	0.52	1.39	0.51	0.05
19	WLC	Finger*Twin_type	Ring	Thumb	MZ Males	MZ Males	0.59	0.36	0.98	0.04	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Females	DZOS Males	0.83	0.51	1.36	0.46	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Females	DZSS Females	0.78	0.41	1.48	0.45	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Females	DZSS Males	1.33	0.67	2.64	0.41	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Females	MZ Females	1.34	0.69	2.58	0.38	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Females	MZ Males	0.87	0.45	1.67	0.67	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Males	DZSS Females	0.94	0.51	1.74	0.84	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Males	DZSS Males	1.60	0.82	3.13	0.17	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Males	MZ Females	1.61	0.85	3.05	0.15	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZOS Males	MZ Males	1.05	0.55	1.98	0.89	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZSS Females	DZSS Males	1.71	0.89	3.26	0.11	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZSS Females	MZ Females	1.71	0.92	3.18	0.09	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZSS Females	MZ Males	1.11	0.60	2.06	0.73	0.05

Continuation of Table 6-25

19	WLC	Finger*Twin_type	Thumb	Thumb	DZSS Males	MZ Females	1.00	0.51	1.96	0.99	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	DZSS Males	MZ Males	0.65	0.34	1.27	0.21	0.05
19	WLC	Finger*Twin_type	Thumb	Thumb	MZ Females	MZ Males	0.65	0.34	1.23	0.19	0.05
20	WLC	Hand*Twin_type	Left	Left	DZOS Females	DZOS Males	0.71	0.40	1.24	0.22	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Females	DZSS Females	0.90	0.45	1.81	0.77	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Females	DZSS Males	2.01	0.90	4.47	0.09	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Females	MZ Females	1.49	0.75	2.96	0.25	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Females	MZ Males	1.05	0.50	2.20	0.90	0.90
20	WLC	Hand*Twin_type	Left	Right	DZOS Females	DZOS Females	0.88	0.43	1.82	0.73	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Males	DZSS Females	1.28	0.65	2.53	0.48	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Males	DZSS Males	2.85	1.29	6.29	0.01	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Males	MZ Females	2.12	1.08	4.14	0.03	0.90
20	WLC	Hand*Twin_type	Left	Left	DZOS Males	MZ Males	1.48	0.72	3.08	0.29	0.90
20	WLC	Hand*Twin_type	Left	Right	DZOS Males	DZOS Males	1.27	0.61	2.67	0.52	0.90
20	WLC	Hand*Twin_type	Left	Left	DZSS Females	DZSS Males	2.23	1.06	4.70	0.03	0.90
20	WLC	Hand*Twin_type	Left	Left	DZSS Females	MZ Females	1.66	0.89	3.08	0.11	0.90
20	WLC	Hand*Twin_type	Left	Left	DZSS Females	MZ Males	1.16	0.59	2.29	0.67	0.90
20	WLC	Hand*Twin_type	Left	Right	DZSS Females	DZSS Females	1.03	0.56	1.87	0.93	0.90
20	WLC	Hand*Twin_type	Left	Left	DZSS Males	MZ Females	0.74	0.36	1.55	0.43	0.90
20	WLC	Hand*Twin_type	Left	Left	DZSS Males	MZ Males	0.52	0.24	1.15	0.10	0.90
20	WLC	Hand*Twin_type	Left	Right	DZSS Males	DZSS Males	0.76	0.35	1.63	0.48	0.90
20	WLC	Hand*Twin_type	Left	Left	MZ Females	MZ Males	0.70	0.36	1.37	0.30	0.90
20	WLC	Hand*Twin_type	Left	Right	MZ Females	MZ Females	1.21	0.65	2.25	0.55	0.90
20	WLC	Hand*Twin_type	Left	Right	MZ Males	MZ Males	1.07	0.54	2.12	0.84	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Females	DZOS Males	1.02	0.55	1.90	0.94	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Females	DZSS Females	1.05	0.56	1.99	0.87	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Females	DZSS Males	1.73	0.87	3.45	0.12	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Females	MZ Females	2.05	1.05	3.98	0.03	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Females	MZ Males	1.28	0.66	2.48	0.47	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Males	DZSS Females	1.03	0.53	2.00	0.93	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Males	DZSS Males	1.69	0.83	3.46	0.15	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Males	MZ Females	2.00	1.00	4.01	0.05	0.90
20	WLC	Hand*Twin_type	Right	Right	DZOS Males	MZ Males	1.25	0.63	2.49	0.53	0.90
20	WLC	Hand*Twin_type	Right	Right	DZSS Females	DZSS Males	1.65	0.88	3.09	0.12	0.90
20	WLC	Hand*Twin_type	Right	Right	DZSS Females	MZ Females	1.95	1.06	3.56	0.03	0.90
20	WLC	Hand*Twin_type	Right	Right	DZSS Females	MZ Males	1.21	0.67	2.21	0.53	0.90
20	WLC	Hand*Twin_type	Right	Right	DZSS Males	MZ Females	1.18	0.61	2.28	0.62	0.90

Continuation of Table 6-25

20	WLC	Hand*Twin_type	Right	Right	DZSS Males	MZ Males	0.74	0.38	1.42	0.36	0.90
20	WLC	Hand*Twin_type	Right	Right	MZ Females	MZ Males	0.62	0.33	1.17	0.14	0.90
21	WLC	Sex*Twin_type	Female	Female	DZOS Females	DZSS Females	0.97	0.61	1.56	0.92	.
21	WLC	Sex*Twin_type	Female	Female	DZOS Females	MZ Females	1.75	1.09	2.81	0.02	.
21	WLC	Sex*Twin_type	Female	Female	DZSS Females	MZ Females	1.79	1.16	2.76	0.01	.
21	WLC	Sex*Twin_type	Male	Male	DZOS Males	DZSS Males	2.19	1.29	3.73	0.00	.
21	WLC	Sex*Twin_type	Male	Male	DZOS Males	MZ Males	1.37	0.83	2.26	0.22	.
21	WLC	Sex*Twin_type	Male	Male	DZSS Males	MZ Males	0.62	0.37	1.04	0.07	.
22	WLC	Hand*Finger	Left	Left	Index	Little	1.24	0.93	1.67	0.15	0.68
22	WLC	Hand*Finger	Left	Left	Index	Middle	0.76	0.59	0.97	0.03	0.68
22	WLC	Hand*Finger	Left	Left	Index	Ring	0.94	0.71	1.23	0.65	0.68
22	WLC	Hand*Finger	Left	Left	Index	Thumb	0.78	0.58	1.05	0.11	0.68
22	WLC	Hand*Finger	Left	Right	Index	Index	1.03	0.69	1.53	0.89	0.68
22	WLC	Hand*Finger	Left	Left	Little	Middle	0.61	0.47	0.80	0.00	0.68
22	WLC	Hand*Finger	Left	Left	Little	Ring	0.76	0.59	0.96	0.02	0.68
22	WLC	Hand*Finger	Left	Left	Little	Thumb	0.63	0.47	0.85	0.00	0.68
22	WLC	Hand*Finger	Left	Right	Little	Little	0.88	0.58	1.33	0.54	0.68
22	WLC	Hand*Finger	Left	Left	Middle	Ring	1.24	0.95	1.61	0.11	0.68
22	WLC	Hand*Finger	Left	Left	Middle	Thumb	1.03	0.81	1.33	0.79	0.68
22	WLC	Hand*Finger	Left	Right	Middle	Middle	1.12	0.77	1.64	0.55	0.68
22	WLC	Hand*Finger	Left	Left	Ring	Thumb	0.84	0.64	1.10	0.20	0.68
22	WLC	Hand*Finger	Left	Right	Ring	Ring	0.96	0.65	1.43	0.85	0.68
22	WLC	Hand*Finger	Left	Right	Thumb	Thumb	1.18	0.79	1.76	0.42	0.68
22	WLC	Hand*Finger	Right	Right	Index	Little	1.06	0.79	1.43	0.69	0.68
22	WLC	Hand*Finger	Right	Right	Index	Middle	0.83	0.62	1.10	0.19	0.68
22	WLC	Hand*Finger	Right	Right	Index	Ring	0.88	0.65	1.20	0.41	0.68
22	WLC	Hand*Finger	Right	Right	Index	Thumb	0.90	0.66	1.22	0.50	0.68
22	WLC	Hand*Finger	Right	Right	Little	Middle	0.78	0.58	1.04	0.09	0.68
22	WLC	Hand*Finger	Right	Right	Little	Ring	0.83	0.60	1.14	0.25	0.68
22	WLC	Hand*Finger	Right	Right	Little	Thumb	0.85	0.62	1.15	0.29	0.68
22	WLC	Hand*Finger	Right	Right	Middle	Ring	1.06	0.81	1.40	0.67	0.68
22	WLC	Hand*Finger	Right	Right	Middle	Thumb	1.09	0.83	1.42	0.54	0.68
22	WLC	Hand*Finger	Right	Right	Ring	Thumb	1.02	0.76	1.38	0.87	0.68

To investigate the associations between outcome FP and various predictors, multinomial logistic models were performed (clustering was not accounted for due to restrictions on the model) (Table 6-26), with interaction of predictor and gender (Table 6-27), and with interaction term (Table 6-28). Highlighted in yellow are the statistically significant models at $p < 0.05$. For Model 23, there is a statistically significant association between FP and TTT (global P value=0.0033). DZOS Females compared to MZ and DZSS females have 1.45 times the odds of FP=1 versus FP=0, and 1.13 times the odds FP=2, both versus FP=0, at 95% confidence interval.

In Tables 6-27 and 6-28, there was not a statistically significant interaction between any of the interactions for the outcome FP. Therefore post-hoc comparisons have not been presented.

Table 6-26. Multinomial Logistic models.

Model	Outcome	Comparison	Response	Odds Ratio	Lower 95%	Upper 95%	Global p
23	FP	TTT		.	.	.	0.00
23	FP	TTT*DZOS Females vs MZ & DZSS Females	2	1.13	0.80	1.61	.
23	FP	TTT*DZOS Females vs MZ & DZSS Females	1	1.45	1.05	2.02	.
24	FP	Twin_type		.	.	.	<.0001
24	FP	Twin_type DZOS Females vs MZ Males	2	1.72	1.18	2.49	.
24	FP	Twin_type DZOS Females vs MZ Males	1	2.62	1.84	3.71	.
24	FP	Twin_type DZOS Males vs MZ Males	2	4.81	3.01	7.69	.
24	FP	Twin_type DZOS Males vs MZ Males	1	5.18	3.28	8.16	.
24	FP	Twin_type DZSS Females vs MZ Males	2	2.02	1.37	2.97	.
24	FP	Twin_type DZSS Females vs MZ Males	1	2.84	1.97	4.08	.
24	FP	Twin_type DZSS Males vs MZ Males	2	1.33	0.93	1.88	.
24	FP	Twin_type DZSS Males vs MZ Males	1	1.90	1.37	2.63	.
24	FP	Twin_type MZ Females vs MZ Males	2	1.30	0.95	1.76	.
24	FP	Twin_type MZ Females vs MZ Males	1	1.36	1.02	1.81	.
25	FP	Sex		.	.	.	0.12
25	FP	Sex*Female vs Male	2	1.00	0.80	1.24	.
25	FP	Sex*Female vs Male	1	1.11	0.90	1.36	.
26	FP	Hand		.	.	.	<.0001
26	FP	Hand*Left vs Right	2	0.81	0.66	1.01	.
26	FP	Hand*Left vs Right	1	1.06	0.87	1.30	.
27	FP	Finger		.	.	.	<.0001
27	FP	Finger*Index vs Thumb	2	0.13	0.08	0.20	.
27	FP	Finger*Index vs Thumb	1	0.12	0.08	0.19	.
27	FP	Finger*Little vs Thumb	2	0.33	0.19	0.57	.
27	FP	Finger*Little vs Thumb	1	0.84	0.50	1.42	.
27	FP	Finger*Middle vs Thumb	2	0.08	0.05	0.13	.
27	FP	Finger*Middle vs Thumb	1	0.21	0.13	0.32	.
27	FP	Finger*Ring vs Thumb	2	0.73	0.42	1.25	.
27	FP	Finger*Ring vs Thumb	1	0.72	0.42	1.23	.

Table 6-27. Multinomial Logistic GEE models.

Model	Outcome	Comparisons	Odds Ratio	Lower 95%	Upper 95%	Global p
28	FP	FP 1: Sex Female vs Male at Hand=Left	0.99	0.74	1.32	.
28	FP	FP 1: Sex Female vs Male at Hand=Right	1.25	0.93	1.67	.
28	FP	FP 1: Hand Left vs Right at Sex=Female	0.95	0.71	1.27	.
28	FP	FP 1: Hand Left vs Right at Sex=Male	1.20	0.89	1.60	.
28	FP	FP 2: Sex Female vs Male at Hand=Left	1.00	0.74	1.37	.
28	FP	FP 2: Sex Female vs Male at Hand=Right	1.00	0.74	1.36	.
28	FP	FP 2: Hand Left vs Right at Sex=Female	0.81	0.60	1.11	.
28	FP	FP 2: Hand Left vs Right at Sex=Male	0.82	0.60	1.11	.
28	FP	Hand*Sex	.	.	.	0.0949
29	FP	FP 1: Finger Index vs Little at Sex=Female	0.15	0.09	0.25	.
29	FP	FP 1: Finger Index vs Little at Sex=Male	0.15	0.09	0.25	.
29	FP	FP 1: Finger Index vs Middle at Sex=Female	0.64	0.45	0.91	.
29	FP	FP 1: Finger Index vs Middle at Sex=Male	0.56	0.40	0.79	.
29	FP	FP 1: Finger Index vs Ring at Sex=Female	0.23	0.14	0.37	.
29	FP	FP 1: Finger Index vs Ring at Sex=Male	0.12	0.07	0.22	.
29	FP	FP 1: Finger Index vs Thumb at Sex=Female	0.13	0.07	0.24	.
29	FP	FP 1: Finger Index vs Thumb at Sex=Male	0.12	0.06	0.22	.
29	FP	FP 1: Finger Little vs Middle at Sex=Female	4.30	2.52	7.32	.
29	FP	FP 1: Finger Little vs Middle at Sex=Male	3.86	2.26	6.61	.
29	FP	FP 1: Finger Little vs Ring at Sex=Female	1.52	0.80	2.88	.
29	FP	FP 1: Finger Little vs Ring at Sex=Male	0.83	0.40	1.75	.
29	FP	FP 1: Finger Little vs Thumb at Sex=Female	0.87	0.42	1.83	.
29	FP	FP 1: Finger Little vs Thumb at Sex=Male	0.81	0.38	1.69	.
29	FP	FP 1: Finger Middle vs Ring at Sex=Female	0.35	0.21	0.59	.
29	FP	FP 1: Finger Middle vs Ring at Sex=Male	0.22	0.11	0.40	.
29	FP	FP 1: Finger Middle vs Thumb at Sex=Female	0.20	0.11	0.38	.
29	FP	FP 1: Finger Middle vs Thumb at Sex=Male	0.21	0.11	0.39	.
29	FP	FP 1: Finger Ring vs Thumb at Sex=Female	0.58	0.28	1.18	.
29	FP	FP 1: Finger Ring vs Thumb at Sex=Male	0.97	0.43	2.18	.
29	FP	FP 1: Sex Female vs Male at Finger=Index	1.22	0.87	1.70	.
29	FP	FP 1: Sex Female vs Male at Finger=Little	1.19	0.61	2.30	.
29	FP	FP 1: Sex Female vs Male at Finger=Middle	1.07	0.74	1.53	.
29	FP	FP 1: Sex Female vs Male at Finger=Ring	0.65	0.32	1.34	.
29	FP	FP 1: Sex Female vs Male at Finger=Thumb	1.09	0.49	2.46	.
29	FP	FP 2: Finger Index vs Little at Sex=Female	0.50	0.28	0.88	.
29	FP	FP 2: Finger Index vs Little at Sex=Male	0.29	0.17	0.50	.
29	FP	FP 2: Finger Index vs Middle at Sex=Female	1.75	1.18	2.61	.
29	FP	FP 2: Finger Index vs Middle at Sex=Male	1.30	0.87	1.93	.
29	FP	FP 2: Finger Index vs Ring at Sex=Female	0.25	0.15	0.42	.
29	FP	FP 2: Finger Index vs Ring at Sex=Male	0.11	0.06	0.21	.
29	FP	FP 2: Finger Index vs Thumb at Sex=Female	0.14	0.07	0.26	.
29	FP	FP 2: Finger Index vs Thumb at Sex=Male	0.12	0.06	0.22	.
29	FP	FP 2: Finger Little vs Middle at Sex=Female	3.51	1.95	6.31	.
29	FP	FP 2: Finger Little vs Middle at Sex=Male	4.51	2.52	8.06	.
29	FP	FP 2: Finger Little vs Ring at Sex=Female	0.51	0.26	0.99	.
29	FP	FP 2: Finger Little vs Ring at Sex=Male	0.38	0.18	0.81	.
29	FP	FP 2: Finger Little vs Thumb at Sex=Female	0.27	0.13	0.59	.
29	FP	FP 2: Finger Little vs Thumb at Sex=Male	0.40	0.19	0.85	.
29	FP	FP 2: Finger Middle vs Ring at Sex=Female	0.14	0.08	0.25	.
29	FP	FP 2: Finger Middle vs Ring at Sex=Male	0.08	0.04	0.16	.
29	FP	FP 2: Finger Middle vs Thumb at Sex=Female	0.08	0.04	0.15	.
29	FP	FP 2: Finger Middle vs Thumb at Sex=Male	0.09	0.05	0.17	.
29	FP	FP 2: Finger Ring vs Thumb at Sex=Female	0.54	0.26	1.13	.
29	FP	FP 2: Finger Ring vs Thumb at Sex=Male	1.06	0.46	2.40	.

Continuation of Table 6-27

29	FP	FP 2: Sex Female vs Male at Finger=Index	1.29	0.90	1.85	.
29	FP	FP 2: Sex Female vs Male at Finger=Little	0.74	0.37	1.51	.
29	FP	FP 2: Sex Female vs Male at Finger=Middle	0.96	0.62	1.47	.
29	FP	FP 2: Sex Female vs Male at Finger=Ring	0.56	0.27	1.16	.
29	FP	FP 2: Sex Female vs Male at Finger=Thumb	1.08	0.48	2.46	.
29	FP	Finger*Sex	.	.	.	0.1709

Table 6-28. Multinomial Logistic GEE models with interactions.

Model	Outcome	Comparison	Odds Ratio	Lower 95%	Upper 95%	p-value
30	FP	FP 1: Finger Index vs Little at Twin_type=DZOS Females	0.21	0.04	1.02	.
30	FP	FP 1: Finger Index vs Little at Twin_type=DZOS Males	0.28	0.03	2.82	.
30	FP	FP 1: Finger Index vs Little at Twin_type=DZSS Females	0.26	0.05	1.40	.
30	FP	FP 1: Finger Index vs Little at Twin_type=DZSS Males	0.07	0.01	0.55	.
30	FP	FP 1: Finger Index vs Little at Twin_type=MZ Females	0.08	0.02	0.38	.
30	FP	FP 1: Finger Index vs Little at Twin_type=MZ Males	0.14	0.04	0.46	.
30	FP	FP 1: Finger Index vs Middle at Twin_type=DZOS Females	0.30	0.07	1.17	.
30	FP	FP 1: Finger Index vs Middle at Twin_type=DZOS Males	0.82	0.16	4.25	.
30	FP	FP 1: Finger Index vs Middle at Twin_type=DZSS Females	0.95	0.28	3.23	.
30	FP	FP 1: Finger Index vs Middle at Twin_type=DZSS Males	0.61	0.23	1.66	.
30	FP	FP 1: Finger Index vs Middle at Twin_type=MZ Females	0.73	0.31	1.73	.
30	FP	FP 1: Finger Index vs Middle at Twin_type=MZ Males	0.42	0.17	1.04	.
30	FP	FP 1: Finger Index vs Ring at Twin_type=DZOS Females	0.26	0.05	1.29	.
30	FP	FP 1: Finger Index vs Ring at Twin_type=DZOS Males	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Index vs Ring at Twin_type=DZSS Females	0.15	0.02	1.37	.
30	FP	FP 1: Finger Index vs Ring at Twin_type=DZSS Males	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Index vs Ring at Twin_type=MZ Females	0.23	0.07	0.77	.
30	FP	FP 1: Finger Index vs Ring at Twin_type=MZ Males	0.17	0.05	0.55	.
30	FP	FP 1: Finger Index vs Thumb at Twin_type=DZOS Females	0.31	0.06	1.53	.
30	FP	FP 1: Finger Index vs Thumb at Twin_type=DZOS Males	0.37	0.04	3.66	.
30	FP	FP 1: Finger Index vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Index vs Thumb at Twin_type=DZSS Males	0.17	0.04	0.81	.
30	FP	FP 1: Finger Index vs Thumb at Twin_type=MZ Females	0.11	0.02	0.50	.
30	FP	FP 1: Finger Index vs Thumb at Twin_type=MZ Males	0.04	0.01	0.31	.
30	FP	FP 1: Finger Little vs Middle at Twin_type=DZOS Females	1.43	0.23	8.85	.
30	FP	FP 1: Finger Little vs Middle at Twin_type=DZOS Males	2.89	0.29	28.67	.
30	FP	FP 1: Finger Little vs Middle at Twin_type=DZSS Females	3.70	0.74	18.61	.
30	FP	FP 1: Finger Little vs Middle at Twin_type=DZSS Males	8.96	1.08	74.17	.
30	FP	FP 1: Finger Little vs Middle at Twin_type=MZ Females	9.00	1.95	41.60	.
30	FP	FP 1: Finger Little vs Middle at Twin_type=MZ Males	3.00	0.89	10.11	.
30	FP	FP 1: Finger Little vs Ring at Twin_type=DZOS Females	1.26	0.17	9.30	.
30	FP	FP 1: Finger Little vs Ring at Twin_type=DZOS Males	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Little vs Ring at Twin_type=DZSS Females	0.60	0.05	6.78	.
30	FP	FP 1: Finger Little vs Ring at Twin_type=DZSS Males	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Little vs Ring at Twin_type=MZ Females	2.88	0.51	16.33	.
30	FP	FP 1: Finger Little vs Ring at Twin_type=MZ Males	1.17	0.28	4.98	.
30	FP	FP 1: Finger Little vs Thumb at Twin_type=DZOS Females	1.49	0.20	11.01	.
30	FP	FP 1: Finger Little vs Thumb at Twin_type=DZOS Males	1.29	0.08	21.29	.
30	FP	FP 1: Finger Little vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Little vs Thumb at Twin_type=DZSS Males	2.49	0.22	28.34	.
30	FP	FP 1: Finger Little vs Thumb at Twin_type=MZ Females	1.33	0.18	9.77	.
30	FP	FP 1: Finger Little vs Thumb at Twin_type=MZ Males	0.27	0.03	2.53	.
30	FP	FP 1: Finger Middle vs Ring at Twin_type=DZOS Females	0.88	0.14	5.51	.
30	FP	FP 1: Finger Middle vs Ring at Twin_type=DZOS Males	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Middle vs Ring at Twin_type=DZSS Females	0.16	0.02	1.36	.
30	FP	FP 1: Finger Middle vs Ring at Twin_type=DZSS Males	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Middle vs Ring at Twin_type=MZ Females	0.32	0.10	1.05	.
30	FP	FP 1: Finger Middle vs Ring at Twin_type=MZ Males	0.39	0.12	1.32	.
30	FP	FP 1: Finger Middle vs Thumb at Twin_type=DZOS Females	1.04	0.17	6.53	.
30	FP	FP 1: Finger Middle vs Thumb at Twin_type=DZOS Males	0.45	0.05	4.46	.
30	FP	FP 1: Finger Middle vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.

Continuation of Table 6-28

30	FP	FP 1: Finger Middle vs Thumb at Twin_type=DZSS Males	0.28	0.06	1.38	.
30	FP	FP 1: Finger Middle vs Thumb at Twin_type=MZ Females	0.15	0.03	0.69	.
30	FP	FP 1: Finger Middle vs Thumb at Twin_type=MZ Males	0.09	0.01	0.73	.
30	FP	FP 1: Finger Ring vs Thumb at Twin_type=DZOS Females	1.18	0.16	8.77	.
30	FP	FP 1: Finger Ring vs Thumb at Twin_type=DZOS Males	>999.999	<0.001	>999.999	.
30	FP	FP 1: Finger Ring vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.
30	FP	FP 1: Finger Ring vs Thumb at Twin_type=DZSS Males	>999.999	<0.001	>999.999	.
30	FP	FP 1: Finger Ring vs Thumb at Twin_type=MZ Females	0.46	0.08	2.64	.
30	FP	FP 1: Finger Ring vs Thumb at Twin_type=MZ Males	0.23	0.03	2.17	.
30	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Finger=Index	0.40	0.10	1.60	.
30	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Finger=Little	0.55	0.05	6.21	.
30	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Finger=Middle	1.11	0.22	5.73	.
30	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Finger=Ring	<0.001	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Finger=Thumb	0.48	0.04	5.46	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Finger=Index	0.83	0.25	2.76	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Finger=Little	1.04	0.14	7.61	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Finger=Middle	2.69	0.66	10.91	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Finger=Ring	0.49	0.04	5.58	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Finger=Thumb	<0.001	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Finger=Index	1.57	0.58	4.27	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Finger=Little	0.52	0.05	5.87	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Finger=Middle	3.25	0.82	12.91	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Finger=Ring	<0.001	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Finger=Thumb	0.87	0.12	6.44	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Females at Finger=Index	2.05	0.78	5.37	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Females at Finger=Little	0.81	0.11	5.89	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Females at Finger=Middle	5.08	1.37	18.82	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Females at Finger=Ring	1.84	0.32	10.53	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Females at Finger=Thumb	0.72	0.10	5.35	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Males at Finger=Index	3.56	1.35	9.39	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Males at Finger=Little	2.42	0.42	13.77	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Males at Finger=Middle	5.08	1.34	19.30	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Males at Finger=Ring	2.24	0.39	12.90	.
30	FP	FP 1: Twin_type DZOS Females vs MZ Males at Finger=Thumb	0.44	0.04	5.08	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Finger=Index	2.08	0.47	9.31	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Finger=Little	1.89	0.17	21.49	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Finger=Middle	2.42	0.60	9.86	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Finger=Thumb	<0.001	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Finger=Index	3.93	1.02	15.07	.

Continuation of Table 6-28

30	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Finger=Little	0.95	0.06	15.52	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Finger=Middle	2.93	0.74	11.67	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Finger=Ring	0.94	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Finger=Thumb	1.82	0.16	20.85	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Females at Finger=Index	5.12	1.37	19.11	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Females at Finger=Little	1.47	0.13	16.67	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Females at Finger=Middle	4.58	1.24	17.01	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Females at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Females at Finger=Thumb	1.52	0.13	17.33	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Males at Finger=Index	8.89	2.37	33.35	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Males at Finger=Little	4.42	0.48	40.90	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Males at Finger=Middle	4.58	1.20	17.45	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Males at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZOS Males vs MZ Males at Finger=Thumb	0.93	0.06	15.39	.
30	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Finger=Index	1.89	0.60	5.94	.
30	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Finger=Little	0.50	0.04	5.67	.
30	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Finger=Middle	1.21	0.41	3.59	.
30	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Finger=Ring	<0.001	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Finger=Thumb	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Females at Finger=Index	2.46	0.81	7.50	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Females at Finger=Little	0.78	0.11	5.70	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Females at Finger=Middle	1.89	0.70	5.12	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Females at Finger=Ring	3.76	0.41	34.87	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Females at Finger=Thumb	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Males at Finger=Index	4.27	1.39	13.09	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Males at Finger=Little	2.33	0.41	13.30	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Males at Finger=Middle	1.89	0.68	5.29	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Males at Finger=Ring	4.59	0.49	42.69	.
30	FP	FP 1: Twin_type DZSS Females vs MZ Males at Finger=Thumb	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Females at Finger=Index	1.30	0.53	3.21	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Females at Finger=Little	1.56	0.14	17.59	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Females at Finger=Middle	1.56	0.60	4.09	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Females at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Females at Finger=Thumb	0.83	0.11	6.15	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Males at Finger=Index	2.26	0.91	5.61	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Males at Finger=Little	4.67	0.50	43.18	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Males at Finger=Middle	1.56	0.58	4.23	.

Continuation of Table 6-28

30	FP	FP 1: Twin_type DZSS Males vs MZ Males at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 1: Twin_type DZSS Males vs MZ Males at Finger=Thumb	0.51	0.05	5.84	.
30	FP	FP 1: Twin_type MZ Females vs MZ Males at Finger=Index	1.74	0.73	4.13	.
30	FP	FP 1: Twin_type MZ Females vs MZ Males at Finger=Little	3.00	0.53	17.03	.
30	FP	FP 1: Twin_type MZ Females vs MZ Males at Finger=Middle	1.00	0.41	2.45	.
30	FP	FP 1: Twin_type MZ Females vs MZ Males at Finger=Ring	1.22	0.29	5.18	.
30	FP	FP 1: Twin_type MZ Females vs MZ Males at Finger=Thumb	0.61	0.05	6.99	.
30	FP	FP 2: Finger Index vs Little at Twin_type=DZOS Females	0.35	0.06	2.01	.
30	FP	FP 2: Finger Index vs Little at Twin_type=DZOS Males	0.46	0.04	4.82	.
30	FP	FP 2: Finger Index vs Little at Twin_type=DZSS Females	1.08	0.18	6.49	.
30	FP	FP 2: Finger Index vs Little at Twin_type=DZSS Males	0.12	0.01	1.11	.
30	FP	FP 2: Finger Index vs Little at Twin_type=MZ Females	0.37	0.07	1.87	.
30	FP	FP 2: Finger Index vs Little at Twin_type=MZ Males	0.39	0.11	1.38	.
30	FP	FP 2: Finger Index vs Middle at Twin_type=DZOS Females	0.88	0.17	4.49	.
30	FP	FP 2: Finger Index vs Middle at Twin_type=DZOS Males	1.83	0.32	10.53	.
30	FP	FP 2: Finger Index vs Middle at Twin_type=DZSS Females	4.73	1.17	19.02	.
30	FP	FP 2: Finger Index vs Middle at Twin_type=DZSS Males	1.09	0.33	3.67	.
30	FP	FP 2: Finger Index vs Middle at Twin_type=MZ Females	1.37	0.54	3.50	.
30	FP	FP 2: Finger Index vs Middle at Twin_type=MZ Males	1.32	0.48	3.66	.
30	FP	FP 2: Finger Index vs Ring at Twin_type=DZOS Females	0.16	0.03	0.86	.
30	FP	FP 2: Finger Index vs Ring at Twin_type=DZOS Males	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Index vs Ring at Twin_type=DZSS Females	0.27	0.03	2.50	.
30	FP	FP 2: Finger Index vs Ring at Twin_type=DZSS Males	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Index vs Ring at Twin_type=MZ Females	0.28	0.08	0.93	.
30	FP	FP 2: Finger Index vs Ring at Twin_type=MZ Males	0.27	0.08	0.93	.
30	FP	FP 2: Finger Index vs Thumb at Twin_type=DZOS Females	0.12	0.02	0.65	.
30	FP	FP 2: Finger Index vs Thumb at Twin_type=DZOS Males	0.26	0.03	2.70	.
30	FP	FP 2: Finger Index vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Index vs Thumb at Twin_type=DZSS Males	0.13	0.03	0.67	.
30	FP	FP 2: Finger Index vs Thumb at Twin_type=MZ Females	0.15	0.03	0.71	.
30	FP	FP 2: Finger Index vs Thumb at Twin_type=MZ Males	0.07	0.01	0.55	.
30	FP	FP 2: Finger Little vs Middle at Twin_type=DZOS Females	2.50	0.32	19.53	.
30	FP	FP 2: Finger Little vs Middle at Twin_type=DZOS Males	4.00	0.37	43.38	.
30	FP	FP 2: Finger Little vs Middle at Twin_type=DZSS Females	4.38	0.71	27.16	.
30	FP	FP 2: Finger Little vs Middle at Twin_type=DZSS Males	8.80	0.93	83.35	.
30	FP	FP 2: Finger Little vs Middle at Twin_type=MZ Females	3.71	0.71	19.32	.
30	FP	FP 2: Finger Little vs Middle at Twin_type=MZ Males	3.39	0.87	13.17	.
30	FP	FP 2: Finger Little vs Ring at Twin_type=DZOS Females	0.46	0.06	3.70	.
30	FP	FP 2: Finger Little vs Ring at Twin_type=DZOS Males	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Little vs Ring at Twin_type=DZSS Females	0.25	0.02	3.10	.
30	FP	FP 2: Finger Little vs Ring at Twin_type=DZSS Males	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Little vs Ring at Twin_type=MZ Females	0.75	0.12	4.64	.
30	FP	FP 2: Finger Little vs Ring at Twin_type=MZ Males	0.70	0.15	3.20	.
30	FP	FP 2: Finger Little vs Thumb at Twin_type=DZOS Females	0.35	0.04	2.78	.
30	FP	FP 2: Finger Little vs Thumb at Twin_type=DZOS Males	0.57	0.03	9.77	.
30	FP	FP 2: Finger Little vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Little vs Thumb at Twin_type=DZSS Males	1.05	0.09	12.88	.
30	FP	FP 2: Finger Little vs Thumb at Twin_type=MZ Females	0.40	0.05	3.17	.
30	FP	FP 2: Finger Little vs Thumb at Twin_type=MZ Males	0.17	0.02	1.70	.
30	FP	FP 2: Finger Middle vs Ring at Twin_type=DZOS Females	0.18	0.03	1.35	.
30	FP	FP 2: Finger Middle vs Ring at Twin_type=DZOS Males	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Middle vs Ring at Twin_type=DZSS Females	0.06	0.01	0.54	.

Continuation of Table 6-28

30	FP	FP 2: Finger Middle vs Ring at Twin_type=DZSS Males	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Middle vs Ring at Twin_type=MZ Females	0.20	0.06	0.70	.
30	FP	FP 2: Finger Middle vs Ring at Twin_type=MZ Males	0.21	0.05	0.78	.
30	FP	FP 2: Finger Middle vs Thumb at Twin_type=DZOS Females	0.14	0.02	1.01	.
30	FP	FP 2: Finger Middle vs Thumb at Twin_type=DZOS Males	0.14	0.01	1.52	.
30	FP	FP 2: Finger Middle vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Middle vs Thumb at Twin_type=DZSS Males	0.12	0.02	0.67	.
30	FP	FP 2: Finger Middle vs Thumb at Twin_type=MZ Females	0.11	0.02	0.53	.
30	FP	FP 2: Finger Middle vs Thumb at Twin_type=MZ Males	0.05	0.01	0.44	.
30	FP	FP 2: Finger Ring vs Thumb at Twin_type=DZOS Females	0.76	0.10	5.82	.
30	FP	FP 2: Finger Ring vs Thumb at Twin_type=DZOS Males	>999.999	<0.001	>999.999	.
30	FP	FP 2: Finger Ring vs Thumb at Twin_type=DZSS Females	<0.001	<0.001	>999.999	.
30	FP	FP 2: Finger Ring vs Thumb at Twin_type=DZSS Males	>999.999	<0.001	>999.999	.
30	FP	FP 2: Finger Ring vs Thumb at Twin_type=MZ Females	0.53	0.09	3.13	.
30	FP	FP 2: Finger Ring vs Thumb at Twin_type=MZ Males	0.25	0.03	2.41	.
30	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Finger=Index	0.24	0.05	1.06	.
30	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Finger=Little	0.31	0.03	3.91	.
30	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Finger=Middle	0.50	0.08	3.27	.
30	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Finger=Ring	<0.001	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Finger=Thumb	0.52	0.04	6.04	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Finger=Index	0.32	0.09	1.18	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Finger=Little	1.00	0.12	8.56	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Finger=Middle	1.75	0.31	9.75	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Finger=Ring	0.55	0.05	6.54	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Finger=Thumb	<0.001	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Finger=Index	1.28	0.40	4.12	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Finger=Little	0.46	0.04	5.81	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Finger=Middle	1.60	0.30	8.49	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Finger=Ring	<0.001	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Finger=Thumb	1.38	0.18	10.61	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Females at Finger=Index	0.79	0.27	2.31	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Females at Finger=Little	0.83	0.10	7.03	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Females at Finger=Middle	1.24	0.26	5.83	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Females at Finger=Ring	1.38	0.23	8.17	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Females at Finger=Thumb	0.97	0.13	7.33	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Males at Finger=Index	1.12	0.38	3.27	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Males at Finger=Little	1.25	0.19	8.13	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Males at Finger=Middle	1.69	0.34	8.40	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Males at Finger=Ring	1.91	0.32	11.52	.
30	FP	FP 2: Twin_type DZOS Females vs MZ Males at Finger=Thumb	0.63	0.05	7.39	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Finger=Index	1.36	0.29	6.32	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Finger=Little	3.20	0.26	40.06	.

Continuation of Table 6-28

30	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Finger=Middle	3.50	0.69	17.71	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Finger=Thumb	<0.001	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Finger=Index	5.38	1.28	22.59	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Finger=Little	1.46	0.08	25.81	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Finger=Middle	3.20	0.67	15.38	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Finger=Ring	1.22	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Finger=Thumb	2.67	0.23	31.41	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Females at Finger=Index	3.31	0.85	12.92	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Females at Finger=Little	2.67	0.22	32.96	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Females at Finger=Middle	2.48	0.59	10.47	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Females at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Females at Finger=Thumb	1.87	0.16	21.74	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Males at Finger=Index	4.69	1.21	18.28	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Males at Finger=Little	4.00	0.40	39.83	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Males at Finger=Middle	3.39	0.76	15.15	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Males at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZOS Males vs MZ Males at Finger=Thumb	1.22	0.07	20.55	.
30	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Finger=Index	3.96	1.16	13.57	.
30	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Finger=Little	0.46	0.04	5.81	.
30	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Finger=Middle	0.91	0.23	3.62	.
30	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Finger=Ring	<0.001	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Finger=Thumb	>999.999	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Females at Finger=Index	2.44	0.78	7.66	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Females at Finger=Little	0.83	0.10	7.03	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Females at Finger=Middle	0.71	0.21	2.42	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Females at Finger=Ring	2.50	0.26	23.99	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Females at Finger=Thumb	>999.999	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Males at Finger=Index	3.46	1.10	10.83	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Males at Finger=Little	1.25	0.19	8.13	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Males at Finger=Middle	0.97	0.27	3.53	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Males at Finger=Ring	3.48	0.36	33.73	.
30	FP	FP 2: Twin_type DZSS Females vs MZ Males at Finger=Thumb	>999.999	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Females at Finger=Index	0.62	0.23	1.68	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Females at Finger=Little	1.83	0.15	23.15	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Females at Finger=Middle	0.77	0.24	2.47	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Females at Finger=Ring	>999.999	<0.001	>999.999	.

Continuation of Table 6-28

30	FP	FP 2: Twin_type DZSS Males vs MZ Females at Finger=Thumb	0.70	0.09	5.37	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Males at Finger=Index	0.87	0.32	2.37	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Males at Finger=Little	2.75	0.27	28.04	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Males at Finger=Middle	1.06	0.31	3.61	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Males at Finger=Ring	>999.999	<0.001	>999.999	.
30	FP	FP 2: Twin_type DZSS Males vs MZ Males at Finger=Thumb	0.46	0.04	5.41	.
30	FP	FP 2: Twin_type MZ Females vs MZ Males at Finger=Index	1.42	0.58	3.45	.
30	FP	FP 2: Twin_type MZ Females vs MZ Males at Finger=Little	1.50	0.24	9.59	.
30	FP	FP 2: Twin_type MZ Females vs MZ Males at Finger=Middle	1.37	0.47	3.94	.
30	FP	FP 2: Twin_type MZ Females vs MZ Males at Finger=Ring	1.39	0.32	6.15	.
30	FP	FP 2: Twin_type MZ Females vs MZ Males at Finger=Thumb	0.65	0.06	7.64	.
.		Finger*Twin_type	.	.	.	0.81
31	FP	FP 1: Hand Left vs Right at Twin_type=DZOS Females	0.67	0.25	1.81	.
31	FP	FP 1: Hand Left vs Right at Twin_type=DZOS Males	0.69	0.16	2.97	.
31	FP	FP 1: Hand Left vs Right at Twin_type=DZSS Females	0.91	0.32	2.59	.
31	FP	FP 1: Hand Left vs Right at Twin_type=DZSS Males	1.32	0.55	3.17	.
31	FP	FP 1: Hand Left vs Right at Twin_type=MZ Females	1.18	0.59	2.40	.
31	FP	FP 1: Hand Left vs Right at Twin_type=MZ Males	1.26	0.62	2.56	.
31	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Hand=Left	0.49	0.16	1.47	.
31	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Hand=Right	0.51	0.13	2.01	.
31	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Hand=Left	0.80	0.31	2.10	.
31	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Hand=Right	1.09	0.37	3.21	.
31	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Hand=Left	0.99	0.40	2.47	.
31	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Hand=Right	1.96	0.75	5.14	.
31	FP	FP 1: Twin_type DZOS Females vs MZ Females at Hand=Left	1.47	0.65	3.34	.
31	FP	FP 1: Twin_type DZOS Females vs MZ Females at Hand=Right	2.61	1.06	6.47	.
31	FP	FP 1: Twin_type DZOS Females vs MZ Males at Hand=Left	1.94	0.85	4.41	.
31	FP	FP 1: Twin_type DZOS Females vs MZ Males at Hand=Right	3.65	1.47	9.03	.
31	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Hand=Left	1.64	0.52	5.15	.
31	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Hand=Right	2.16	0.54	8.54	.
31	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Hand=Left	2.03	0.68	6.12	.
31	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Hand=Right	3.86	1.06	14.05	.
31	FP	FP 1: Twin_type DZOS Males vs MZ Females at Hand=Left	3.02	1.08	8.41	.
31	FP	FP 1: Twin_type DZOS Males vs MZ Females at Hand=Right	5.15	1.48	17.95	.
31	FP	FP 1: Twin_type DZOS Males vs MZ Males at Hand=Left	3.97	1.42	11.11	.
31	FP	FP 1: Twin_type DZOS Males vs MZ Males at Hand=Right	7.19	2.06	25.05	.
31	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Hand=Left	1.24	0.47	3.25	.
31	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Hand=Right	1.79	0.68	4.71	.
31	FP	FP 1: Twin_type DZSS Females vs MZ Females at Hand=Left	1.84	0.77	4.41	.
31	FP	FP 1: Twin_type DZSS Females vs MZ Females at Hand=Right	2.39	0.96	5.93	.
31	FP	FP 1: Twin_type DZSS Females vs MZ Males at Hand=Left	2.42	1.01	5.83	.

Continuation of Table 6-28

31	FP	FP 1: Twin_type DZSS Females vs MZ Males at Hand=Right	3.34	1.35	8.27	.
31	FP	FP 1: Twin_type DZSS Males vs MZ Females at Hand=Left	1.49	0.66	3.36	.
31	FP	FP 1: Twin_type DZSS Males vs MZ Females at Hand=Right	1.34	0.62	2.89	.
31	FP	FP 1: Twin_type DZSS Males vs MZ Males at Hand=Left	1.95	0.86	4.44	.
31	FP	FP 1: Twin_type DZSS Males vs MZ Males at Hand=Right	1.86	0.86	4.03	.
31	FP	FP 1: Twin_type MZ Females vs MZ Males at Hand=Left	1.32	0.64	2.69	.
31	FP	FP 1: Twin_type MZ Females vs MZ Males at Hand=Right	1.40	0.70	2.80	.
31	FP	FP 2: Hand Left vs Right at Twin_type=DZOS Females	0.75	0.26	2.18	.
31	FP	FP 2: Hand Left vs Right at Twin_type=DZOS Males	0.42	0.10	1.85	.
31	FP	FP 2: Hand Left vs Right at Twin_type=DZSS Females	0.76	0.25	2.28	.
31	FP	FP 2: Hand Left vs Right at Twin_type=DZSS Males	0.96	0.37	2.47	.
31	FP	FP 2: Hand Left vs Right at Twin_type=MZ Females	0.85	0.40	1.79	.
31	FP	FP 2: Hand Left vs Right at Twin_type=MZ Males	0.91	0.43	1.96	.
31	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Hand=Left	0.48	0.15	1.51	.
31	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Hand=Right	0.27	0.07	1.09	.
31	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Hand=Left	0.86	0.31	2.41	.
31	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Hand=Right	0.87	0.28	2.69	.
31	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Hand=Left	1.17	0.44	3.12	.
31	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Hand=Right	1.49	0.53	4.15	.
31	FP	FP 2: Twin_type DZOS Females vs MZ Females at Hand=Left	1.28	0.53	3.07	.
31	FP	FP 2: Twin_type DZOS Females vs MZ Females at Hand=Right	1.43	0.55	3.73	.
31	FP	FP 2: Twin_type DZOS Females vs MZ Males at Hand=Left	1.59	0.65	3.85	.
31	FP	FP 2: Twin_type DZOS Females vs MZ Males at Hand=Right	1.93	0.74	5.02	.
31	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Hand=Left	1.81	0.55	5.98	.
31	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Hand=Right	3.27	0.80	13.32	.
31	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Hand=Left	2.44	0.77	7.80	.
31	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Hand=Right	5.60	1.49	21.00	.
31	FP	FP 2: Twin_type DZOS Males vs MZ Females at Hand=Left	2.67	0.91	7.81	.
31	FP	FP 2: Twin_type DZOS Males vs MZ Females at Hand=Right	5.40	1.52	19.20	.
31	FP	FP 2: Twin_type DZOS Males vs MZ Males at Hand=Left	3.32	1.13	9.79	.
31	FP	FP 2: Twin_type DZOS Males vs MZ Males at Hand=Right	7.25	2.04	25.84	.
31	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Hand=Left	1.35	0.48	3.81	.
31	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Hand=Right	1.71	0.62	4.75	.
31	FP	FP 2: Twin_type DZSS Females vs MZ Females at Hand=Left	1.48	0.58	3.77	.
31	FP	FP 2: Twin_type DZSS Females vs MZ Females at Hand=Right	1.65	0.64	4.27	.
31	FP	FP 2: Twin_type DZSS Females vs MZ Males at Hand=Left	1.84	0.72	4.73	.
31	FP	FP 2: Twin_type DZSS Females vs MZ Males at Hand=Right	2.22	0.86	5.75	.
31	FP	FP 2: Twin_type DZSS Males vs MZ Females at Hand=Left	1.09	0.45	2.65	.
31	FP	FP 2: Twin_type DZSS Males vs MZ Females at Hand=Right	0.96	0.42	2.19	.
31	FP	FP 2: Twin_type DZSS Males vs MZ Males at Hand=Left	1.36	0.56	3.33	.
31	FP	FP 2: Twin_type DZSS Males vs MZ Males at Hand=Right	1.30	0.57	2.95	.
31	FP	FP 2: Twin_type MZ Females vs MZ Males at Hand=Left	1.24	0.57	2.71	.
31	FP	FP 2: Twin_type MZ Females vs MZ Males at Hand=Right	1.34	0.64	2.80	.

Continuation of Table 6-28

.		Hand*Twin_type	.	.	.	0.88
32	FP	FP 1: Gender Female vs Male at Twin_type=DZOS Females	0.40	0.20	0.80	.
32	FP	FP 1: Gender Female vs Male at Twin_type=DZOS Males	0.40	0.20	0.80	.
32	FP	FP 1: Gender Female vs Male at Twin_type=DZSS Females	0.40	0.20	0.80	.
32	FP	FP 1: Gender Female vs Male at Twin_type=DZSS Males	0.40	0.20	0.80	.
32	FP	FP 1: Gender Female vs Male at Twin_type=MZ Females	0.40	0.20	0.80	.
32	FP	FP 1: Gender Female vs Male at Twin_type=MZ Males	0.40	0.20	0.80	.
32	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Gender=Female	1.27	0.45	3.56	.
32	FP	FP 1: Twin_type DZOS Females vs DZOS Males at Gender=Male	1.27	0.45	3.56	.
32	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Gender=Female	0.92	0.45	1.89	.
32	FP	FP 1: Twin_type DZOS Females vs DZSS Females at Gender=Male	0.92	0.45	1.89	.
32	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Gender=Female	3.46	1.30	9.21	.
32	FP	FP 1: Twin_type DZOS Females vs DZSS Males at Gender=Male	3.46	1.30	9.21	.
32	FP	FP 1: Twin_type DZOS Females vs MZ Females at Gender=Female	1.93	1.05	3.53	.
32	FP	FP 1: Twin_type DZOS Females vs MZ Females at Gender=Male	1.93	1.05	3.53	.
32	FP	FP 1: Twin_type DZOS Females vs MZ Males at Gender=Female	6.58	2.50	17.31	.
32	FP	FP 1: Twin_type DZOS Females vs MZ Males at Gender=Male	6.58	2.50	17.31	.
32	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Gender=Female	0.73	0.25	2.08	.
32	FP	FP 1: Twin_type DZOS Males vs DZSS Females at Gender=Male	0.73	0.25	2.08	.
32	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Gender=Female	2.72	1.19	6.24	.
32	FP	FP 1: Twin_type DZOS Males vs DZSS Males at Gender=Male	2.72	1.19	6.24	.
32	FP	FP 1: Twin_type DZOS Males vs MZ Females at Gender=Female	1.52	0.83	2.78	.
32	FP	FP 1: Twin_type DZOS Males vs MZ Females at Gender=Male	1.52	0.83	2.78	.
32	FP	FP 1: Twin_type DZOS Males vs MZ Males at Gender=Female	5.18	2.35	11.39	.
32	FP	FP 1: Twin_type DZOS Males vs MZ Males at Gender=Male	5.18	2.35	11.39	.
32	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Gender=Female	3.75	1.37	10.24	.
32	FP	FP 1: Twin_type DZSS Females vs DZSS Males at Gender=Male	3.75	1.37	10.24	.
32	FP	FP 1: Twin_type DZSS Females vs MZ Females at Gender=Female	2.09	1.11	3.92	.
32	FP	FP 1: Twin_type DZSS Females vs MZ Females at Gender=Male	2.09	1.11	3.92	.
32	FP	FP 1: Twin_type DZSS Females vs MZ Males at Gender=Female	7.13	2.64	19.26	.
32	FP	FP 1: Twin_type DZSS Females vs MZ Males at Gender=Male	7.13	2.64	19.26	.
32	FP	FP 1: Twin_type DZSS Males vs MZ Females at Gender=Female	0.56	0.33	0.93	.
32	FP	FP 1: Twin_type DZSS Males vs MZ Females at Gender=Male	0.56	0.33	0.93	.
32	FP	FP 1: Twin_type DZSS Males vs MZ Males at Gender=Female	1.90	1.08	3.34	.
32	FP	FP 1: Twin_type DZSS Males vs MZ Males at Gender=Male	1.90	1.08	3.34	.
32	FP	FP 1: Twin_type MZ Females vs MZ Males at Gender=Female	3.41	2.08	5.59	.
32	FP	FP 1: Twin_type MZ Females vs MZ Males at Gender=Male	3.41	2.08	5.59	.
32	FP	FP 2: Gender Female vs Male at Twin_type=DZOS Females	0.55	0.26	1.16	.
32	FP	FP 2: Gender Female vs Male at Twin_type=DZOS Males	0.55	0.26	1.16	.
32	FP	FP 2: Gender Female vs Male at Twin_type=DZSS Females	0.55	0.26	1.16	.

Continuation of Table 6-28

32	FP	FP 2: Gender Female vs Male at Twin_type=DZSS Males	0.55	0.26	1.16	.
32	FP	FP 2: Gender Female vs Male at Twin_type=MZ Females	0.55	0.26	1.16	.
32	FP	FP 2: Gender Female vs Male at Twin_type=MZ Males	0.55	0.26	1.16	.
32	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Gender=Female	0.65	0.22	1.92	.
32	FP	FP 2: Twin_type DZOS Females vs DZOS Males at Gender=Male	0.65	0.22	1.92	.
32	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Gender=Female	0.85	0.40	1.82	.
32	FP	FP 2: Twin_type DZOS Females vs DZSS Females at Gender=Male	0.85	0.40	1.82	.
32	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Gender=Female	2.36	0.83	6.66	.
32	FP	FP 2: Twin_type DZOS Females vs DZSS Males at Gender=Male	2.36	0.83	6.66	.
32	FP	FP 2: Twin_type DZOS Females vs MZ Females at Gender=Female	1.32	0.70	2.52	.
32	FP	FP 2: Twin_type DZOS Females vs MZ Females at Gender=Male	1.32	0.70	2.52	.
32	FP	FP 2: Twin_type DZOS Females vs MZ Males at Gender=Female	3.12	1.12	8.72	.
32	FP	FP 2: Twin_type DZOS Females vs MZ Males at Gender=Male	3.12	1.12	8.72	.
32	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Gender=Female	1.31	0.43	3.97	.
32	FP	FP 2: Twin_type DZOS Males vs DZSS Females at Gender=Male	1.31	0.43	3.97	.
32	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Gender=Female	3.63	1.54	8.56	.
32	FP	FP 2: Twin_type DZOS Males vs DZSS Males at Gender=Male	3.63	1.54	8.56	.
32	FP	FP 2: Twin_type DZOS Males vs MZ Females at Gender=Female	2.04	1.09	3.83	.
32	FP	FP 2: Twin_type DZOS Males vs MZ Females at Gender=Male	2.04	1.09	3.83	.
32	FP	FP 2: Twin_type DZOS Males vs MZ Males at Gender=Female	4.81	2.13	10.84	.
32	FP	FP 2: Twin_type DZOS Males vs MZ Males at Gender=Male	4.81	2.13	10.84	.
32	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Gender=Female	2.77	0.96	8.01	.
32	FP	FP 2: Twin_type DZSS Females vs DZSS Males at Gender=Male	2.77	0.96	8.01	.
32	FP	FP 2: Twin_type DZSS Females vs MZ Females at Gender=Female	1.56	0.80	3.02	.
32	FP	FP 2: Twin_type DZSS Females vs MZ Females at Gender=Male	1.56	0.80	3.02	.
32	FP	FP 2: Twin_type DZSS Females vs MZ Males at Gender=Female	3.67	1.28	10.49	.
32	FP	FP 2: Twin_type DZSS Females vs MZ Males at Gender=Male	3.67	1.28	10.49	.
32	FP	FP 2: Twin_type DZSS Males vs MZ Females at Gender=Female	0.56	0.33	0.97	.
32	FP	FP 2: Twin_type DZSS Males vs MZ Females at Gender=Male	0.56	0.33	0.97	.
32	FP	FP 2: Twin_type DZSS Males vs MZ Males at Gender=Female	1.33	0.72	2.43	.
32	FP	FP 2: Twin_type DZSS Males vs MZ Males at Gender=Male	1.33	0.72	2.43	.
32	FP	FP 2: Twin_type MZ Females vs MZ Males at Gender=Female	2.36	1.40	3.98	.
32	FP	FP 2: Twin_type MZ Females vs MZ Males at Gender=Male	2.36	1.40	3.98	.
.		Gender*Twin_type	.	.	.	.
33	FP	FP 1: Finger Index vs Little at Hand=Left	0.13	0.05	0.35	.
33	FP	FP 1: Finger Index vs Little at Hand=Right	0.16	0.07	0.38	.
33	FP	FP 1: Finger Index vs Middle at Hand=Left	0.74	0.41	1.33	.
33	FP	FP 1: Finger Index vs Middle at Hand=Right	0.48	0.26	0.89	.
33	FP	FP 1: Finger Index vs Ring at Hand=Left	0.13	0.04	0.37	.
33	FP	FP 1: Finger Index vs Ring at Hand=Right	0.22	0.09	0.52	.
33	FP	FP 1: Finger Index vs Thumb at Hand=Left	0.19	0.08	0.48	.
33	FP	FP 1: Finger Index vs Thumb at Hand=Right	0.06	0.01	0.25	.

Continuation of Table 6-28

33	FP	FP 1: Finger Little vs Middle at Hand=Left	5.67	2.12	15.18	.
33	FP	FP 1: Finger Little vs Middle at Hand=Right	2.98	1.23	7.25	.
33	FP	FP 1: Finger Little vs Ring at Hand=Left	0.97	0.26	3.68	.
33	FP	FP 1: Finger Little vs Ring at Hand=Right	1.35	0.46	3.95	.
33	FP	FP 1: Finger Little vs Thumb at Hand=Left	1.49	0.44	4.97	.
33	FP	FP 1: Finger Little vs Thumb at Hand=Right	0.37	0.08	1.80	.
33	FP	FP 1: Finger Middle vs Ring at Hand=Left	0.17	0.06	0.50	.
33	FP	FP 1: Finger Middle vs Ring at Hand=Right	0.45	0.19	1.10	.
33	FP	FP 1: Finger Middle vs Thumb at Hand=Left	0.26	0.10	0.66	.
33	FP	FP 1: Finger Middle vs Thumb at Hand=Right	0.12	0.03	0.54	.
33	FP	FP 1: Finger Ring vs Thumb at Hand=Left	1.53	0.42	5.54	.
33	FP	FP 1: Finger Ring vs Thumb at Hand=Right	0.27	0.06	1.34	.
33	FP	FP 1: Hand Left vs Right at Finger=Index	1.20	0.67	2.14	.
33	FP	FP 1: Hand Left vs Right at Finger=Little	1.49	0.47	4.80	.
33	FP	FP 1: Hand Left vs Right at Finger=Middle	0.79	0.42	1.47	.
33	FP	FP 1: Hand Left vs Right at Finger=Ring	2.08	0.59	7.26	.
33	FP	FP 1: Hand Left vs Right at Finger=Thumb	0.37	0.07	1.86	.
33	FP	FP 2: Finger Index vs Little at Hand=Left	0.36	0.13	1.02	.
33	FP	FP 2: Finger Index vs Little at Hand=Right	0.39	0.16	0.96	.
33	FP	FP 2: Finger Index vs Middle at Hand=Left	1.74	0.88	3.46	.
33	FP	FP 2: Finger Index vs Middle at Hand=Right	1.30	0.65	2.60	.
33	FP	FP 2: Finger Index vs Ring at Hand=Left	0.15	0.05	0.44	.
33	FP	FP 2: Finger Index vs Ring at Hand=Right	0.19	0.08	0.46	.
33	FP	FP 2: Finger Index vs Thumb at Hand=Left	0.22	0.08	0.56	.
33	FP	FP 2: Finger Index vs Thumb at Hand=Right	0.06	0.01	0.24	.
33	FP	FP 2: Finger Little vs Middle at Hand=Left	4.85	1.66	14.19	.
33	FP	FP 2: Finger Little vs Middle at Hand=Right	3.33	1.27	8.79	.
33	FP	FP 2: Finger Little vs Ring at Hand=Left	0.41	0.10	1.61	.
33	FP	FP 2: Finger Little vs Ring at Hand=Right	0.49	0.16	1.50	.
33	FP	FP 2: Finger Little vs Thumb at Hand=Left	0.60	0.17	2.11	.
33	FP	FP 2: Finger Little vs Thumb at Hand=Right	0.14	0.03	0.72	.
33	FP	FP 2: Finger Middle vs Ring at Hand=Left	0.08	0.03	0.26	.
33	FP	FP 2: Finger Middle vs Ring at Hand=Right	0.15	0.06	0.38	.
33	FP	FP 2: Finger Middle vs Thumb at Hand=Left	0.12	0.05	0.33	.
33	FP	FP 2: Finger Middle vs Thumb at Hand=Right	0.04	0.01	0.19	.
33	FP	FP 2: Finger Ring vs Thumb at Hand=Left	1.48	0.40	5.48	.
33	FP	FP 2: Finger Ring vs Thumb at Hand=Right	0.29	0.06	1.43	.
33	FP	FP 2: Hand Left vs Right at Finger=Index	1.02	0.55	1.89	.
33	FP	FP 2: Hand Left vs Right at Finger=Little	1.10	0.32	3.78	.
33	FP	FP 2: Hand Left vs Right at Finger=Middle	0.76	0.36	1.60	.
33	FP	FP 2: Hand Left vs Right at Finger=Ring	1.34	0.38	4.77	.
33	FP	FP 2: Hand Left vs Right at Finger=Thumb	0.26	0.05	1.34	.
.		Hand*Finger	.	.	.	0.67

6.10 Principal components analysis (PCA)

Principal components analysis (PCA) was undertaken to explore patterns of covariation within the data. Analysis was conducted on finger ridge counts (RC). Fingerprint pattern (FP) was excluded from the dermatoglyphic data due to its categorical data structure. White line count (WLC) was excluded from the dermatoglyphic data due to the complexity of the zero-inflated data.

The percentages of variation accounted for by the first five principal components were as follows:

PC1 32.2%

PC2 11.5%

PC3 9.9%

PC4 9.4%

PC5 8.6%

PC1 accounted for 32.2% and indicated overall ridge count with all fingers positively correlated. PC2 (11.5%) indicated the right thumb to be positively correlated with the left little finger, and both fingers were seen negatively correlated with the left thumb, and the right little finger to a much lesser extent. PC3 (9.9%) showed both thumbs are positively correlated, and both negatively correlated with middle fingers. PC4 indicated that the left ring finger is negatively correlated with the right ring finger and right little finger. PC5 seemed to indicate left-right differences, as opposing sides were observed to be negatively correlated (see Figure 6-1).

In Figures 6-2 to 6-4, it is observed that male fingerprints are more varied than females in PC1 and PC2 as indicated by the scattered dots. DZOS males were also seen as more negative for PC2.

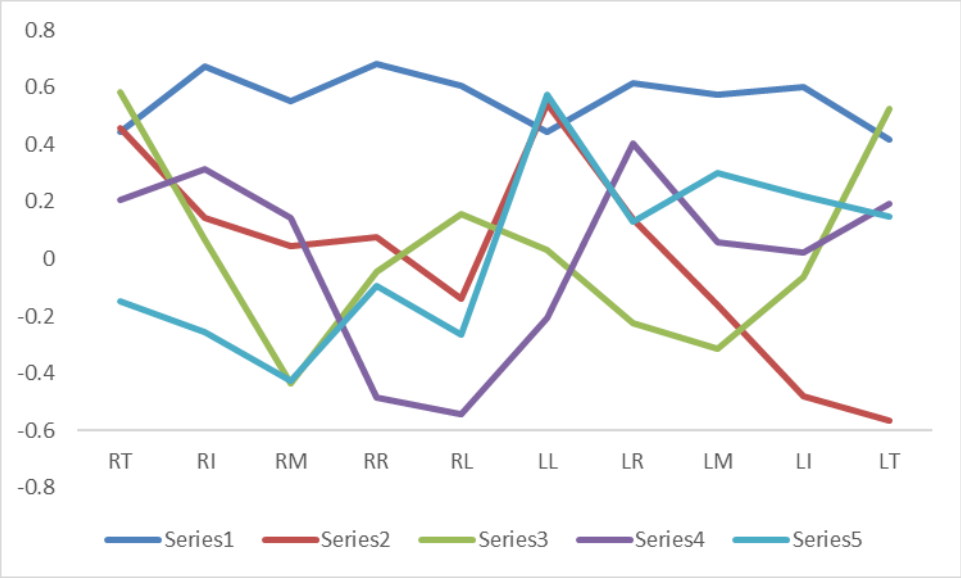

Figure 6-1. PCA graph for fingerprints.
Legend: R- right; L- left; T-thumb; I-index; M-middle; R-ring; L-little

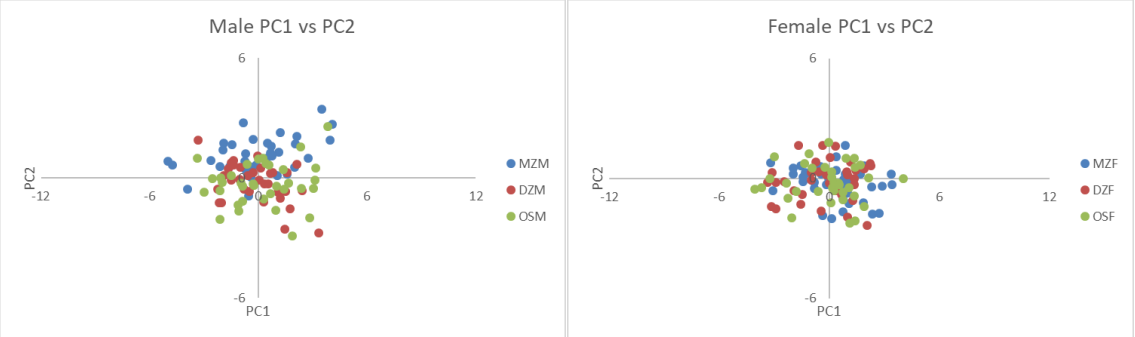

Figure 6-2. Sex and zygosity comparisons of PC1 and PC2 of fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

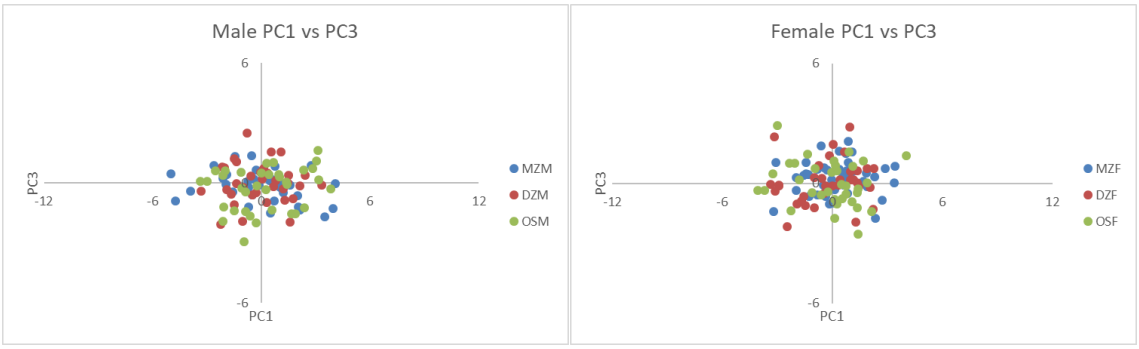

Figure 6-3. Sex and zygosity comparisons of PC1 and PC3 of fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

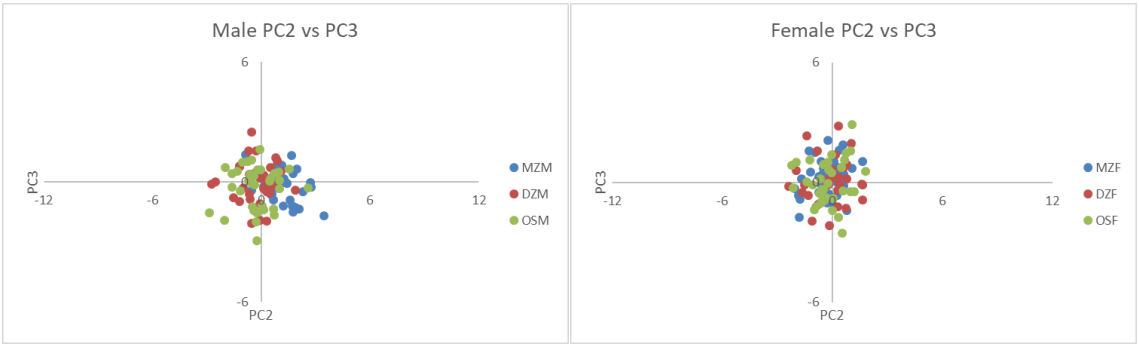

Figure 6-4. Sex and zygosity comparisons of PC2 and PC3 of fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

Chapter 7 Results of statistical analysis of dental and dermatoglyphic variables

7.1 Introduction

The development of the human dentition and of dermatoglyphs has similar embryological origin from epithelial-mesenchymal interactions (Nanci, 2008). Dental and dermatoglyphic patterns develop in utero, and once stabilised, their unique and persistent morphology makes them valuable models in studying sexual dimorphism.

This chapter presents correlations and associations between the dental and dermatoglyphic variables in this study. It also aims to determine differences in correlations and associations between sexes and among zygosities.

To determine how strong the relationship is between the two variables, Pearson and Spearman's correlation coefficients were calculated. To determine the associations between variables, linear-mixed effect models and logistic generalized estimating equations models were computed.

7.2 Correlations

Coefficients (r) between and fingerprints are presented in Tables 7-1, 7-2, 7-3 and 7-4. Highlighted in yellow are the statistically significant correlations at $p < 0.05$. Overall, the correlations between teeth and fingerprints are low in magnitude in both sexes, whether positive or negative, and whether statistically significant or insignificant differences.

Table 7-1. Correlation coefficients of primary teeth and fingerprints of Australian male twins.

Variables	TFP	TRC	TWLC	IFP	IRC	IWLC	MFP	MRC	MWLC	RFP	RRC	RWLC	LFP	LRC	LWLC
MXI1MD	0.04	-0.06	-0.05	0.01	-0.10	0.03	0.05	-0.11	0.07	0.07	-0.02	0.01	-0.13	-0.05	0.03
MXI1BL	0.11	-0.08	-0.06	-0.03	-0.02	**0.15**	0.08	**-0.15**	0.11	-0.02	-0.11	0.12	-0.04	-0.09	0.09
MXCMD	0.01	-0.09	0.05	0.04	-0.05	-0.01	0.05	-0.05	0.12	0.06	-0.05	0.09	-0.01	0.08	0.08
MXCBL	0.02	-0.08	-0.03	0.00	-0.05	-0.01	**0.14**	-0.12	0.06	0.04	-0.10	0.02	0.00	-0.01	0.02
MXM1MD	0.01	-0.09	-0.01	0.02	-0.05	0.03	0.07	-0.08	0.08	0.01	0.01	0.04	-0.07	0.06	0.07
MXM1BL	0.01	**-0.15**	-0.01	-0.08	-0.06	0.06	0.04	-0.07	0.05	-0.05	-0.10	0.03	**-0.14**	-0.05	-0.01
MXM2MD	-0.09	-0.09	-0.01	-0.10	-0.05	0.01	-0.03	-0.03	0.02	-0.09	0.05	0.08	**-0.21**	0.09	0.06
MXM2BL	-0.07	**-0.14**	-0.03	**-0.14**	-0.05	-0.02	-0.05	-0.08	-0.06	-0.11	-0.07	-0.02	**-0.20**	0.05	-0.02
MXM2CT	-0.02	-0.04	0.04	0.05	-0.05	0.01	0.05	-0.03	0.04	0.00	-0.07	-0.04	-0.07	-0.09	-0.06
MNI1MD	0.05	-0.04	-0.12	-0.06	0.00	**-0.16**	-0.04	0.08	**-0.20**	0.04	0.03	**-0.14**	-0.10	0.10	-0.13
MNI1BL	0.04	-0.05	-0.09	-0.09	0.00	-0.05	-0.10	0.03	-0.10	-0.04	-0.01	0.00	-0.12	0.03	-0.06
MNI2MD	0.10	-0.10	-0.03	0.05	-0.11	-0.10	0.00	0.02	0.01	0.03	-0.03	-0.02	-0.02	0.07	0.00
MNI2BL	0.03	-0.09	-0.07	-0.02	-0.12	-0.05	-0.04	-0.08	0.03	0.00	-0.11	0.06	-0.01	-0.02	-0.05
MNCMD	0.00	**-0.18**	0.10	-0.02	**-0.14**	0.01	0.01	-0.09	**0.15**	-0.03	-0.07	0.09	-0.07	0.05	0.09
MNCBL	0.06	-0.10	-0.07	0.05	-0.11	-0.08	0.14	**-0.17**	0.01	0.07	-0.12	-0.06	0.07	-0.05	-0.07
MNM1MD	0.05	-0.03	0.00	-0.03	-0.11	-0.01	0.09	-0.08	0.08	-0.04	-0.11	0.00	-0.10	0.00	-0.04
MNM1BL	0.00	-0.12	-0.11	-0.11	-0.12	**-0.16**	0.08	-0.05	-0.07	0.05	-0.10	-0.10	-0.13	-0.04	-0.04
MNM2MD	-0.06	-0.09	-0.08	-0.13	-0.06	0.01	-0.08	-0.09	0.02	-0.04	-0.05	0.05	-0.10	0.10	0.04
MNM2BL	0.00	**-0.15**	**-0.14**	-0.01	-0.12	-0.07	0.08	-0.03	-0.04	0.02	-0.10	-0.10	-0.12	-0.02	-0.06

Legend: MX- maxillary; MN- mandibular; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; MD- mesiodistal; BL- buccolingual

Table 7-2. Correlation coefficients of permanent teeth and fingerprints of Australian male twins.

Variables	TFP	TRC	TWLC	IFP	IRC	IWLC	MFP	MRC	MWLC	RFP	RRC	RWLC	LFP	LRC	LWLC
MXI1MD	0.02	-0.07	-0.01	0.12	-0.12	0.02	0.02	-0.03	-0.01	0.12	0.00	-0.10	-0.01	0.07	0.01
MXI1BL	0.00	0.06	0.02	0.05	-0.03	0.07	0.03	-0.05	0.04	0.00	-0.11	0.01	-0.06	-0.08	0.07
MXCMD	0.02	0.00	0.00	-0.01	**0.18**	0.04	-0.02	0.09	-0.05	-0.02	0.09	0.03	-0.02	0.13	0.03
MXCBL	0.02	-0.05	0.06	0.02	-0.08	0.08	-0.07	**-0.15**	0.02	0.06	**-0.14**	0.01	0.00	-0.11	0.04
MXM1MD	-0.02	-0.13	-0.11	-0.13	0.03	-0.01	-0.05	-0.02	-0.08	-0.05	-0.02	-0.07	**-0.19**	0.08	-0.03
MXM1BL	0.05	**-0.17**	-0.07	-0.06	0.01	-0.07	-0.01	-0.09	-0.09	0.00	-0.04	0.00	-0.09	-0.04	0.01
MXM1CT	-0.02	-0.03	0.02	0.07	0.04	0.01	0.05	**-0.18**	-0.03	0.11	-0.09	0.00	0.05	0.01	0.03
MXM2MD	-0.05	**-0.19**	-0.01	-0.01	**-0.17**	0.00	-0.09	-0.13	0.06	0.02	-0.04	0.06	-0.05	0.00	0.03
MXM2BL	0.05	-0.09	0.06	0.08	-0.05	0.05	0.03	-0.06	**0.15**	0.13	-0.05	0.06	0.05	0.01	0.07
MNI1MD	-0.05	0.01	-0.10	-0.01	0.01	-0.10	-0.08	-0.04	-0.04	0.00	0.10	-0.08	-0.04	0.12	-0.02
MNI1BL	0.00	0.01	-0.10	0.03	-0.02	-0.06	-0.04	**-0.15**	0.00	-0.08	-0.06	-0.05	-0.10	-0.03	-0.03
MNI2MD	0.00	-0.07	**-0.15**	0.03	0.03	-0.08	-0.10	0.00	-0.01	0.02	**0.14**	-0.08	-0.02	0.06	**-0.17**
MNI2BL	0.07	0.01	-0.11	-0.04	-0.09	-0.08	-0.07	-0.06	-0.05	-0.01	-0.07	**-0.14**	0.01	**-0.14**	**-0.14**
MNCMD	-0.01	-0.05	-0.01	-0.04	0.03	-0.02	-0.01	-0.06	0.07	0.02	-0.03	-0.07	-0.11	0.03	-0.08
MNCBL	**0.16**	-0.01	-0.07	0.12	**-0.15**	-0.01	0.00	-0.07	-0.02	**0.14**	**-0.18**	**-0.15**	0.11	**-0.14**	**-0.17**
MNM1MD	-0.06	-0.13	-0.01	-0.04	0.01	0.06	-0.09	0.03	0.04	0.02	-0.02	0.08	-0.08	0.05	0.09
MNM1BL	0.02	**-0.18**	**-0.17**	0.00	0.03	-0.13	0.06	-0.08	-0.12	0.01	-0.05	-0.08	-0.08	-0.03	-0.02
MNM2MD	-0.06	0.10	0.09	-0.11	-0.05	-0.07	-0.05	-0.03	0.03	0.00	-0.01	-0.02	-0.09	0.01	-0.01
MNM2BL	0.02	-0.02	0.04	**0.14**	-0.01	-0.07	0.07	**-0.21**	0.08	0.01	-0.07	0.02	0.03	0.04	0.03

Legend: MX- maxillary; MN- mandibular; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; MD- mesiodistal; BL- buccolingual

Table 7-3. Correlation coefficients of primary teeth and fingerprints of Australian female twins.

Variables	TFP	TRC	TWLC	IFP	IRC	IWLC	MFP	MRC	MWLC	RFP	RRC	RWLC	LFP	LRC	LWLC
MXI1MD	-0.07	0.04	0.09	-0.02	-0.02	**0.18**	-0.07	-0.13	**0.21**	-0.09	0.01	0.06	0.02	-0.07	0.09
MXI1BL	0.06	0.04	0.11	0.03	0.02	0.12	-0.06	-0.01	**0.23**	0.05	-0.01	0.09	0.11	0.05	0.03
MXCMD	0.04	0.01	**0.13**	0.02	-0.03	0.07	-0.08	-0.09	0.05	0.00	-0.04	0.07	-0.03	-0.07	0.12
MXCBL	**0.17**	0.07	0.06	0.01	0.12	0.01	0.05	-0.05	0.02	0.07	-0.03	-0.11	-0.01	0.00	-0.05
MXM1MD	0.05	**-0.15**	0.07	0.05	**-0.21**	**0.14**	-0.01	**-0.15**	0.13	0.07	**-0.20**	0.08	0.05	-0.12	**0.17**
MXM1BL	0.04	0.02	0.12	0.05	-0.06	0.08	0.06	-0.06	0.07	**0.16**	-0.01	0.06	0.09	-0.02	0.09
MXM2MD	0.10	**-0.15**	0.12	**0.13**	**-0.16**	0.12	0.08	**-0.15**	0.02	0.07	**-0.17**	0.10	0.04	-0.12	**0.19**
MXM2BL	0.12	-0.03	0.10	-0.02	-0.07	0.07	0.00	-0.13	0.01	0.13	-0.08	0.01	0.01	-0.03	0.09
MXM2CT	0.11	-0.08	-0.10	-0.05	-0.02	**-0.15**	-0.12	-0.08	-0.04	-0.07	0.05	-0.11	-0.11	-0.01	**-0.20**
MNI1MD	**-0.14**	-0.03	**0.15**	**-0.15**	-0.08	**0.20**	**-0.15**	-0.02	**0.16**	**-0.15**	-0.02	0.11	-0.08	0.01	**0.19**
MNI1BL	-0.07	-0.01	0.12	0.00	0.03	0.12	-0.11	-0.06	**0.16**	-0.05	-0.02	0.05	-0.05	0.10	0.07
MNI2MD	-0.02	-0.05	**0.17**	-0.08	-0.05	**0.27**	-0.10	0.00	**0.20**	-0.09	0.05	**0.18**	0.03	-0.06	**0.14**
MNI2BL	0.09	0.05	0.11	-0.06	0.07	**0.14**	-0.03	0.05	0.12	0.03	0.05	0.07	0.04	0.07	0.06
MNCMD	0.03	-0.03	0.11	0.00	0.05	0.07	-0.04	-0.02	0.05	-0.03	-0.03	0.03	-0.05	-0.01	0.11
MNCBL	0.08	0.07	-0.05	-0.05	0.04	-0.01	-0.02	0.02	-0.03	0.03	0.02	**-0.15**	-0.04	0.09	-0.12
MNM1MD	-0.04	**-0.13**	0.05	-0.04	**-0.15**	0.10	-0.04	-0.10	**0.14**	-0.06	-0.11	0.07	-0.02	-0.09	**0.15**
MNM1BL	0.03	0.05	0.09	-0.03	0.00	0.06	-0.08	-0.06	0.12	0.01	0.03	0.08	0.01	-0.03	0.12
MNM2MD	0.05	-0.09	0.12	0.00	**-0.18**	0.12	0.00	**-0.19**	0.07	-0.02	-0.11	0.10	-0.03	**-0.13**	**0.20**
MNM2BL	0.10	-0.08	0.06	-0.08	-0.05	0.06	-0.12	**-0.14**	0.07	0.02	-0.04	0.01	-0.08	-0.05	**0.14**

Legend: MX- maxillary; MN- mandibular; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; MD- mesiodistal; BL- buccolingual

Table 7-4. Correlation coefficients of permanent teeth and fingerprints of Australian female twins.

Variables	TFP	TRC	TWLC	IFP	IRC	IWLC	MFP	MRC	MWLC	RFP	RRC	RWLC	LFP	LRC	LWLC
MXI1MD	0.01	0.00	0.08	0.02	-0.07	0.05	0.07	-0.03	0.10	0.05	-0.03	0.00	-0.05	0.03	0.05
MXI1BL	0.03	0.01	0.05	-0.02	0.05	0.09	-0.01	-0.13	0.07	0.04	0.02	-0.05	0.01	-0.04	-0.07
MXCMD	0.13	**-0.14**	**0.15**	-0.04	-0.07	0.10	-0.04	-0.12	0.06	0.02	-0.06	0.06	-0.06	-0.06	0.08
MXCBL	0.11	-0.09	**0.18**	0.13	-0.12	0.08	0.01	**-0.14**	**0.15**	0.08	0.00	0.09	0.04	-0.05	0.07
MXM1MD	0.11	**-0.13**	-0.02	0.08	-0.10	0.01	0.07	-0.13	-0.02	0.08	-0.10	-0.10	0.04	0.01	0.01
MXM1BL	**0.15**	**-0.16**	0.00	0.08	-0.02	-0.03	0.01	-0.11	-0.04	0.09	-0.09	-0.13	-0.10	-0.05	-0.08
MXM1CT	0.03	0.03	-0.09	-0.08	0.03	-0.02	-0.10	-0.05	-0.04	0.06	0.01	0.02	-0.01	0.02	-0.10
MXM2MD	**0.17**	-0.07	-0.09	0.09	-0.06	0.04	-0.01	-0.05	-0.11	-0.03	0.02	-0.09	-0.13	0.01	-0.02
MXM2BL	0.11	-0.03	**0.14**	0.06	-0.08	**0.18**	-0.04	-0.07	0.09	0.09	-0.06	0.09	0.08	-0.04	0.12
MNI1MD	0.13	0.07	0.02	-0.01	-0.07	0.00	0.03	-0.02	0.07	0.01	0.06	-0.06	-0.04	0.09	-0.02
MNI1BL	**0.21**	-0.02	0.03	0.04	-0.01	0.11	-0.02	-0.12	0.00	0.04	0.06	-0.04	0.02	-0.05	-0.04
MNI2MD	0.11	0.01	0.04	-0.01	-0.07	-0.02	0.02	-0.12	0.03	0.04	-0.05	-0.06	-0.04	-0.06	-0.01
MNI2BL	**0.17**	-0.02	0.01	0.05	-0.04	0.12	0.00	-0.11	0.01	0.08	0.04	-0.08	-0.01	-0.02	-0.05
MNCMD	0.07	-0.10	0.00	0.05	-0.08	-0.01	0.01	-0.10	-0.02	-0.03	0.00	-0.06	-0.06	-0.04	0.02
MNCBL	0.06	-0.03	-0.02	-0.01	**-0.15**	0.03	-0.03	**-0.16**	0.01	0.06	-0.05	-0.06	-0.05	-0.11	-0.07
MNM1MD	0.08	-0.09	0.04	0.11	-0.06	0.04	0.07	**-0.13**	0.06	0.11	-0.10	-0.03	0.07	0.02	0.08
MNM1BL	0.03	**-0.18**	0.03	0.00	-0.02	0.11	-0.12	-0.12	0.03	0.00	-0.02	-0.05	-0.04	-0.03	0.03
MNM2MD	**0.26**	0.01	0.02	0.07	-0.04	0.10	0.06	**-0.14**	-0.05	0.10	-0.08	-0.09	0.03	-0.04	-0.02
MNM2BL	**0.17**	-0.05	**0.15**	-0.01	-0.04	**0.15**	**-0.13**	**-0.13**	0.08	-0.04	-0.01	0.00	-0.04	-0.04	**0.13**

Legend: MX- maxillary; MN- mandibular; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; MD- mesiodistal; BL- buccolingual

7.2 Associations

Table 7-5 gives Differences of Marginal Means for each model (post-hoc comparisons). For Model 1 (primary teeth), there is a statistically significant association between MD and FP, controlling for clustering on tooth nested within subject (global P value<0.0001). FP=0 has mean MD value 0.22 units greater than FP=1 while FP=1 has MD value 0.18 less than FP=2. For Model 2 (permanent teeth), there is a statistically significant association between MD and FP, controlling for clustering on tooth nested within subject (global P value<0.0001). FP=0 has mean MD value 0.31 less than FP=2, and FP=1 has MD value 0.41 less than FP=2.

For Model 7 (primary teeth), there is a statistically significant association between BL and FP, controlling for clustering on tooth nested within subject (global P value<0.0001). FP=0 has mean BL value 0.53 units greater than FP=1 and 0.45 greater than FP=2, and FP=1 has BL value 0.08 less than FP=2. For Model 8 (permanent teeth), there is a statistically significant association between BL and FP, controlling for clustering on tooth nested within subject (global P value<0.0001). FP=0 has mean BL value 0.22 units greater than FP=1 while FP=1 has BL value 0.10 less than FP=2.

To investigate the association between outcome CT binary (0, >0) and various predictors, logistic generalized estimating equations (GEE) models were performed, adjusting for clustering on tooth nested within subject (Table 7-6). There were no statistically significant associations found.

Table 7-5. Linear mixed-effects models.

Model	Type	Outcome	Predictor	Comparison	Reference	Estimate	Lower 95%	Upper 95%	p- value	Global p
1	Primary	MD	FP	0	1	0.22	0.08	0.36	0.00	<.0001
1	Primary	MD	FP	0	2	0.04	-0.12	0.19	0.66	<.0001
1	Primary	MD	FP	1	2	-0.18	-0.26	-0.11	<.0001	<.0001
2	Permanent	MD	FP	0	1	0.10	-0.14	0.34	0.42	<.0001
2	Permanent	MD	FP	0	2	-0.31	-0.57	-0.04	0.02	<.0001
2	Permanent	MD	FP	1	2	-0.41	-0.53	-0.29	<.0001	<.0001
3	Primary	MD	RC	.	.	-0.01	-0.01	0.00	0.06	0.06
4	Permanent	MD	RC	.	.	-0.04	-0.05	-0.03	<.0001	<.0001
5	Primary	MD	WLC	.	.	0.01	-0.01	0.03	0.42	0.42
6	Permanent	MD	WLC	.	.	0.00	-0.02	0.03	0.81	0.81
7	Primary	BL	FP	0	1	0.53	0.40	0.66	<.0001	<.0001
7	Primary	BL	FP	0	2	0.45	0.30	0.60	<.0001	<.0001
7	Primary	BL	FP	1	2	-0.08	-0.16	-0.01	0.03	<.0001
8	Permanent	BL	FP	0	1	0.22	0.07	0.37	0.00	0.00
8	Permanent	BL	FP	0	2	0.12	-0.04	0.28	0.15	0.00
8	Permanent	BL	FP	1	2	-0.10	-0.18	-0.03	0.01	0.00
9	Primary	BL	RC	.	.	0.00	-0.01	0.01	0.77	0.77
10	Permanent	BL	RC	.	.	0.00	-0.01	0.01	0.88	0.88
11	Primary	BL	WLC	.	.	0.02	0.00	0.03	0.09	0.09
12	Permanent	BL	WLC	.	.	0.00	-0.02	0.01	0.66	0.66

Table 7-6. Logistic or Ordinal logistic Generalized Estimating Equations (GEE) models.

Model	Type	Outcome	Predictor	Comparison	Reference	Odds Ratio	Lower 95%	Upper 95%	p- value	Global p
13	Primary	CT binary	FP	0	1	0.75	0.40	1.39	0.37	0.11
13	Primary	CT binary	FP	0	2	1.11	0.55	2.26	0.77	0.11
13	Primary	CT binary	FP	1	2	1.48	1.00	2.20	0.05	0.11
14	Permanent	CT binary	FP	0	1	0.65	0.29	1.48	0.31	0.46
14	Permanent	CT binary	FP	0	2	0.56	0.23	1.39	0.21	0.46
14	Permanent	CT binary	FP	1	2	0.87	0.55	1.36	0.54	0.46
15	Primary	CT binary	RC	.	.	0.98	0.94	1.02	.	0.25
16	Permanent	CT binary	RC	.	.	0.97	0.93	1.01	.	.
17	Primary	CT binary	WLC	.	.	0.98	0.90	1.08	.	0.73
18	Permanent	CT binary	WLC	.	.	1.01	0.92	1.11	.	0.86
19	Primary	CT	FP	0	1	0.87	0.47	1.59	0.64	0.08
19	Primary	CT	FP	0	2	1.31	0.67	2.60	0.43	0.08
19	Primary	CT	FP	1	2	1.52	1.05	2.20	0.03	0.08
20	Permanent	CT	FP	0	1	0.68	0.32	1.45	0.32	0.59
20	Permanent	CT	FP	0	2	0.67	0.30	1.50	0.33	0.59
20	Permanent	CT	FP	1	2	0.98	0.67	1.45	0.94	0.59
21	Primary	CT	RC	.	.	0.98	0.94	1.01	.	0.24
22	Permanent	CT	RC	.	.	0.99	0.96	1.02	.	0.51
23	Primary	CT	WLC	.	.	0.96	0.88	1.04	.	0.31
24	Permanent	CT	WLC	.	.	1.00	0.92	1.09	.	0.98

Table 7-7 gives Differences of Marginal Means for each model (post-hoc comparisons). For Model 35 (primary teeth) there is a statistically significant interaction between WLC and sex for outcome BL, controlling for clustering on tooth nested within subject (interaction P value=0.04). When WLC is at its mean (1.0), females have mean BL value 0.26 units greater than males.

To investigate the association between outcome CT binary (0, >0) and various predictor and sex interactions, logistic generalized estimating equations (GEE) models were performed, adjusting for clustering on tooth nested within subject, and to investigate the association between outcome CT (ordinal) and various predictor and sex interactions, ordinal logistic GEE models were performed, adjusting for clustering on tooth nested within subject (Table 7-8). There were no significant outcomes found.

Table 7-7. Linear mixed-effects models with interactions.

Model	Type	Outcome	Interaction	Comparison 1	Reference 1	Comparison 2	Reference 2	Estimate	Lower 95%	Upper 95%	p- value	Global p
25	Primary	MD	FP*Sex	0	0	Female	Male	-0.09	-0.35	0.17	0.50	0.06
25	Primary	MD	FP*Sex	0	1	Female	Female	0.28	0.10	0.47	0.00	0.06
25	Primary	MD	FP*Sex	0	2	Female	Female	0.05	-0.16	0.25	0.64	0.06
25	Primary	MD	FP*Sex	0	1	Male	Male	0.16	-0.03	0.36	0.10	0.06
25	Primary	MD	FP*Sex	0	2	Male	Male	0.10	-0.12	0.32	0.38	0.06
25	Primary	MD	FP*Sex	1	1	Female	Male	-0.21	-0.30	-0.12	<.0001	0.06
25	Primary	MD	FP*Sex	1	2	Female	Female	-0.23	-0.33	-0.14	<.0001	0.06
25	Primary	MD	FP*Sex	1	2	Male	Male	-0.06	-0.18	0.06	0.31	0.06
25	Primary	MD	FP*Sex	2	2	Female	Male	-0.04	-0.17	0.10	0.58	0.06
26	Permanent	MD	FP*Sex	0	0	Female	Male	0.14	-0.31	0.60	0.54	0.24
26	Permanent	MD	FP*Sex	0	1	Female	Female	0.15	-0.18	0.48	0.37	0.24
26	Permanent	MD	FP*Sex	0	2	Female	Female	-0.35	-0.70	0.01	0.05	0.24
26	Permanent	MD	FP*Sex	0	1	Male	Male	0.04	-0.30	0.38	0.81	0.24
26	Permanent	MD	FP*Sex	0	2	Male	Male	-0.25	-0.62	0.12	0.18	0.24
26	Permanent	MD	FP*Sex	1	1	Female	Male	0.03	-0.12	0.18	0.65	0.24
26	Permanent	MD	FP*Sex	1	2	Female	Female	-0.50	-0.66	-0.34	<.0001	0.24
26	Permanent	MD	FP*Sex	1	2	Male	Male	-0.29	-0.47	-0.11	0.00	0.24
26	Permanent	MD	FP*Sex	2	2	Female	Male	0.24	0.02	0.45	0.03	0.24
27	Primary	MD	RC(mean)=22.3	.	.	Female	Male	-0.17	-0.26	-0.09	<.0001	0.52
28	Permanent	MD	RC(mean)=21.3	.	.	Female	Male	0.06	-0.08	0.19	0.41	0.01
29	Primary	MD	WLC(mean)=1.0	.	.	Female	Male	-0.18	-0.26	-0.09	<.0001	0.92
30	Permanent	MD	WLC(mean)=1.1	.	.	Female	Male	0.08	-0.05	0.22	0.23	0.12
31	Permanent	BL	FP*Sex	0	0	Female	Male	0.10	-0.17	0.38	0.47	0.91
31	Permanent	BL	FP*Sex	0	1	Female	Female	0.19	-0.01	0.38	0.06	0.91
31	Permanent	BL	FP*Sex	0	2	Female	Female	0.09	-0.12	0.30	0.41	0.91
31	Permanent	BL	FP*Sex	0	1	Male	Male	0.25	0.04	0.46	0.02	0.91
31	Permanent	BL	FP*Sex	0	2	Male	Male	0.14	-0.09	0.37	0.22	0.91
31	Permanent	BL	FP*Sex	1	1	Female	Male	0.16	0.07	0.25	0.00	0.91
31	Permanent	BL	FP*Sex	1	2	Female	Female	-0.10	-0.20	-0.01	0.04	0.91
31	Permanent	BL	FP*Sex	1	2	Male	Male	-0.11	-0.21	0.00	0.05	0.91
31	Permanent	BL	FP*Sex	2	2	Female	Male	0.15	0.02	0.29	0.02	0.91
32	Permanent	BL	FP*Sex	0	0	Female	Male	0.10	-0.17	0.38	0.47	0.91
32	Permanent	BL	FP*Sex	0	1	Female	Female	0.19	-0.01	0.38	0.06	0.91
32	Permanent	BL	FP*Sex	0	2	Female	Female	0.09	-0.12	0.30	0.41	0.91
32	Permanent	BL	FP*Sex	0	1	Male	Male	0.25	0.04	0.46	0.02	0.91

Continuation of Table 7-7

32	Permanent	BL	FP*Sex		0		2	Male	Male	0.14	-0.09	0.37	0.22	0.91
32	Permanent	BL	FP*Sex		1		1	Female	Male	0.16	0.07	0.25	0.00	0.91
32	Permanent	BL	FP*Sex		1		2	Female	Female	-0.10	-0.20	-0.01	0.04	0.91
32	Permanent	BL	FP*Sex		1		2	Male	Male	-0.11	-0.21	0.00	0.05	0.91
32	Permanent	BL	FP*Sex		2		2	Female	Male	0.15	0.02	0.29	0.02	0.91
33	Primary	BL	RC(mean)=22.3	.		.		Female	Male	0.27	0.19	0.34	<.0001	1.00
34	Permanent	BL	RC(mean)=21.3	.		.		Female	Male	0.16	0.08	0.24	0.00	0.51
35	Primary	BL	WLC(mean)=1.0	.		.		Female	Male	0.26	0.18	0.33	<.0001	0.04
36	Permanent	BL	WLC(mean)=1.1	.		.		Female	Male	0.15	0.07	0.24	0.00	0.44

Table 7-8. Logistic Generalized Estimating Equations (GEE) models with interactions.

Model	Type	Outcome	Interaction	Comparison 1	Reference 1	Comparison 2	Reference 2	Odd Ratio	Lower 95%	Upper 95%	p- value	Global p
37	Primary	CT binary	FP*Sex	0	0	Female	Male	0.50	0.14	1.80	0.29	0.97
37	Primary	CT binary	FP*Sex	0	1	Female	Female	0.68	0.28	1.68	0.41	0.97
37	Primary	CT binary	FP*Sex	0	2	Female	Female	1.04	0.39	2.78	0.94	0.97
37	Primary	CT binary	FP*Sex	0	1	Male	Male	0.79	0.33	1.90	0.60	0.97
37	Primary	CT binary	FP*Sex	0	2	Male	Male	1.14	0.39	3.30	0.82	0.97
37	Primary	CT binary	FP*Sex	1	1	Female	Male	0.58	0.37	0.90	0.01	0.97
37	Primary	CT binary	FP*Sex	1	2	Female	Female	1.52	0.93	2.46	0.09	0.97
37	Primary	CT binary	FP*Sex	1	2	Male	Male	1.44	0.74	2.82	0.29	0.97
37	Primary	CT binary	FP*Sex	2	2	Female	Male	0.55	0.26	1.14	0.11	0.97
38	Permanent	CT binary	FP*Sex	0	0	Female	Male	0.44	0.08	2.41	0.35	0.28
38	Permanent	CT binary	FP*Sex	0	1	Female	Female	0.57	0.18	1.78	0.33	0.28
38	Permanent	CT binary	FP*Sex	0	2	Female	Female	0.72	0.22	2.36	0.58	0.28
38	Permanent	CT binary	FP*Sex	0	1	Male	Male	0.74	0.20	2.71	0.64	0.28
38	Permanent	CT binary	FP*Sex	0	2	Male	Male	0.42	0.10	1.80	0.24	0.28
38	Permanent	CT binary	FP*Sex	1	1	Female	Male	0.57	0.33	0.98	0.04	0.28
38	Permanent	CT binary	FP*Sex	1	2	Female	Female	1.25	0.73	2.15	0.41	0.28
38	Permanent	CT binary	FP*Sex	1	2	Male	Male	0.58	0.26	1.30	0.19	0.28
38	Permanent	CT binary	FP*Sex	2	2	Female	Male	0.26	0.12	0.60	0.00	0.28
39	Primary	CT binary	RC(mean)=22.3	.	.	Female	Male	0.58	0.39	0.86	0.01	0.54
40	Permanent	CT binary	RC(mean)=21.3	.	.	Female	Male	0.46	0.29	0.72	0.00	0.71
41	Primary	CT binary	WLC(mean)=1.0	.	.	Female	Male	0.57	0.38	0.84	0.00	0.85
42	Permanent	CT binary	WLC(mean)=1.1	.	.	Female	Male	0.46	0.29	0.72	0.00	0.74
43	Primary	CT	FP*Sex	0	0	Female	Male	0.56	0.18	1.77	0.33	0.96
43	Primary	CT	FP*Sex	0	1	Female	Female	0.77	0.31	1.95	0.59	0.96
43	Primary	CT	FP*Sex	0	2	Female	Female	1.20	0.45	3.22	0.72	0.96
43	Primary	CT	FP*Sex	0	1	Male	Male	0.92	0.45	1.89	0.82	0.96
43	Primary	CT	FP*Sex	0	2	Male	Male	1.38	0.58	3.32	0.47	0.96
43	Primary	CT	FP*Sex	1	1	Female	Male	0.67	0.45	1.00	0.05	0.96
43	Primary	CT	FP*Sex	1	2	Female	Female	1.55	0.96	2.49	0.07	0.96
43	Primary	CT	FP*Sex	1	2	Male	Male	1.50	0.86	2.64	0.16	0.96
43	Primary	CT	FP*Sex	2	2	Female	Male	0.65	0.34	1.26	0.20	0.96
44	Permanent	CT	FP*Sex	0	0	Female	Male	0.56	0.12	2.52	0.45	0.50
44	Permanent	CT	FP*Sex	0	1	Female	Female	0.69	0.23	2.09	0.51	0.50
44	Permanent	CT	FP*Sex	0	2	Female	Female	0.92	0.29	2.93	0.88	0.50
44	Permanent	CT	FP*Sex	0	1	Male	Male	0.59	0.20	1.70	0.33	0.50

Continuation of Table 7-8

44	Permanent	CT	FP*Sex	0	2	Male	Male	0.52	0.17	1.54	0.24	0.50
44	Permanent	CT	FP*Sex	1	1	Female	Male	0.47	0.30	0.74	0.00	0.50
44	Permanent	CT	FP*Sex	1	2	Female	Female	1.32	0.80	2.18	0.27	0.50
44	Permanent	CT	FP*Sex	1	2	Male	Male	0.88	0.51	1.54	0.66	0.50
44	Permanent	CT	FP*Sex	2	2	Female	Male	0.32	0.17	0.59	0.00	0.50
45	Primary	CT	RC(mean)=22.3	.	.	Female	Male	0.58	0.39	0.86	0.01	0.54
46	Permanent	CT	RC(mean)=21.3	.	.	Female	Male	0.46	0.29	0.72	0.00	0.71
47	Primary	CT	WLC(mean)=1.0	.	.	Female	Male	0.57	0.38	0.84	0.00	0.85
48	Permanent	CT	WLC(mean)=1.1	.	.	Female	Male	0.46	0.29	0.72	0.00	0.74

7.3 Principal components analysis (PCA)

Principal components analysis (PCA) was undertaken to explore patterns of covariation within the data. Analysis was conducted on primary tooth size data, permanent tooth size data, finger ridge counts, and combinations of data for primary tooth size/ridge count and permanent tooth size/ridge count. The Carabelli trait was excluded from the dental data due to being measured on a different scale and due to the complexity of the zero-inflated data. Finger pattern was excluded from the dermatoglyphic data due to its categorical data structure. White line count was excluded from the dermatoglyphic data due to the complexity of the zero-inflated data.

7.3.1 Primary teeth and fingerprints

The percentages of variation accounted for by the first five principal components for each model were as follows:

PC1 39.2%

PC2 7.8%

PC3 6.2%

PC4 5.4%

PC5 3.0%

PC1 accounted for 39.2% and indicated overall primary tooth size and finger ridge counts appear to be uncorrelated. PC1 represents tooth size variability only. PC2 (7.8%) showed anterior buccolingual (BL) dimensions of primary teeth are correlated with finger ridge counts on all fingers. PC3 (6.2%) represents ridge counts only and all fingers are positively correlated. PC4 (5.4%) indicated anterior mesiodistal (MD) dimensions to be negatively correlated with all posterior dimensions and no

association with fingerprint ridge counts. PC5 accounted for 3.0% and showed weak association between maxillary MD dimensions of lateral incisors and ridge counts of right middle finger, right ring finger and left little finger; and negative correlation with MD dimension of all canines and ridge counts of right little finger (see Figures 7-1 to 7-5).

In Figures 7-6 to 7-8, we can see comparisons of PC1, PC2 and PC3 in terms of sex and zygosity. Males are observed to be more positive for PC3 than females.

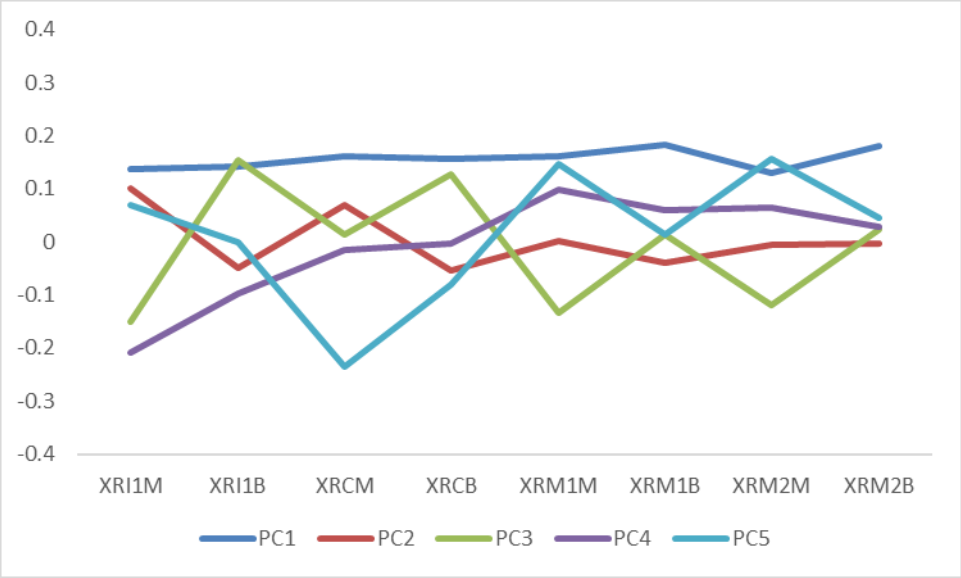

Figure 7-1. PCA graph for primary maxillary right teeth and finger ridge count.
Legend: X- maxillary; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

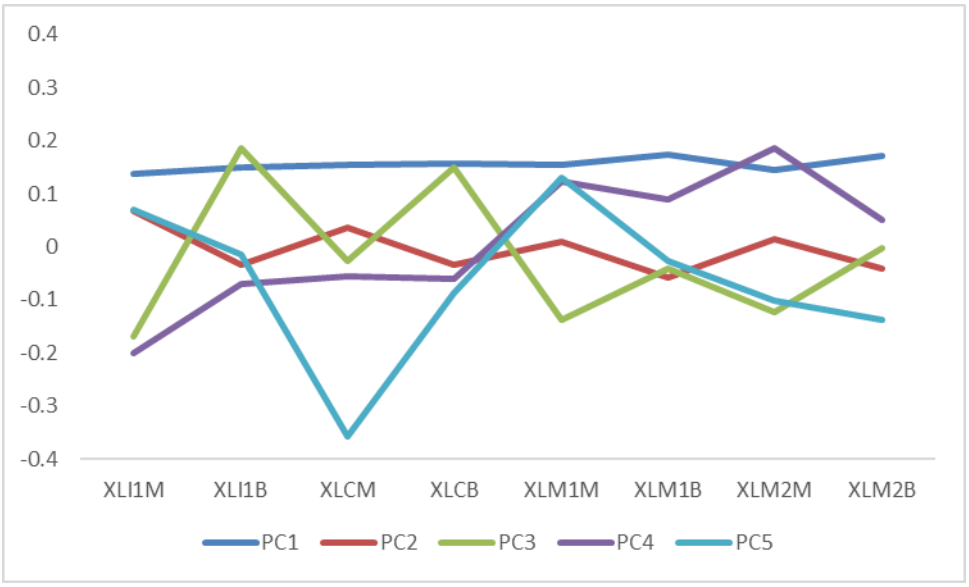

Figure 7-2. PCA graph for primary maxillary left teeth and finger ridge count.
Legend: X- maxillary; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

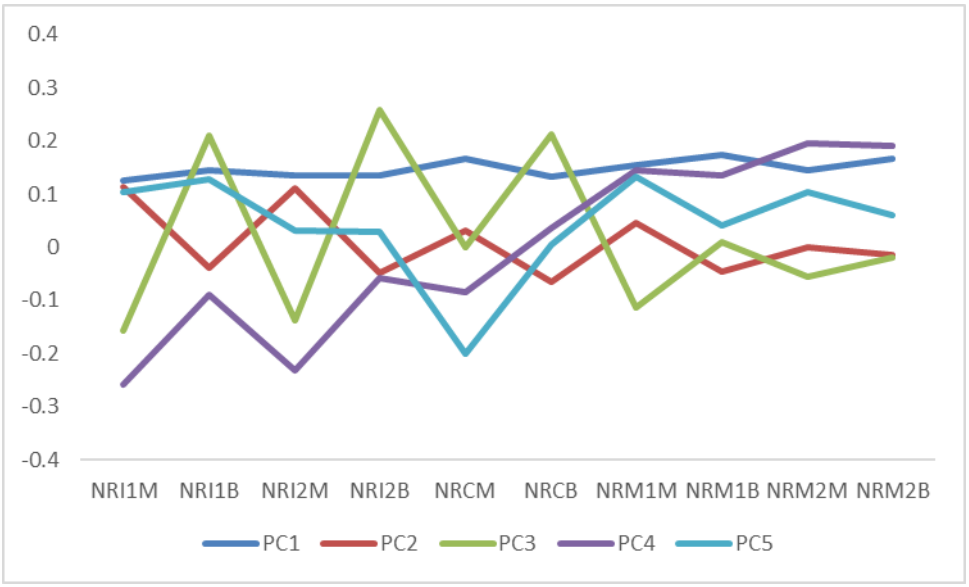

Figure 7-3. PCA graph for primary mandibular right teeth and finger ridge count.
Legend: N- mandibular; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

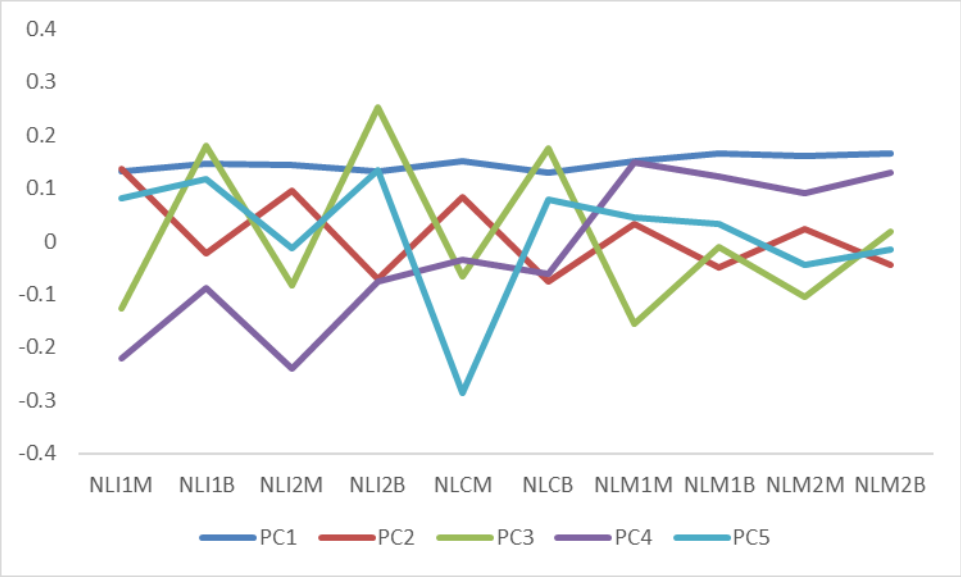

Figure 7-4. PCA graph for primary mandibular left teeth and finger ridge count.
Legend: N- mandibular; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

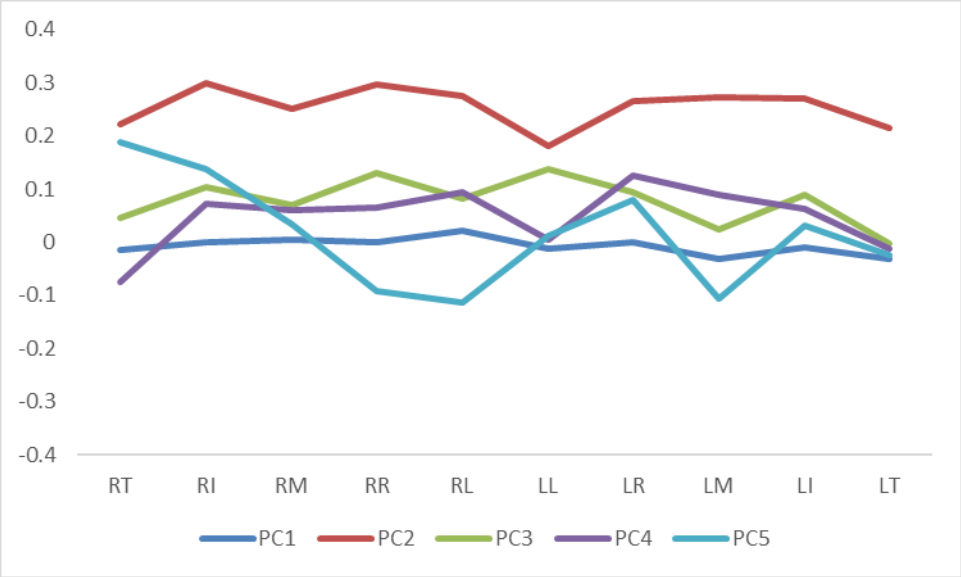

Figure 7-5. PCA graph for finger ridge count and primary teeth.
Legend: R- right; L- left; T-thumb; I-index; M-middle; R-ring; L-little

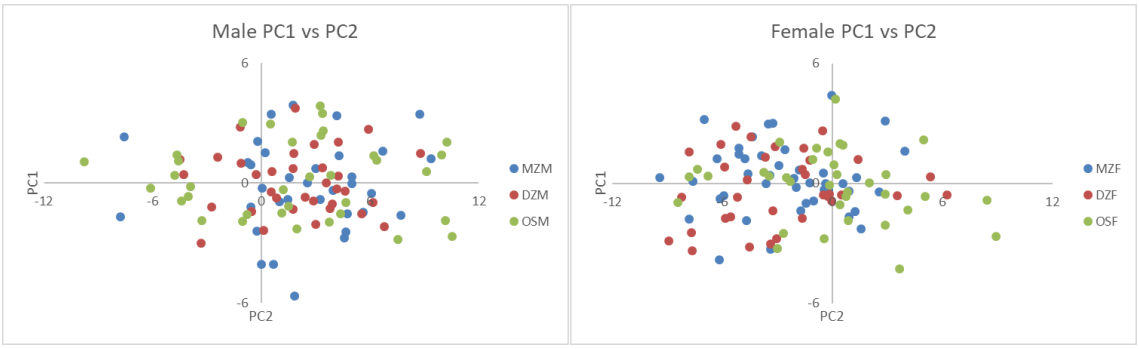

Figure 7-6. Sex and zygosity comparisons of PC1 and PC2 of primary teeth and fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

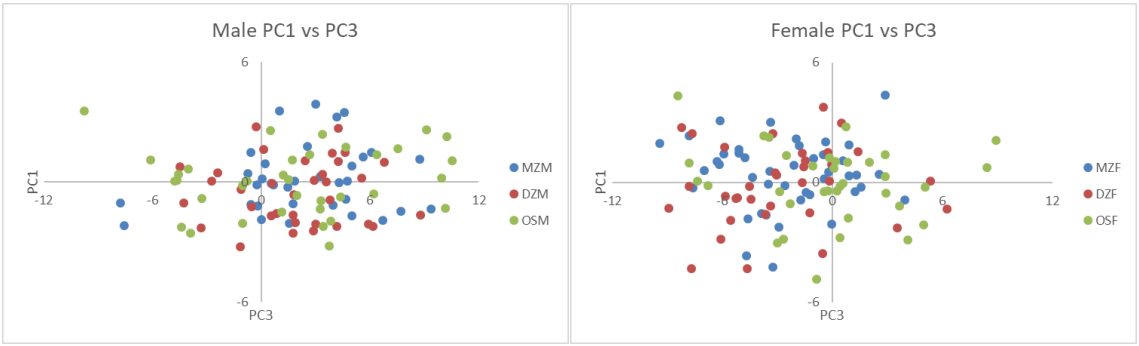

Figure 7-7. Sex and zygosity comparisons of PC1 and PC3 of primary teeth and fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

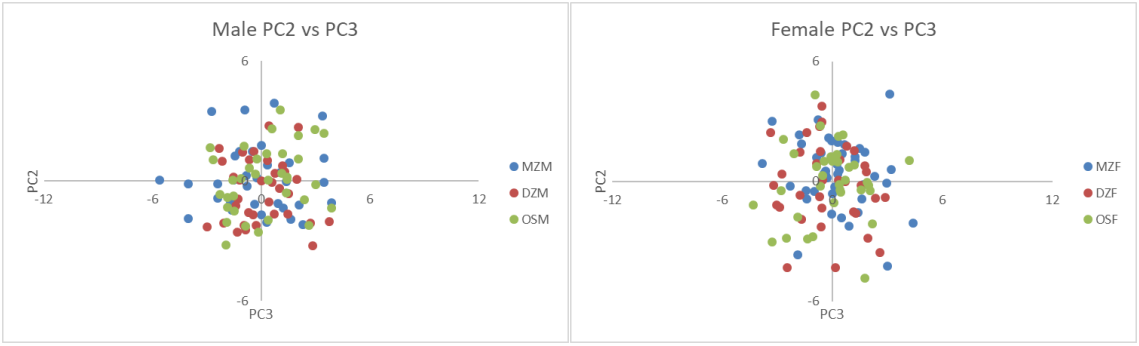

Figure 7-8. Sex and zygosity comparisons of PC2 and PC3 of primary teeth and fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

7.3.2 Permanent teeth and fingerprints

The percentages of variation accounted for by the first five principal components for each model were as follows:

PC1 42.0%

PC2 7.3%

PC3 6.8%

PC4 5.5%

PC5 2.9%

PC1 accounted for 42.0% and indicated overall permanent tooth size and finger ridge counts appear to be uncorrelated. PC1 represents tooth size variability only. PC2 (7.3%) represents finger ridge counts and all fingers are positively correlated. There were also minor positive correlation with mandibular, anterior mesiodistal (MD) dimensions. PC3 (6.8%) indicated the contrast between anterior MD and anterior buccolingual (BL dimensions), particularly in the mandible. PC4 (5.5%) indicated a positive correlation between central incisors MD dimensions in the maxilla and all incisor dimensions in the mandible; and a negative correlation with molar teeth in all arcades. PC5 accounted for 2.9% and showed positive correlation between MD dimensions on the canines and RC of the right ring finger, right little finger and left middle finger; and negative correlation with RC of the right thumb and right index finger (see Figures 7-9 to 7-13).

In Figures 7-14 to 7-16, we can see comparisons of PC1, PC2 and PC3 in terms of sex and zygosity. Males were observed to be more positive for PC1 than females,

DZOS females were slightly more positive for PC1 than MZ and DZSS females. Females were more variable for PC3 than males.

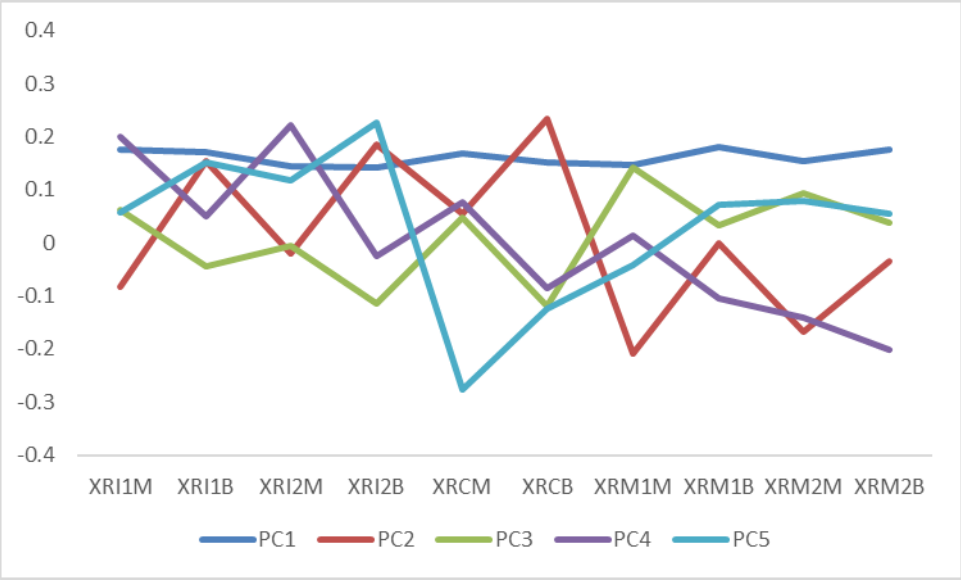

Figure 7-9. PCA graph for permanent maxillary right teeth and finger ridge count.
Legend: X- maxillary; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

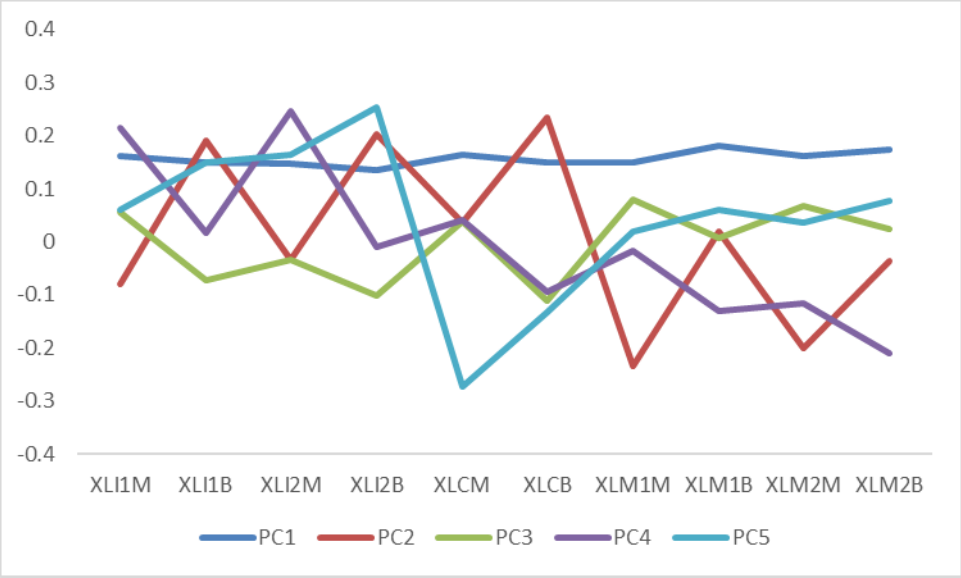

Figure 7-10. PCA graph for permanent maxillary left teeth and finger ridge count.
Legend: X- maxillary; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

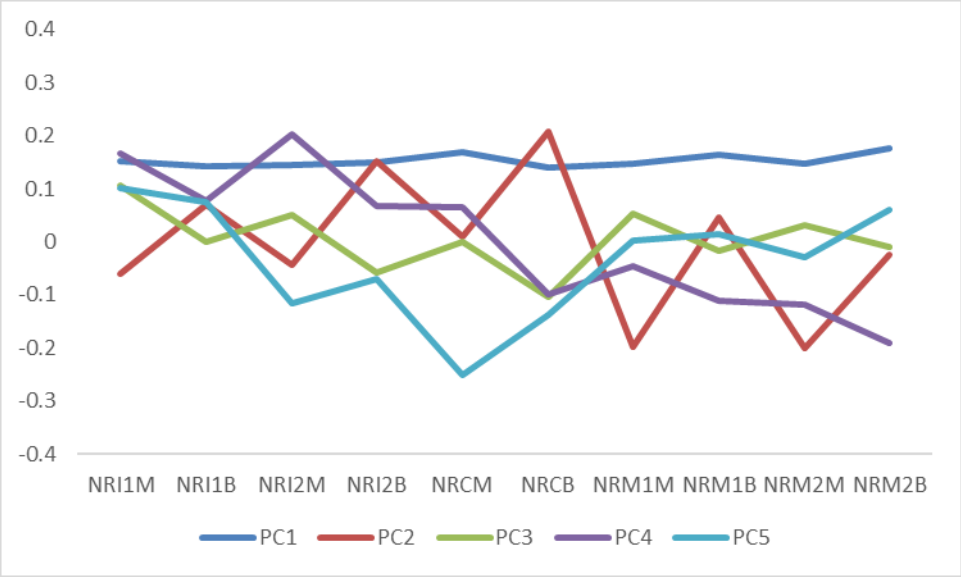

Figure 7-11. PCA graph for permanent mandibular right teeth and finger ridge count.
Legend: N- mandibular; R- right; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

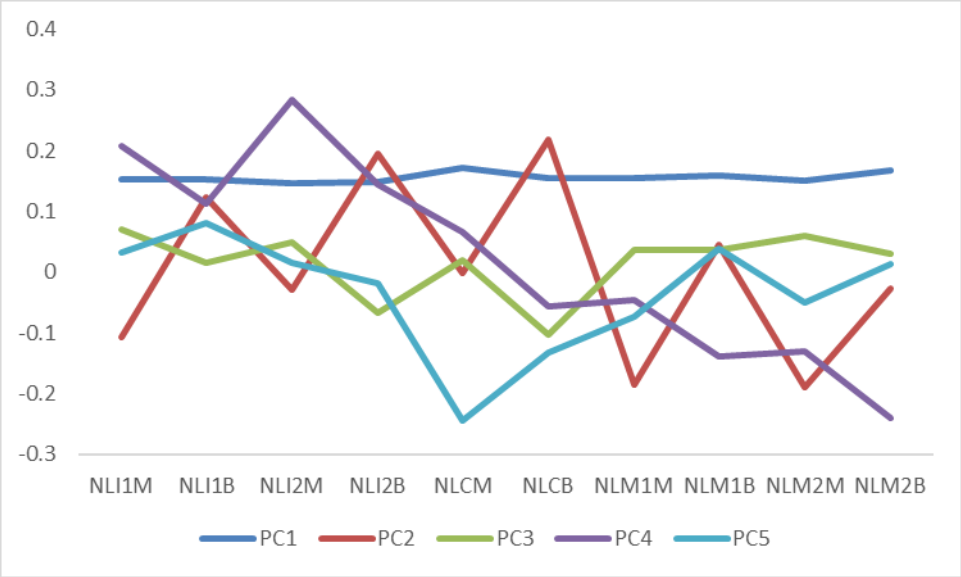

Figure 7-12. PCA graph for permanent mandibular left teeth and finger ridge count.
Legend: N- mandibular; L- left; I1- central incisor; I2- lateral incisor; C- canine; M1- first molar; M2- second molar; M- mesiodistal; B- buccolingual

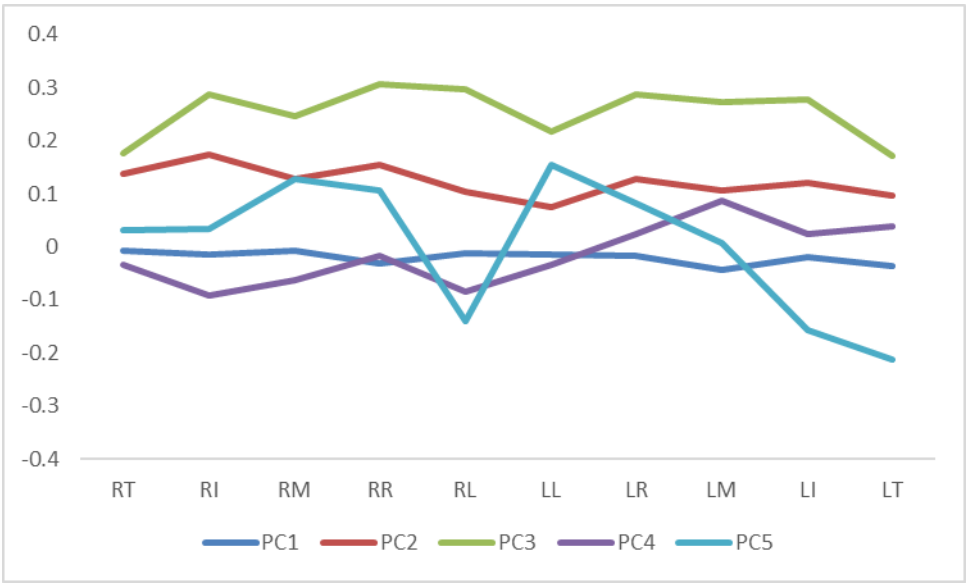

Figure 7-13. PCA graph for finger ridge count and permanent teeth.
Legend: R- right; L- left; T-thumb; I-index; M-middle; R-ring; L-little

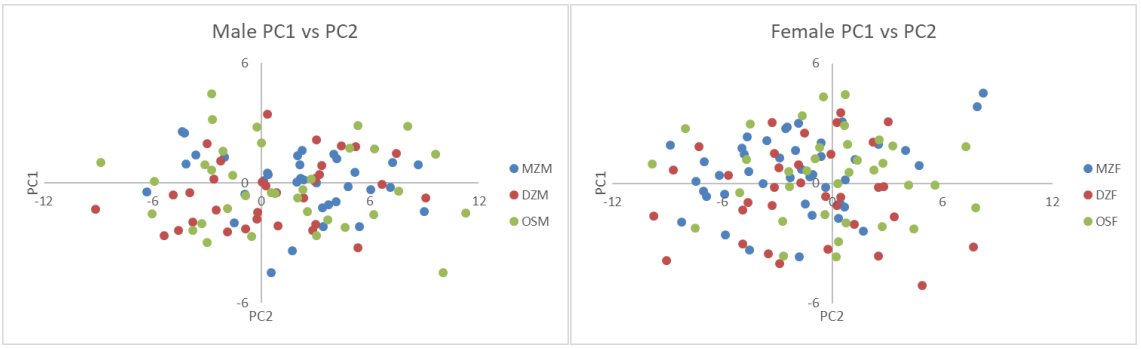

Figure 7-14. Sex and zygosity comparisons of PC1 and PC2 of permanent teeth and fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

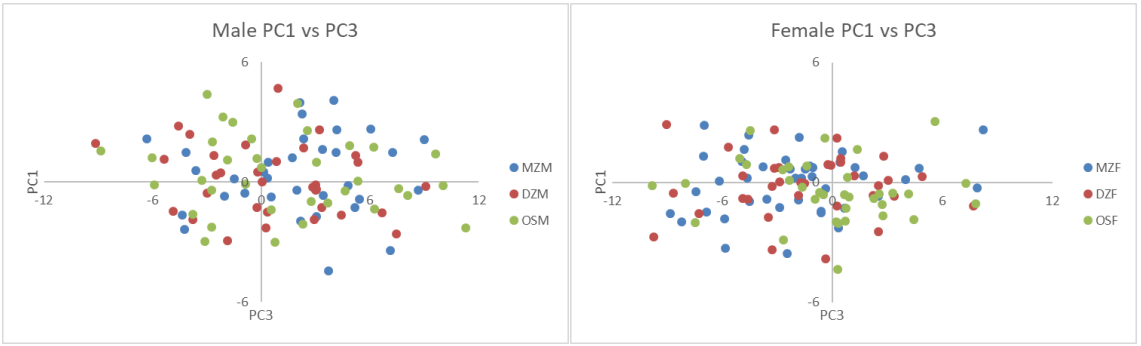

Figure 7-15. Sex and zygosity comparisons of PC1 and PC3 of permanent teeth and fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

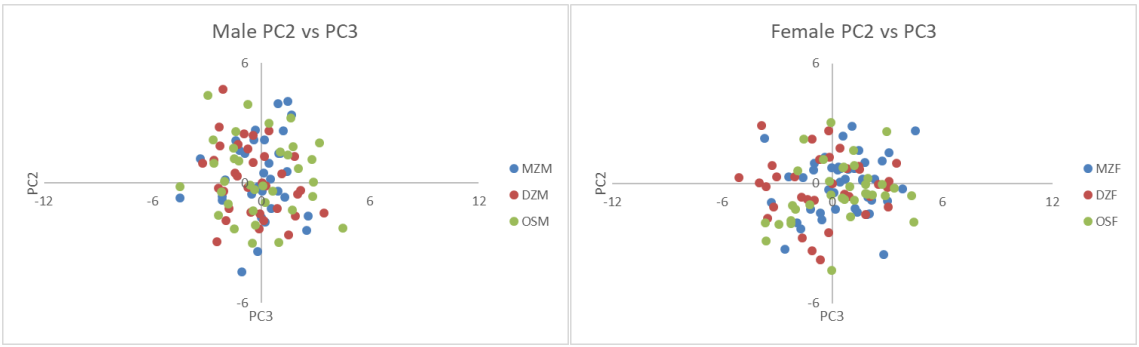

Figure 7-16. Sex and zygosity comparisons of PC2 and PC3 of permanent teeth and fingerprints.
Legend: MZM- monozygotic male twins; DZM- dizygotic same sex male twins; OSM- dizygotic opposite sex male twins; MZF- monozygotic female twins; DZF- dizygotic same sex female twins; OSF- dizygotic opposite sex female twins

Chapter 8 Discussion

8.1 Significance of the results

Using data from twins allowed this research to examine the influence of genetic, epigenetic, and environmental factors in the development of human teeth and fingerprints, which is essential for many fields of study, such as anthropology, biology, dentistry, forensics, and medicine. Findings indicate that both dental and dermatoglyphic development are Complex Adaptive Systems, in which the factors interact and the outcomes show a range of variation.

This research is the first to investigate both human dental and dermatoglyphic traits in the same sample. Although a number of studies have been conducted on human dentition and dermatoglyphs separately, no attempt has been made previously to explore possible correlations and associations between the two phenotypes and their respective developmental process. The development of the human dentition and of dermatoglyphs has similar embryological origin from epithelial-mesenchymal interactions (Nanci, 2008).

Dental and dermatoglyphic patterns both develop in utero, and once stabilised, their unique and persistent morphology makes them valuable models in studying the nature and extent of sexual dimorphism.

8.2 Methodologies

This investigation was able to utilise a unique sample in which the individuals studied and the material examined had been carefully gathered. Serial dental casts of primary and permanent dentitions, and rolled ink prints of fingers of individuals aged 8 to 10 years of the same set of monozygotic and dizygotic Australian twins were obtained from the ongoing longitudinal studies of the Craniofacial Biology Research Group in the School of Dentistry at the University of Adelaide (Townsend et al., 2012). All participants were of European ancestry and had no relevant medical and dental history that could influence the study (Townsend et al., 2005; Hughes et al., 2007). The study sample included 103 males and 112 females, which were further divided by zygosity into six groups: 43 MZ same-sex female (MZF), 34 MZ same-sex male (MZM), 34 DZ same-sex female (DZSSF), 34 DZ same-sex males (DZSSM), and 35 DZ opposite-sex females (DZOSF), and 35 DZ opposite-sex males (DZOSM) twin pairs. Results of the power analysis determined that approximately 40 individuals per group (sex) would be needed to provide the desired power and these were randomly selected from the total sample of twins in the collection. Thus, the sample allows confidence in the results.

The 2D imaging system and the measurement technique utilised has been previously validated and used in the study of Ribeiro et al. (2013). Dental casts were oriented using a tripod to obtain correct plane or angle in taking images and a calibrated Image J software (National Institute of Health, USA) was used to digitize landmarks. Measurements were obtained from central incisors (I1), lateral incisors (I2), canines (C), first molars (M1) and second molars (M2) of primary and permanent teeth. The dental dimensions measured were the maximum mesiodistal crown diameter (MD),

which refers to the distance between the mesial and distal contact points of the tooth crown (Brook et al., 1999; Brook et al., 2005), and the maximum buccolingual (BL) or labiolingual diameter, which refers to the breadth or distance between the buccal/labial and lingual surfaces of the crown (Brook et al., 1999; Brook et al., 2005). Primary second and permanent first molars were also scored for expression of Carabelli trait, a feature that varies in expression from small pits and grooves to large accessory cusps, by strictly following the procedures indicated in the Arizona Dental Anthropology Scoring System (Turner et al., 1991), which is the widely used scoring system in dental anthropology. Thus, for the dental results, the measurement techniques were carefully chosen, were well proven, and allow confidence in the results.

The ten-prints selected for the dermatoglyphic component of this research were scanned using the maximum image dot density and print quality for accuracy and precision, and this method has been validated in previous fingerprint studies (Gutierrez-Redomero et al., 2008; Mundorff et al., 2014; Taduran et al., 2016; Taduran et al., 2017). ImageJ software (National Institute of Health, USA) was used in calibration and counting. Fingerprint pattern (FP) was classified by type, that is, whether arches, loops or whorls. The dermatoglyphic traits recorded were a modified ridge count (RC), or the number of ridges that touch a straight one-centimetre line that is not influenced by finger patterns (Taduran et al., 2017) was employed, and white lines count (WLC), which was extracted manually (Taduran et al., 2016). Ridge and white line counts, and fingerprint patterns were obtained from all the fingerprints. Thus, the dermatoglyphic measurement techniques allow confidence in the results.

The importance of teeth and fingerprints as a model system for general human development is further emphasised through the updated methodologies and correlations in both phenotypes. Consistency between two or more measurements of an object under the same experimental conditions can be improved further by repeat measurements (Harris and Smith, 2009). Results of the paired t-tests and κ-statistic showed no significant systematic errors occurred in the research. No evidence of substantial random errors was observed according to the Dahlberg formula as well. Overall, the chance of errors in data collection was highly unlikely or slim to none. Therefore, the data obtained in this study is accurate, precise, reliable and valid.

8.3 Discussion on dental findings

The degree and patterning of sexual dimorphism in the dentition varies according to tooth type. The permanent dentition showed more pronounced sexual dimorphism than the primary dentition, and it agrees with previous findings of Ribeiro et al. (2012). The permanent lower canines displayed the greatest sexual dimorphism in MD measurements, similar to the results of Garn et al. (1967) and Ribeiro et al. (2012). The permanent molars showed the largest sexual dimorphism in BL measurements, similar to previous studies (Ząd́zínska et al., 2008; Girija and Ambika, 2012). It has been suggested that dental development might occur under relatively high levels of testosterone influence (Ribeiro et al., 2012), and this could explain the differences in sexual dimorphism between primary and permanent teeth of same individuals. Primary and permanent teeth start to form in utero at different times. The primary teeth develop around 4-6 weeks post-conception, while the permanent teeth start around 16 weeks of gestation. Furthermore, tooth crown dimensions form at different times: the mesiodistal dimension is formed when tooth crown formation reaches its greatest

convexity in size, and the buccolingual dimension is shaped when the dental crown is nearly completed.

There was also sexual dimorphism observed in the Carabelli trait, with males having greater scores than females in both primary second molars and permanent first molars, which is consistent with previous findings for the permanent dentition (Noss et al., 1983; Kieser, 1984; Hsu et al, 1997; Kondo and Townsend, 2006) but contradicts previous studies on deciduous dentition (Kieser, 1984; Hsu et al, 1997; Joshi et al, 1972). The permanent first molar displayed more pronounced sexual dimorphism than the primary second molar, based on median of scores, and this agrees with findings of Ribeiro et al. (2012).

All dental variables in all tooth types were observed to be sexually dimorphic in MZ twins. Most were significantly sexually different in DZSS twins except for primary upper and lower central incisors, primary upper canines and primary upper second molars for MD dimensions; and primary lower central incisors for BL measurements. Meanwhile, only a few were observed as significantly sexually dimorphic in DZOS twins, which were, in MD measurements, for primary teeth: upper right ad left first molar, upper right second molar, and lower right canine; and for permanent teeth: upper and lower canines; and in BL measurements, for primary teeth: upper right first and second molars; and for permanent teeth: upper left first molar, lower right canine, and lower right first molar. The Carabelli trait (CT) scores in DZOS twins had no male-female differences as well. From these results, it can be deducted the strong influence of genetics in the sexual dimorphism of the teeth. Comparisons between MZ and DZ twins were done to evaluate the extent of genetic and environmental influences on

certain traits. MZ twins share 100% of their genes, DZ twins can be DZSS (same-sex) or DZOS (opposite-sex) and share, on average, 50% of their genes.

Sexual dimorphism percentage (SD%) was quantified for all variables by calculating ratios of sexual differences between males and females. These sex differences were defined by Garn et al. (1967) as ((M-F)/F)*100, where M is the mean value of males and F is the mean values of females. Most of the greatest SD% were observed from MZ twins in both MD and BL measurements, which can be seen as the strong genetic influence in sexual dimorphism.

Most of the smallest SD% were seen from DZOS twins in both MD and BL measurements. When comparing the means of MD and BL crown dimensions in female twins, DZOS females were consistently greater compared to MZ females and DZSS females. CT scores were observed as different among female twins because DZOS females obtained higher scores than MZ females and DZSS females. These results indicate that the teeth of DZOS females can be described as male-like in many characteristics because of their similarities with DZOS males.

This could be an epigenetic effect of prenatal testosterone influencing females of DZOS twin pairs in utero. There are three surges of testosterone that occur in normal male development. The first surge begins at around the 7th to 9th week of pregnancy, following testicular differentiation, and the testosterone level is at its highest around the 14th week (Reyes et al, 1974; Knickmeyer and Baron-Cohen, 2006). The second surge occurs after birth due to the reduction of oestrogen produced by the placenta (Griffin and Wilson, 2003). The third surge occurs during puberty. Primary dentition

starts to develop at around 4 to 6 weeks in utero (Nanci, 2008) and continues until around one year after birth. Permanent dentition begins to form 14 weeks in utero and continues to develop until at around 14 years of age (AlQahtani et al., 2010). Results suggest that the first two testosterone surges have a critical role in the sexual dimorphism of both the primary and permanent dentitions, and are consistent with the Twin Testosterone Transfer hypothesis.

DZOS pairs present a good model in determining the influence and make possible the assessment of genetic, epigenetic and environmental influences in human variation, specifically phenotypic features. The importance of this opposite-sex twin model is that males and females from DZOS twins share the same intrauterine environment and most likely develop under different concentrations of sex hormones than singletons or same-sex twins (Miller, 1994). DZOS females with more male-like traits than MZ females and DZSS females would infer prenatal testosterone transfer and therefore show the impact of epigenetics and environmental influences as well.

8.4 Discussion on dermatoglyphic findings

The degree and patterning of sexual dimorphism in the dermatoglyphs varies according to zygosity, finger type and side. There was no observed sex differences in RC. For WLC, the little finger was seen as significantly sexually different when all zygosities were pooled together. Both males and females of MZ twins had median values of 0 WLC in all ten fingers. DZOS twins were observed to have median values of 1 WLC in the left hand, particularly the thumb, middle finger and ring finger for the males; and the middle finger for the females. Yet DZOS twins did not exhibit statistically significant sexual differences in all fingers as well. The right index finger,

left middle finger, and left ring finger of DZSS twins showed significant sexual differences in WLC. If MZ twins show more similarity on a given trait compared to DZ twins, this provides evidence that genes significantly influence that certain trait. If DZOS females displayed more male-like traits, as compared with DZSS and MZ females, this would infer prenatal testosterone transfer or epigenetic factors. There is not enough evidence for this at the moment, but this study's findings suggest that WLC is mainly environmental.

Based on ordinal logistic generalized estimating equations (GEE) models performed, a statistically significant association between WLC and twin type was found. When WLC values are pooled together per zygosity, MZ females was seen significantly different with both DZ females, while there was no significant differences between DZSS and DZOS. This further supports the assumption that WLC is mainly environmental. White lines are skin folds found in friction ridges and are seen as white lines in print (Cummins and Midlo, 1943). The frequency of white lines increases later in life or when changes in subcutaneous body fat occurs (Ashbaugh, 1999; Cummins and Midlo 1943). This result could be considered original since white lines are rarely studied in the field of dermatoglyphics.

For fingerprint pattern (FP), there was no sexual differences found, as the percentages of arch, loop and whorl patterns remain consistent in both sexes. However, based on multinomial logistic models, DZOS females compared to MZ and DZSS females have 1.45 times the odds of having a loop fingerprint pattern, and 1.13 times the odds of having a whorl fingerprint versus an arch fingerprint pattern. This is statistically

significant at 95% confidence interval and could pertain to a different kind of epigenetic effect of testosterone to human development.

8.5 Discussion on dental and dermatoglyphic variables combined

Correlations between teeth and fingerprints are low in magnitude in both sexes, whether positive or negative, and whether statistically significant or insignificant differences. Based on post-hoc comparisons, there was a statistically significant association between measured dental crown traits mesiodistal (MD) and buccolingual (BL) with fingerprint pattern (FP). In primary teeth, an arch FP would suggest a mean MD value 0.22 units greater than a loop FP, and a loop FP would pertain to MD value 0.18 less than whorl. An arch FP has mean BL value 0.53 units greater than loop FP and 0.45 greater than whorl, and loop has BL value 0.08 less than whorl.

In permanent teeth, an arch FP indicate a mean MD value 0.10 units less than whorl FP, and loop FP has MD value 0.41 less than whorl FP. An arch FP has mean BL value 0.22 units greater than loop FP and loop FP has BL value 0.10 less than whorl FP.

Human development is a complex adaptive process (Brook et al., 2014) and the human body is a complex adaptive system (Kaidonis et al., 2016). This study has shown that both teeth and fingerprints are interconnected, yet they still have a degree of autonomy. They share a similar embryological origin and epithelial-mesenchymal interactions (Nanci, 2008), yet they develop and interact with epigenetic and environmental factors differently. The interactions may be unpredictable, with no

central control, but they are not random, as regularities and patterns emerge to find the best fit with the environment.

8.6 Limitations and possible future studies

This research is the first to study both human dental and dermatoglyphic traits and explore possible correlations between the two. While it is limited to teeth and fingerprint variables, this research furthers the investigation on the complex mechanisms and interactions occurring not only in dental and dermatoglyphic, but also general development. The sample did not reach power calculation but were full number available from the Twin Studies collection of the University of Adelaide and still valid for the statistics applied.

It is recommended that other dental parameters could be studied to provide more details of size and shape (e.g. area and perimeter of labial/buccal and occlusal surfaces, morphological traits such as the hypocone, metacone, paracone, protocone, metaconule, and parastyle) in relation with the Twin Testosterone Transfer (TTT) Hypothesis. Fingerprint techniques such as ridge breadth and ridge density, and palm print traits could be explored in relation with TTT as well. Fingerprint patterns need to be studied in MZ twins to determine the role of genetics in patterning, while white lines count should be studied in older twins, as the third surge of testosterone in males and occurrence of menarche in females could be factors that influence the phenotypic trait. The use of innovative technology such as 3D scanners can also be explored. In the future, more dental and dermatoglyphic traits could be studied together for more understanding of human development.

8.7 Excerpts from published papers

The published papers that are presented in the Appendix provide further discussion of how the dental traits and dermatoglyphs can be considered as Complex Adaptive Systems. Here are excerpts from the papers:

From Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (2016). Complex systems in human development: sexual dimorphism in teeth and fingerprints of Australian twins. International Journal of Design & Nature and Ecodynamics 11(4), 676-685.

“The degree and patterning of sexual dimorphism in the dentition varies according to tooth type. Our observation of the permanent dentition showing more pronounced sexual dimorphism than primary dentition agrees with previous findings. The permanent lower canines displayed the largest sexual dimorphism in MD measurements, similar to the results of Garn et al. and Ribeiro et al. who pointed out that dental development might occur under fairly high levels of testosterone influence, and this could explain the differences in sexual dimorphism between primary and permanent teeth of same individuals.

The degree and patterning of sexual dimorphism in the dermatoglyph varies according to the finger area and finger type. In this study, there was no observed sexual dimorphism in the 8 to 10 year old group, while fingerprints of the 13 to 16 year old group displayed sexual dimorphism in the ulnar and radial areas of the index finger, and radial and proximal areas of the little finger. Few studies have investigated subadult fingerprints, and our results could be preliminary empirical evidence that

friction ridges expand as individuals grow and develop, and possibly more so in males than females. It seems that sexual dimorphism in dermatoglyphic development commences during puberty, when a testosterone surge occurs in males”

From Taduran RJO, Tadeo AKV, Escalona NAC, Townsend GC. (2016). Sex determination from fingerprint ridge density and white line counts in Filipinos. HOMO - Journal of Comparative Human Biology, 67(2), 163-171.

“Our results agree with the observation by Badawi et al. (2006) that females have higher white linecounts. A comparison of WLC in males and females of Filipino origin with other populations is not possible as there are no other published studies, apart from Badawi et al.’s (2006) research, which established WLC as a significant feature for sexual determination purposes.”

From Taduran RJO, Ishimura RB, Rosario MRN, Brook AH, Townsend GC. (2017). Sex variation in fingerprint ridge counts in Filipinos. European Journal of Forensic Sciences, 4(3), 1-6.

“Although previous studies of other ancestries have indicated higher RC in males, the different methodology that we used may account for the difference in our results. Earlier RC studies used a technique dependent on fingerprint pattern. This procedure would automatically designate the RC for arches as zero and, since females are known to have a higher frequency of arches, higher RC in males would be expected as a result. What these earlier studies showed was more about the sex difference in fingerprint patterns than the nature of fingerprint ridges. We employed the method

suggested by Cummins and Midlo and overcame the problems encountered with arch pattern types when counting ridges. RC is the most consistent and reliable measurement for familial investigations and is an inherited metrical character. Its quantitative nature allows for objective characterization of fingerprints, which may be helpful in identification matching."

From Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (2018). Two complex adaptive systems in human development: further studies of dental and fingerprint parameters. International Journal of Design & Nature and Ecodynamics 13(1), 93-100.

"Our results are consistent with our previous study and support the idea that friction ridges expand as individuals grow and develop, probably more in males than females. Sexual dimorphism in dermatoglyphic development seems to be initiated during puberty, when a testosterone surge occurs in males."

Chapter 9 Conclusion

This study accomplished its general aim by measuring tooth dimensions (mesiodistal and buccolingual diameters) with an enhanced 2D analysis method and scoring the Carabelli trait with a widely used scoring system in the field of anthropology; and also counting ridges and white lines with improved methods and classifying fingerprint patterns as dermatoglyphic variables, to determine the nature and extent of sexual dimorphism in teeth and fingerprints of Australian twins who were 8-10 years old.

The results contradicted the null hypotheses by showing that:

1. there are significant differences between males and females in the expression of all dental and some dermatoglyphic traits;
2. there are significant differences between females from DZOS twin pairs and females from MZ and DZSS twin pairs in all dental and some dermatoglyphic traits; and
3. there are correlations and associations in the phenotypic expression of teeth and fingerprints.

This study has shown the strong genetic influence on sexual dimorphism of the MD and BL measurements of MZ twins, which is the only zygosity group with all tooth types observed to be sexually different. The role of environmental factors was suggested for the sexual dimorphism of WLC in DZSS twins.

Epigenetic influence in sexual dimorphism was observed in DZOS females' male-like MD and BL measurements and Carabelli scores. DZOS females were also observed to have more loop or whorl fingerprints than arch as compared to MZ females and DZSS females. The differences in tooth size and shape and fingerprint pattern provide further support for the Twin Testosterone Transfer (TTT) hypothesis.

While teeth and fingerprints showed low correlations in both sexes, it was observed that fingerprint patterns are associated with measurements of MD and BL in both primary and permanent teeth.

Key findings have been the larger tooth size and increased expression of Carabelli trait in males compared with females, and in DZOS females; and the different WLC in DZSS and fingerprint patterns in DZOS. Moreover, the findings provide further evidence that the development of teeth and the development of fingerprints are outcomes of Complex Adaptive Systems.

APPENDICES

Appendix A – Published papers relevant to dissertation

The following research papers have been published from work undertaken during PhD candidature:

Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (2016). Complex systems in human development: sexual dimorphism in teeth and fingerprints of Australian twins. International Journal of Design & Nature and Ecodynamics 11(4), 676-685.

Taduran RJO, Tadeo AKV, Escalona NAC, Townsend GC. (2016). Sex determination from fingerprint ridge density and white line counts in Filipinos. HOMO - Journal of Comparative Human Biology, 67(2), 163-171.

Taduran RJO, Ishimura RB, Rosario MRN, Brook AH, Townsend GC. (2017). Sex variation in fingerprint ridge counts in Filipinos. European Journal of Forensic Sciences, 4(3), 1-6.

Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (2018). Two complex adaptive systems in human development: further studies of dental and fingerprint parameters. International Journal of Design & Nature and Ecodynamics 13(1), 93-100.

Appendix B - List of achievements and professional development activities of Richard Jonathan Ordóñez Taduran during PhD candidature 2014 to 2018

Research scholarship

Adelaide Scholarships International (2014 to 2018) – The selection and ranking of applicants within the University of Adelaide is undertaken by the Graduate Scholarships Committee, using the criteria of academic merit and research potential.

Travel award

J.L. Eustace Travelling Award (2016) – The purpose of the travelling awards is to support undergraduate and postgraduate students of the Adelaide Dental School who are of outstanding merit to present their research findings at scientific conferences.

Published papers relevant to the dissertation

Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (2016). Complex systems in human development: sexual dimorphism in teeth and fingerprints of Australian twins. International Journal of Design & Nature and Ecodynamics 11(4), 676-685.

Taduran RJO, Tadeo AKV, Escalona NAC, Townsend GC. (2016). Sex determination from fingerprint ridge density and white line counts in Filipinos. HOMO - Journal of Comparative Human Biology, 67(2), 163-171.

Taduran RJO, Ishimura RB, Rosario MRN, Brook AH, Townsend GC. (2017). Sex variation in fingerprint ridge counts in Filipinos. European Journal of Forensic Sciences, 4(3), 1-6.

Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (2018). Two complex adaptive systems in human development: further studies of dental and fingerprint parameters. International Journal of Design & Nature and Ecodynamics 13(1), 93-100.

Other published paper during PhD candidature

Taduran RJO, Tan ML, Townsend GC. (2017). Different methods for estimating height in a Filipino sample: forensic implications. Australian Journal of Forensic Sciences, 49(1), 59-68.

Published abstracts for conference presentations during PhD candidature

Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (May 2017). Two complex adaptive systems in human development: further studies of dental and fingerprint parameters. Unpublished paper presented at the 3rd International Conference on Complex Systems, New Forest, United Kingdom.

Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (June 2016). Complex systems in human development: sexual dimorphism in teeth and fingerprints of Australian twins. Unpublished paper presented at the 2nd International Conference on Complex Systems, New Forest, United Kingdom.

Taduran RJO, Ranjitkar S, Hughes T, Townsend G, Brook AH. (December 2015). Sexual dimorphism in dermatoglyphic and dental characteristics in Australian twins. Unpublished paper presented at the 29th Annual Australasian Society for Human Biology Conference, Brisbane, Australia.

Taduran RJO, Tadeo AKV, Escalona NAC, Townsend GC. (December 2014). Sex determination from fingerprint ridge and white line counts in Filipinos. Unpublished paper presented at the 28th Annual Australasian Society for Human Biology Conference, Adelaide, Australia.

Other professional development activities:

Visited hospitals and dental clinics in Sydney, Melbourne and Canberra to collect fingerprints of Australian twins using ink and fingerprint scanner (L SCAN 1000PX) for the ongoing longitudinal studies of the Craniofacial Biology Research Group at the University of Adelaide, which is one of the four most extensive investigation of its type in the world.

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Sex determination from fingerprint ridge density and white line counts in Filipinos

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ABSTRACT

Fingerprints are distinct physical characteristics that remain unchanged throughout an individual's lifetime. This study derived Filipino-specific probability formulae from fingerprints to be used for sex discrimination in human identification cases. Ridge density from three different areas – distal radial area, distal ulnar area, and proximal area – as well as white line counts from fingerprints of 200 male and 200 female Filipinos were collected and analyzed statistically. Ridge densities of radial and ulnar areas emerged as displaying significant differences between the sexes, with 16 ridges/25 mm^2 or more in radial area and 15 ridges/25 mm^2 or more in ulnar area being more likely to be female, whereas 13 ridges/25 mm^2 or less in radial area and 12 ridges/25 mm^2 or less in ulnar area were more likely to be male. A white line count of 0 was more likely to be male while a white line count of 2 or more was more likely to be female. The results of this study show sex differences in Filipino fingerprints and support the observation of previous studies that females have finer ridges than males.

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Introduction

Fingerprints have been used extensively to establish human identity. This is because no two persons, even pairs of monozygotic twins, have the same prints. The possibility of sex differentiation using fingerprints has been attributed to the observation that females have fine epidermal ridge detail while males have coarse ridge detail (Cummins et al., 1941; Mi et al., 1982; Moore, 1994). This suggestion remained purely anecdotal until Acree's (1999) introduction of quantitative method in 1999, which verified sex differences among European and African descent Americans with empirical data.

Similar results have been achieved and confirmed in Indian (Gungadin, 2007; Kapoor and Badiye, 2015; Krishan et al., 2013; Nayak et al., 2010b; Nithin et al., 2011), European Spanish (Gutiérrez-Redomero et al., 2008), Mataco-Mataguayon (Gutiérrez-Redomero et al., 2011), Argentinian (Gutiérrez-Redomero et al., 2013), Chinese and Malaysian populations (Nayak et al., 2010a). Gutiérrez-Redomero et al. (2008) extended the chosen area of fingerprint analysis by adding two more regions, namely the ulnar and the proximal. Sex differences were found to be significant in the distal (radial and ulnar) but not proximal regions, with females having greater ridge density compared to males. Gutiérrez-Redomero et al. (2014) noted significant differences in ridge density in different areas, and also from the different recording methods (rolled and plain) of fingerprint impressions.

Meanwhile Badawi et al. (2006) introduced counting white lines as a reliable method for sex determination using fingerprints, with females having a greater number of white lines than males. White lines are skin folds in the friction ridges that appear as white lines in print, hence the name, and they increase in frequency later in life or when subcutaneous body fat changes (Ashbaugh, 1999; Cummins and Midlo, 1943).

Hand morphology and fingerprint patterns of Filipinos have never been the subject of any published journal article. Likewise, Filipino-specific sex determination techniques in the forensic sciences have never been a topic of scientific inquiry except for Taduran's (2012) formulae derived from canine measurements. The aim of this research, therefore, was to derive Filipino-specific probability formulae from fingerprints that could be used as a primary tool for sex discrimination in human identification. This was accomplished by employing the method developed by Gutiérrez-Redomero et al. (2008), based on the work of Acree (1999), to identify sex differences in ridge densities from different fingerprint locations (radial, ulnar, and proximal). Furthermore, the appearance of white lines on each of the ten fingerprints was included as a classifier. The results obtained were compared with other populations from similar studies.

This research is the first of its kind to be conducted and the data collected should prove useful in disaster, forensic and human rights cases within the Philippine setting.

Materials and methods

This research underwent the necessary ethical, legal and procedural scrutiny before being approved by Philippine National Police (PNP) officials. Fingerprint samples were obtained and scanned in the PNP Crime Laboratory Fingerprint Division located in Camp Crame, Quezon City, Philippines. A fingerprint sample refers to a single standard PNP ten-print card containing all inked fingerprint impressions of an individual when applying for police clearance.

Significant inclusion criteria for the sample were:

1. Full finger rolling for all ten impressions; and
2. No scarred patterns for any of the ten fingerprints.

Samples were obtained of ten-prints of 200 males and 200 females aged 18–57 years. All samples were classified according to fingerprint classes as loops, whorls or arches.

Three different fingerprint ridge locations, namely, distal radial area (R), distal ulnar area (U), and proximal area (P) of all ten fingerprints from each individual were chosen as areas for analysis. The Acree's method (1999) of measuring ridge density (RD) and, indirectly, the breadth of the ridges, was used. A ridge count was performed diagonally on a square measuring 5 mm × 5 mm on the three locations to isolate ridges within a well-defined area and because most fingerprint classes show a

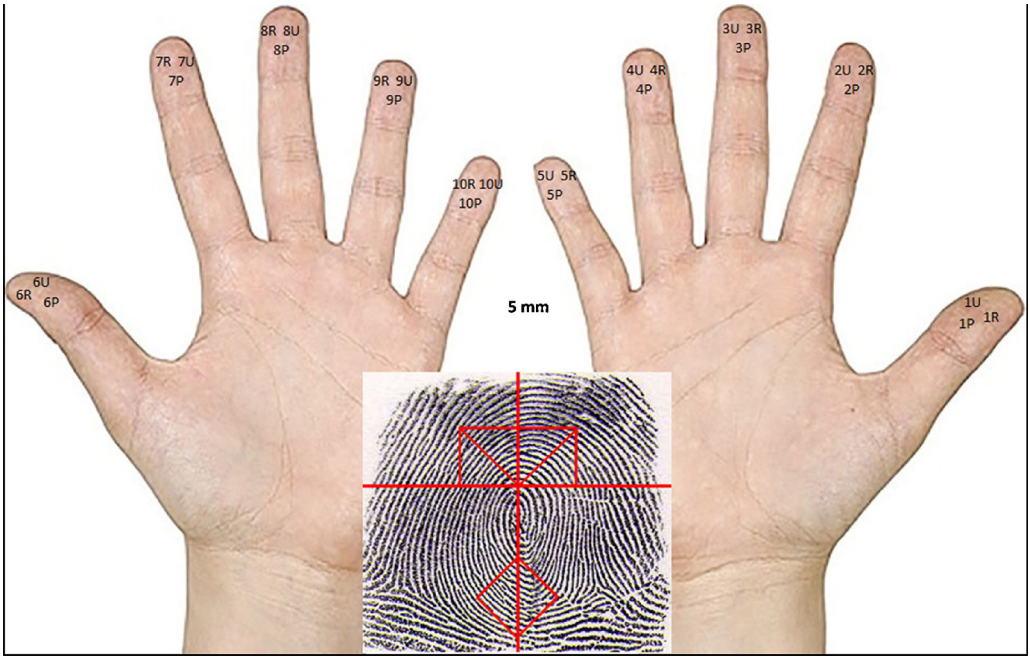

Fig. 1. Locations of ridge count areas – radial (R), ulnar (U) and proximal (P).

similar ridge flow in these regions. Dots were not counted while forks were counted as two ridges excluding the handle; a lake was counted as two ridges.

The method used by Gutiérrez-Redomero et al. (2008) for locating ridges was employed. The three areas were located by dividing loop and whorl fingerprint classes into four sectors, with two perpendicular axes that cross two ridges above the center. In the case of the arch fingerprint class, the axes traverse at the center of the dactylogram, since it has no defined midpoint. RDs were obtained per unit area (25 mm^2) in both the ulnar and radial sides of the distal area, as well as in the proximal area. In order to facilitate counting, images were enlarged to four times their original size, on which a 20 mm × 20 mm area was defined. Intra and inter-operator repeatability tests were conducted on all fingerprint areas on 100 samples.

The ridge counts for the three areas (radial, ulnar, and proximal) of all ten fingers of each individual allowed the mean for each area and each finger to be estimated for both sexes. The differences between sexes for the radial, ulnar, and proximal areas were analyzed individually (i.e., each finger), for both hands (i.e., left and right), and globally (i.e., ten fingers). Fingers were identified by the numerical sequence 1–10, with finger 1 being the right thumb and finger 10 as the left-hand little finger (Fig. 1).

White line counts (WLC) were extracted manually for each fingerprint and differences between the sexes were analyzed individually (i.e., each finger), for both hands (i.e., left and right hands), and globally (i.e., ten fingers). Fig. 2 presents an example of WLC sex difference, with female fingerprints showing a greater number of white lines than men.

Data were statistically analyzed using R statistical software. Differences between sexes and hands were compared using Student's *t*-test and differences among fingers and areas were examined with analysis of variance (ANOVA). Posterior probability inferences of sex, based on ridge and white line counts, were made through calculating the likelihood ratio (LR) based on the Bayes' theorem. The odds were computed with the following equations:

$$\mathrm{LR}(D) = \frac{\text{Probability of observing a given ridge density if the donor was male}\,(\mathrm{C})}{\text{Probability of observing a given ridge density if the donor was female}\,(\mathrm{C}^1)}$$

Fig. 2. Fingerprint samples of males (left) and females (right), showing a greater number of white lines in females.

$$\mathrm{LR}(W) = \frac{\text{Probability of observing a given white line count if the donor was male (C)}}{\text{Probability of observing a given white line count if the donor was female (C}^1\text{)}}$$

Results

Results of intra and inter-operator repeatability tests showed that methodological errors were negligible and unlikely to bias the data. Presented in Table 1 are the percentage distributions for ridge patterns in males, females and both sexes combined.

The ridge density mean values for all fingers and each area, classified according to sex, are shown in Table 2. Males and females presented significant differences in the radial and ulnar areas. Mean ridge density in the radial area in both sexes was greater than in the ulnar area, with females having 15.89 ridges/25 mm^2 in the radial area and 14.22 ridges/25 mm^2 in the ulnar area, and with males having 14.57 ridges/25 mm^2 in the radial area and 13.10 ridges/25 mm^2 in the ulnar area. No significant

Table 1
Percentage distribution of fingerprint ridge patterns of Filipinos.

	Arch	Loop	Whorl
Male (n = 2000)	3.65%	54.05%	42.30%
Female (n = 2000)	2.90%	59.65%	37.45%
Both (n = 4000)	3.28%	56.85%	39.88%

Table 2
Descriptive statistics of fingerprint ridge density per area (R, U, P) and white line count (WLC) of Filipinos.

Finger area	Males (n = 2000)			Females (n = 2000)		
	Mean	SD	SE	Mean	SD	SE
R	14.57	1.43	0.07	15.89	1.69	0.08
U	13.10	1.27	0.06	14.22	1.51	0.08
P	11.36	1.54	0.07	11.97	1.70	0.08
WLC	0.38	1.13	0.06	7.33	5.83	0.29

Table 3
Descriptive statistics of fingerprint ridge density (R, U, P) and white lines count (WLC) per finger in Filipinos.

Finger	Finger area	Males ($n = 400$)		Females ($n = 400$)	
		Mean	SD	Mean	SD
Thumb	R	12.57	1.72	13.61	1.80
	U	14.53	1.99	15.51	2.23
	P	11.95	1.91	12.48	2.24
	WLC	0.43	1.37	6.91	6.31
Index	R	14.51	1.88	15.94	2.11
	U	12.54	1.63	13.67	1.96
	P	11.37	2.42	12.20	2.34
	WLC	0.32	1.18	6.61	5.84
Middle	R	14.87	1.86	16.41	2.21
	U	12.45	1.66	13.67	1.86
	P	11.14	2.16	11.90	2.20
	WLC	0.43	1.47	8.51	7.33
Ring	R	15.50	2.02	17.03	2.37
	U	12.98	1.81	14.13	1.79
	P	11.87	2.21	12.49	2.45
	WLC	0.45	1.69	7.64	7.08
Little	R	15.42	2.00	16.49	2.34
	U	12.98	1.63	14.11	1.94
	P	10.49	2.03	10.80	2.20
	WLC	0.29	1.20	6.97	6.36

sex differences were found in the proximal area. The mean white line count was significantly greater in females (7.33) than males (0.38).

Student's *t*-test was used to determine whether means of ridge density and white line count differed significantly between the sexes. Mean RDs and WLC of males and females were significantly different with *p* values below the 0.05 significance level. Another Student's paired *t*-test was conducted to determine whether the mean values of RDs and WLC between hands were significantly different. With *p* values above the 0.05 significance level, this result indicates that mean RDs and WLC from the left and the right hand did not differ significantly. ANOVA was used to examine differences among fingers and *p* values were below the 0.05 significance level, indicating that RDs and WLC differed significantly per finger. Table 3 shows the descriptive statistics for RDs and WLC per finger in the Filipino sample.

Table 4
Frequency distribution of mean fingerprint ridge densities of Filipinos.

Mean ridge density	Radial		Ulnar		Proximal	
	Male	Female	Male	Female	Male	Female
<9	0	0	0	0	6	5
9–9.99	0	0	1	0	32	15
10–10.99	2	0	4	1	49	40
11–11.99	3	2	32	7	46	50
12–12.99	17	4	69	26	40	39
13–13.99	55	17	58	64	25	32
14–14.99	51	37	21	51	1	11
15–15.99	46	43	13	33	0	8
16–16.99	19	50	2	12	1	0
17–17.99	6	29	0	5	0	0
>18	2	17	0	1	0	0
Total	200	200	200	200	200	200

Table 5
Probability densities and likelihood ratios in the radial area of fingerprints of Filipinos.

Ridge count (radial)	Probability density		Likelihood ratio		Odds
	Male (C)	Female (C^1)	C:C^1	C^1:C	Male Female
10	0.010	0.000	–	–	1.00 > 0.00
11	0.015	0.010	1.500	0.667	0.60 > 0.40
12	0.085	0.020	4.250	0.235	0.81 > 0.19
13	0.275	0.085	3.230	0.309	0.76 > 0.24
14	0.255	0.185	1.380	0.725	0.58 > 0.42
15	0.230	0.215	1.070	0.935	0.52 > 0.48
16	0.095	0.250	0.380	2.630	0.28 < 0.72
17	0.030	0.145	0.207	4.830	0.17 < 0.83
>18	0.010	0.085	0.118	8.500	0.11 < 0.89

Shown in Table 4 are the frequency distributions of mean ridge densities in the radial (R), ulnar (U) and proximal (P) areas. Ridge count was greater in distal areas (R and U), with no instance of a count less than nine, as compared to the proximal (P) area's minimum of seven. In the radial area, 64% of males had a mean ridge density of 15 and below, whereas 70% of females had 16 and above. In the ulnar area, 82% of males had a ridge count of below 13 while 83% of females had above 13 ridges. Ninety nine percent (99%) of males and 91% of females had mean ridge densities of 14 or below in the proximal area.

With the relative frequencies of mean ridge density from the samples presented in Table 4, the probabilities P(RD|C) and P(RD|C^1) were calculated. Assuming prior probabilities of 50%, the odds were then obtained (Tables 5 and 6).

Shown in Table 5 are the probability densities and likelihood ratios in the radial area based on the Filipino samples. A radial ridge count of 13 ridges/25 mm^2 is more likely to be male ($p = 0.76$) and a mean ridge density of 16 ridges/25 mm^2 is more likely to be female ($p = 0.72$). There is a high probability of a fingerprint possessing 18 or more ridges to be female ($p = 0.89$), and a high probability of a fingerprint with 10 or less ridges to be male ($p = 1.00$).

Table 6 presents the likelihood ratios for the ulnar area. An ulnar ridge count of 12 ridges/25 mm^2 is more likely to be male ($p = 0.73$), and 14 ridges/25 mm^2 is more likely to be female ($p = 0.71$). In Filipinos, there is a high probability of a fingerprint possessing 16 or more ridges to be female ($p = 1.00$), and a high probability of a fingerprint with 10 or less ridges to be male ($p = 1.00$).

The proximal area exhibited varying results. With moderate values from <9 to 14 ridges/25 mm^2, and showing no pattern at all, this suggests identification will be unreliable when this feature is used.

Table 7 shows the frequency distribution of mean fingerprint white lines count (WLC). No Filipino male had a mean WLC greater than 8 while there were Filipino females with mean WLC greater than 15.

A mean fingerprint WLC of 0 is more likely to be male ($p = 0.88$), and a mean WLC of 2 is more likely to be female (0.79), as shown in Table 8. There is a high probability of a fingerprint possessing 4 or

Table 6
Probability densities and likelihood ratios in the ulnar area of fingerprints of Filipinos.

Ridge count (ulnar)	Probability density		Likelihood ratio		Odds
	Male (C)	Female (C^1)	C:C^1	C^1:C	Male Female
9	0.005	0.000	–	–	1.00 > 0.00
10	0.020	0.005	4.000	0.250	0.80 > 0.20
11	0.160	0.035	4.570	0.219	0.82 > 0.18
12	0.345	0.130	2.650	0.377	0.73 > 0.27
13	0.290	0.320	0.906	1.100	0.48 < 0.52
14	0.105	0.255	0.412	2.430	0.29 < 0.71
15	0.065	0.165	0.394	2.540	0.28 < 0.72
16	0.010	0.060	0.167	6.000	0.14 < 0.86
>17	0.000	0.030	–	–	0.00 < 1.00

Table 7
Frequency distribution of mean fingerprint white line count of the Filipinos.

Mean WLC	Males	Females
0–0.99	175	25
1–1.99	14	12
2–2.99	4	15
3–3.99	3	13
4–4.99	2	12
5–5.99	1	10
6–6.99	0	21
7–7.99	1	17
8–8.99	0	13
9–9.99	0	10
10–10.99	0	10
11–11.99	0	7
12–12.99	0	6
13–13.99	0	7
14–14.99	0	5
>15	0	17
Total	200	200

Table 8
Probability densities and likelihood ratios of fingerprints white lines of Filipinos.

White lines count	Probability density		Likelihood ratio		Odds
	Male (C)	Female (C^1)	C:C^1	C^1:C	Male Female
0	0.870	0.120	7.250	0.138	0.88 > 0.12
1	0.070	0.060	1.170	0.857	0.54 > 0.46
2	0.020	0.075	0.267	3.750	0.21 < 0.79
3	0.015	0.065	0.231	4.330	0.19 < 0.81
4	0.010	0.060	0.167	6.000	0.14 < 0.86
5	0.005	0.050	0.100	10.000	0.09 < 0.91
6	0.001	0.105	0.009	105.000	0.02 < 0.99
7	0.005	0.085	0.059	17.000	0.06 < 0.94
>8	0.000	0.375	–	–	0.00 < 1.00

more white lines to be female ($p = 0.86–0.99$), and a high probability of a fingerprint with no white lines to be male ($p = 0.88$).

Discussion

Gutiérrez-Redomero et al. (2014) observed substantial differences in ridge density in the different areas, and also from the different fingerprinting methods. Since most earlier research on sex determination based on fingerprint ridge distribution have used the Acree's method (1999), the ridge density in the radial area is the only sector that can be compared between different populations (Table 9).

The ridge density in this area in both sexes shows that Filipinos tend to have finer ridges than European-Americans, African-Americans, Indians, South Indians, Chinese, and Malaysians, but thicker ridges than Spaniards, Mataco-Mataguayos, North Indians, and Argentinians. Nonetheless, in all previous research, females have shown significantly higher mean ridge density than men. There is a difference of at least 1 ridge/25 mm^2 between sexes among the various populations studied. For the Filipino population, differences of 1.32 ridges/25 mm^2 in the radial area and 1.12 ridges/25 mm^2 in the ulnar area emerged.

The difference we noted in ridge density between the radial and ulnar areas agrees with the observation of Jantz and Owsley (1977) who pointed out that the radial and ulnar areas respond to different developmental instructions and should thus be treated as separate variables.

Table 9
Descriptive statistics of fingerprint ridge density according to sex in different populations for a radial area of 25 mm^2.

Population	Females		Males	
	Mean	SD	Mean	SD
European-American (Acree, 1999)	13.32	1.24	11.14	1.31
African-American (Acree, 1999)	12.61	1.43	10.90	1.31
Indian (Gungadin, 2007)	14.60	0.08	12.80	0.90
Spanish (Gutiérrez-Redomero et al., 2008)	17.91	1.47	16.23	1.39
Chinese (Nayak et al., 2010a)	14.15	1.04	11.73	1.07
Malaysian (Nayak et al., 2010a)	13.63	0.90	11.44	0.99
Indian (Nayak et al., 2010a)	14.20	0.63	11.05	1.11
Mataco-Mataguayo (Gutiérrez-Redomero et al., 2011)	17.82	2.87	16.62	2.71
South Indian (Nithin et al., 2011)	14.15	1.68	12.57	1.49
North Indian (Krishan et al., 2013)	17.94	1.23	15.84	1.23
Ramal Argentinian (Gutiérrez-Redomero et al., 2013)	19.08	1.84	17.04	1.68
Puna-Quebrada Argentinian (Gutiérrez-Redomero et al., 2013)	18.47	1.56	16.67	1.78
Filipino	15.89	1.69	14.57	1.43

In both sexes, the thumb showed higher ridge density in the ulnar area than in the radial area compared with the other four fingers which exhibited higher ridge density in the radial area than in the ulnar area. Arranging the digits from lowest to highest RD in the radial area, the general order in both sexes was: thumb < index < middle < little finger < ring, while the ranking in order of increasing ridge density in the ulnar area in both sexes was: middle < index < little finger < ring < thumb. This observation implies the presence of finer ridges in the radial area of the ring finger and in the ulnar area of the thumb, and the presence of thicker ridges in the radial area of the thumb and in the ulnar area of the middle finger. These results agree with the observations of Ohler and Cummins (1942) and Gutiérrez-Redomero et al. (2011) regarding the presence of finer ridges on the ring finger. However, it contradicts the suggestion of Ohler and Cummins (1942) that ridges become coarser through greater use because the ulnar area of the thumb is used more than the radial, but the former is associated with a greater mean value than the latter.

Our results agree with the observation by Badawi et al. (2006) that females have higher white line counts. A comparison of WLC in males and females of Filipino origin with other populations is not possible as there are no other published studies, apart from Badawi et al.'s (2006) research, which established WLC as a significant feature for sexual determination purposes.

It is recommended that digit-specific formulae be derived and multivariate formulae be explored when using dermatoglyphic data for sex determination.

The Filipino specific formulae derived in this paper would be best applied to assist in the identification of patent, plastic or latent fingerprints found in a crime scene with no matches in the Automated Fingerprint Identification System (AFIS), especially in cases where there are no suspects to interrogate. They could also be used as a tool for sex discrimination of not yet decomposing fingers recovered from aviation disasters, murder-mutilation (colloquially called 'chopchop') forensic cases, and natural disasters like the typhoon Haiyan in 2013, with thousands of victims still remaining unidentified.

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COMPLEX SYSTEMS IN HUMAN DEVELOPMENT: SEXUAL DIMORPHISM IN TEETH AND FINGERPRINTS OF AUSTRALIAN TWINS

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ABSTRACT

Human teeth and fingerprints have similar embryological origin from epithelial-mesenchymal interactions. This study aims to determine the nature and extent of sexual dimorphism in fingerprints and teeth of twins; investigate the influences of genetic, epigenetic and environmental factors on observed variation; identify possible developmental associations between the phenotypes; and explore whether both systems display the features of complex adaptive systems. Mesiodistal (MD) measurements from both primary and permanent teeth and ridge density (RD) from three different finger areas, namely ulnar (U), radial (R), and proximal (P), from fingerprints of the same set of monozygotic and dizygotic Australian twins (28 males and 31 females aged 8 to 10 years, and aged 13 to 16 years, respectively) were collected and analysed. Sexual dimorphism was observed in both the primary and permanent dentitions, with the latter showing greater magnitude of differences than the former. There was no observed sexual dimorphism in the fingerprints of the 8 to 10 year cohort, but a few finger areas (left index U, right index R, left little R, and left little P) of the 13- to 16-year cohort exhibited significant differences, showing that friction ridges expand over time. It was concluded that both dentition and dermatoglyphics display characteristics of complex adaptive systems.
Keywords: complex adaptive system, dentition, tooth size, dermatoglyphics, fingerprints, human development, mesiodistal, ridge density, sexual dimorphism.

1 INTRODUCTION

Sexual dimorphism is defined as the phenotypic or observable difference between males and females of the same biological species. A number of studies have been conducted on sexual dimorphism in the human dentition. In general, males have larger crown diameters than females [1,2], and sexual dimorphism is greater in permanent than in primary dentition [2,3]. Meanwhile, studies on sexual dimorphism in adult human dermatoglyphs reveal that males have fewer ridges than females [4,5].

The development of the human dentition and of dermatoglyphs has similar embryological origin from epithelial-mesenchymal interactions [6]. During embryonic growth, patterning, or the establishment of groups of cells in the proper relationship to each other and to surrounding tissues, occurs. Patterning is a longitudinal event that eventually leads to differentiation of cells to assume specialised functions and shapes. Primary teeth start to develop around 4 to 6 weeks in utero [6], while ridged skin begins to form around 10 to 16 weeks in utero [7].

Human development in general is a complex adaptive process that is influenced by genetic, epigenetic and environmental factors [8]. The genetic factors interact with epigenetic and environmental elements at the molecular level and form complex networks within the cells, and from these dynamics arise the higher level tissues. Sexual dimorphism has been suggested by some researchers to be

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governed by sex chromosomes [9,10] but there have been others who have suggested that hormones are also important [11,12]. Dental and dermatoglyphic patterns develop in utero, and once stabilised, their unique and persistent morphology makes them valuable models in studying sexual dimorphism. This study aimed to determine the nature and extent of sexual dimorphism in mesiodistal crown measurements of teeth and ridge density counts of fingerprints of twins; to investigate the influences of genetic, epigenetic and environmental factors; and to identify possible developmental associations and covariance of the studied phenotypes.

2 MATERIALS AND METHODS

Twin samples were obtained from the ongoing longitudinal studies of the Craniofacial Biology Research Group in the School of Dentistry at the University of Adelaide [13], which is one of the four most extensive investigation of its type in the world [14]. Serial dental casts of primary and permanent dentitions, and rolled ink prints of fingers of individuals aged 8 to 10 years and 13 to 16 years of the same cohort of monozygotic and dizygotic Australian twins (28 males and 31 females) were collected and analysed. Dental casts showing wear, caries, or restorations and ten-prints with smudge ink and scarred patterns in any of the fingerprints were excluded.

Mesiodistal crown diameter (MD) was measured as the distance between the mesial and distal contact points of the tooth crown [1,15] by using a 2D imaging system. Dental casts were oriented using an adjustable stage to obtain the correct plane or angle before taking images and a calibrated Image J [16] software was used to digitise landmarks (Fig. 1). Measurements were obtained for central incisors (I1), lateral incisors (I2), canines (C), first molars (M1) and second molars (M2) of primary and permanent teeth.

Ridge density (RD) was measured by counting friction ridges diagonally on a square measuring 5 mm × 5 mm to isolate ridges within a well-defined area [4,17]. Measurements were obtained in three different finger ridge locations, namely, distal ulnar (U), distal radial (R), and proximal (P), of each of the ten fingerprints in both cohorts. The three areas were located by dividing the rolled prints into four sectors, with two perpendicular axes that cross two ridges above the centre [17]. Fingers

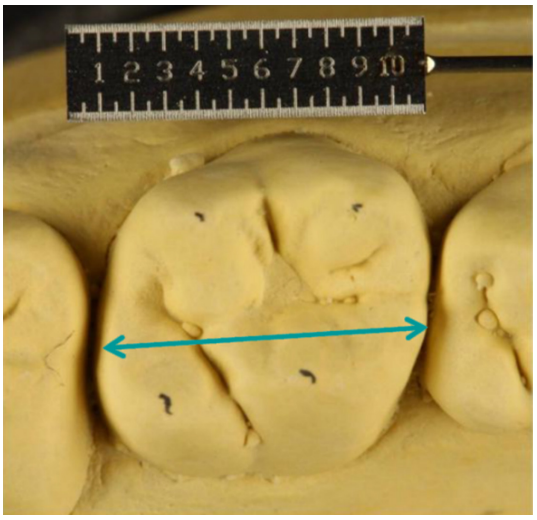

Figure 1: Mesiodistal (MD) measurement on a permanent upper first molar from the occlusal view.

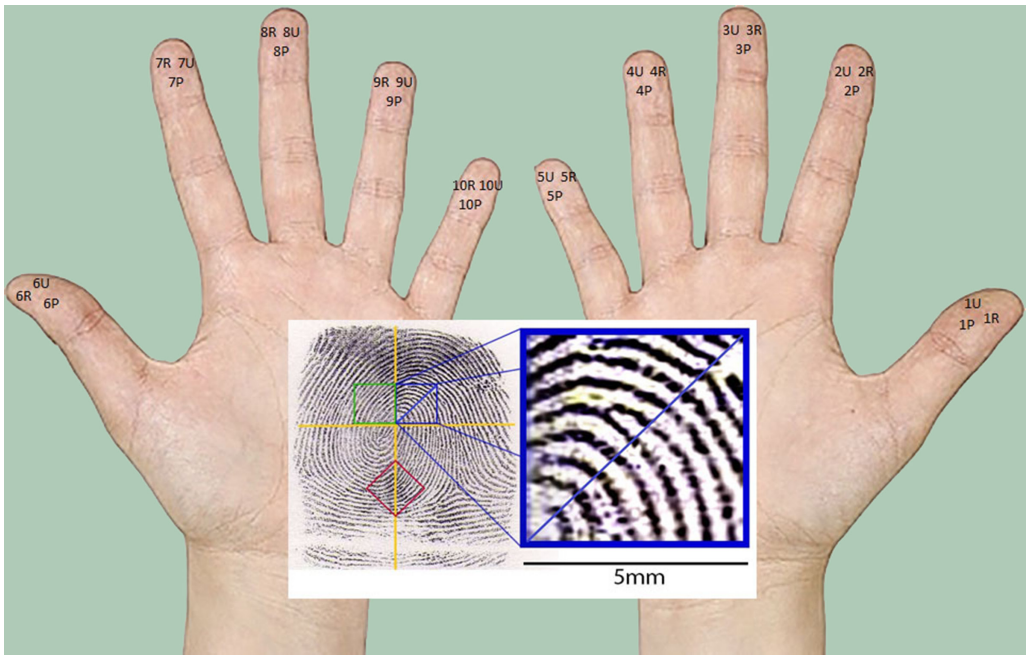

Figure 2: Locations of fingerprint areas – distal ulnar (U), distal radial (R) and proximal (P) – on each finger, and an enlarged 5 mm × 5 mm area to facilitate ridge density (RD) count.

were assigned with a numerical order 1–10, with finger 1 being the right thumb and finger 10 being the left little finger (Fig. 2).

Data were statistically analysed using XLSTAT statistical software. Descriptive statistics including means, standard deviations (SD) and coefficients of variation (CV) were computed for MD and RD. Differences between sexes and sides were calculated using student's unpaired t-test. Differences among fingers and finger areas were examined with analysis of variance (ANOVA). Finger ridge differences between age groups were compared with paired t-test. Pearson's coefficient was calculated to examine correlations between the variables.

3 RESULTS

MD measurements and RD counts were normally distributed, and results of intra and inter-operator repeatability tests showed that errors in methodological measurements were negligible and not likely to bias data. Shown in Table 1 are the mean values, SD and CV of mesiodistal (MD) measurements of primary and permanent teeth.

Highlighted in yellow background and bold text are the sexually dimorphic dental measurements, where mean values are different between sexes at $p < 0.05$. Mean values of MD crown dimensions of males were consistently greater compared to females in all teeth. Permanent dentitions displayed greater sexual dimorphism compared to primary dentitions. There were no left-right differences observed in MD measurements of all primary and permanent dentitions.

Shown in Table 2 are the mean values, SD and CV of ridge density (RD) counts of fingerprints of 8 to 10 years old cohort and 13 to 16 years old cohort.

All mean values of RD based on finger type and finger area were statistically different to each other at $p < 0.05$. Highlighted in blue background and italics are the RD counts that were found to

Table 1: Descriptive statistics for mesiodistal (MD) measurements of primary and permanent teeth in male and female twins.

	Males								Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV	n	Mean	SD	CV	n	Mean	SD	CV	n	Mean	SD	CV
Primary																
Maxillary																
il	28	6.34	0.37	0.06	28	**6.32**	0.42	0.07	31	6.23	0.39	0.06	31	**6.22**	0.41	0.07
c	28	**6.87**	0.37	0.05	28	**6.84**	0.36	0.05	31	**6.70**	0.39	0.06	31	**6.69**	0.37	0.06
ml	28	**7.05**	0.44	0.06	28	**7.12**	0.41	0.06	31	**6.83**	0.38	0.06	31	**6.90**	0.40	0.06
m2	28	**8.86**	0.47	0.05	28	**8.83**	0.43	0.05	31	**8.62**	0.40	0.05	31	**8.63**	0.41	0.05
Mandibular																
il	28	**4.05**	0.31	0.08	28	**4.03**	0.30	0.07	31	**3.92**	0.27	0.07	31	**3.90**	0.28	0.07
i2	28	**4.61**	0.35	0.08	28	**4.62**	0.32	0.07	31	**4.50**	0.31	0.07	31	**4.49**	0.31	0.07
c	28	**5.89**	0.33	0.06	28	**5.90**	0.32	0.05	31	**5.73**	0.30	0.05	31	**5.74**	0.32	0.06
ml	28	**7.87**	0.49	0.06	28	**7.91**	0.44	0.06	31	**7.67**	0.38	0.05	31	**7.65**	0.40	0.05
m2	28	**10.07**	0.47	0.05	28	**10.03**	0.46	0.05	31	**9.81**	0.41	0.04	31	**9.77**	0.41	0.04
Permanent																
Maxillary																
Il	28	**8.70**	0.49	0.06	28	**8.64**	0.48	0.05	31	**8.43**	0.53	0.06	31	**8.43**	0.48	0.06
C	28	**8.13**	0.41	0.05	28	**8.18**	0.45	0.06	31	**7.71**	0.46	0.06	31	**7.66**	0.41	0.05
Ml	28	**10.45**	0.52	0.05	28	**10.46**	0.52	0.05	31	**10.09**	0.51	0.05	31	**10.11**	0.48	0.05
M2	28	**10.35**	0.58	0.06	28	**10.46**	0.64	0.06	31	**9.86**	0.53	0.05	31	**9.81**	0.56	0.06
Mandibular																
Il	28	5.42	0.33	0.06	28	**5.46**	0.32	0.06	31	5.30	0.33	0.06	31	**5.29**	0.33	0.06
12	28	6.00	0.37	0.06	28	**5.98**	0.34	0.06	31	5.80	0.37	0.06	31	**5.78**	0.37	0.06
C	28	**7.19**	0.42	0.06	28	**7.17**	0.44	0.06	31	**6.66**	0.40	0.06	31	**6.65**	0.41	0.06
Ml	28	**11.31**	0.63	0.06	28	**11.33**	0.60	0.05	31	**10.83**	0.63	0.06	31	**10.85**	0.62	0.06
M2	28	**10.95**	0.71	0.06	28	**11.11**	0.79	0.07	31	**10.21**	0.55	0.05	31	**10.42**	0.67	0.06

Table 2: Descriptive statistics for ridge density (RD) counts of fingerprints and finger areas in male and female twins.

	Males								Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV	n	Mean	SD	CV	n	Mean	SD	CV	n	Mean	SD	CV
Ulnar																
8–10 years old																
Thumb	28	15.9	1.7	0.1	28	16.1	1.9	0.1	31	*15.7*	2.1	0.1	31	*16.3*	2.0	0.1
Index	28	16.4	1.7	0.1	28	16.5	2.1	0.1	31	16.3	1.8	0.1	31	16.6	2.0	0.1
Middle	28	17.1	1.7	0.1	28	17.2	2.3	0.1	31	16.9	2.1	0.1	31	17.4	2.3	0.1
Ring	28	*17.7*	2.1	0.1	28	*18.5*	2.3	0.1	31	*17.5*	2.3	0.1	31	*18.6*	2.1	0.1
Little	28	17.2	2.0	0.1	28	17.5	2.0	0.1	31	*17.0*	1.9	0.1	31	*17.7*	*1.7*	0.1
13–16 years old																
Thumb	28	14.3	1.7	0.1	28	14.0	2.1	0.1	31	14.8	2.0	0.1	31	14.5	1.8	0.1
Index	28	14.5	1.9	0.1	28	**13.8**	1.7	0.1	31	15.3	2.1	0.1	31	**15.0**	2.2	0.1
Middle	28	15.8	1.9	0.1	28	16.4	1.8	0.1	31	15.7	2.2	0.1	31	16.6	1.9	0.1
Ring	28	16.5	1.9	0.1	28	17.0	2.0	0.1	31	16.6	2.1	0.1	31	17.5	2.1	0.1
Little	28	15.9	1.9	0.1	28	15.6	1.5	0.1	31	15.4	1.9	0.1	31	16.2	1.8	0.1
Radial																
8–10 years old																
Thumb	28	17.8	1.9	0.1	28	17.3	2.1	0.1	31	17.5	1.8	0.1	31	17.2	2.4	0.1
Index	28	17.0	1.8	0.1	28	17.2	2.0	0.1	31	17.3	1.8	0.1	31	17.4	2.0	0.1
Middle	28	18.3	2.2	0.1	28	18.1	2.3	0.1	31	18.2	1.9	0.1	31	18.0	2.3	0.1
Ring	28	*19.0*	2.1	0.1	28	*18.4*	2.2	0.1	31	18.9	2.2	0.1	31	18.4	2.3	0.1
Little	28	18.2	2.1	0.1	28	17.6	2.1	0.1	31	18.3	2.0	0.1	31	17.8	2.3	0.1

13–16 years old																
Thumb	28	15.5	2.2	0.1	28	15.7	2.2	0.1	31	16.3	1.9	0.1	31	15.5	2.9	0.2
Index	28	**15.0**	2.0	0.1	28	15.4	1.7	0.1	31	**16.3**	1.8	0.1	31	15.8	1.8	0.1
Middle	28	16.4	1.7	0.1	28	16.8	1.7	0.1	31	16.9	2.2	0.1	31	17.1	2.0	0.1
Ring	28	*17.3*	*1.7*	0.1	28	*16.3*	1.8	0.1	31	17.5	2.6	0.2	31	17.1	1.9	0.1
Little	28	16.8	2.0	0.1	28	**16.1**	1.6	0.1	31	16.9	2.8	0.2	31	**17.1**	2.1	0.1
Proximal																
8–10 years old																
Thumb	28	14.9	1.7	0.1	28	14.6	1.7	0.1	31	*15.1*	*1.7*	0.1	31	*14.5*	1.9	0.1
Index	28	14.2	1.9	0.1	28	13.9	2.2	0.2	31	14.3	1.9	0.1	31	13.9	2.0	0.1
Middle	28	14.3	2.1	0.1	28	14.1	1.8	0.1	31	*14.3*	1.8	0.1	31	*13.8*	*1.7*	0.1
Ring	28	14.7	2.0	0.1	28	14.3	2.1	0.1	31	14.6	1.8	0.1	31	14.1	2.1	0.2
Little	28	14.1	2.4	0.2	28	13.8	2.0	0.1	31	13.6	1.9	0.1	31	13.5	2.0	0.1
13–16 years old																
Thumb	28	13.2	1.8	0.1	28	13.2	1.8	0.1	31	13.7	2.4	0.2	31	13.2	1.7	0.1
Index	28	12.9	1.7	0.1	28	12.7	1.5	0.1	31	13.4	1.6	0.1	31	13.0	1.6	0.1
Middle	28	12.5	2.1	0.2	28	12.6	1.2	0.1	31	13.1	1.4	0.1	31	12.8	1.5	0.1
Ring	28	13.1	1.9	0.1	28	12.8	1.6	0.1	31	13.6	1.8	0.1	31	13.4	2.2	0.2
Little	28	12.3	1.9	0.2	28	**12.1**	2.0	0.2	31	12.6	1.7	0.1	31	**13.4**	2.4	0.2

Table 3: Pearson correlation coefficients of the dental (mesiodistal width) and dermatoglyphic (ridge density) traits.

	Males	Females	Males	Females
Finger Area	**Primary**		**Permanent**	
		Maxillary MD		
Ulnar	**0.20**	**0.16**	**0.16**	**0.13**
Radial	**0.12**	**0.11**	0.11	0.08
Proximal	–0.03	**–0.12**	–0.04	0.00
		Mandibular MD		
Ulnar	**0.27**	**0.25**	**0.38**	**0.30**
Radial	**0.13**	**0.16**	**0.24**	**0.23**
Proximal	**–0.07**	**–0.16**	–0.11	–0.01

be statistically different on both sides. More differences were observed in the younger (8–10 years old) cohort. The ulnar area (U) was the most irregular of all finger ridge areas in terms of left-right discrepancies, yet it was observed to have smaller RD in the right side, which indicates thicker finger ridges. Most of the thicker ridges in the radial (R) and proximal (P) areas were observed in the left fingers.

Highlighted in yellow background and bold text are the sexually dimorphic dermatoglyphic measurements, where mean values are different between sexes at $p < 0.05$. Only a few sexually dimorphic finger ridge areas were observed to be greater from the older cohort (13–16 years old), with smaller mean values for RD in males, which indicates thicker and fewer friction ridges within the 5 mm^2 square. Based on paired t-test, all mean values of RD are different between age groups at $p < 0.05$, with the older cohort showing smaller RD values compared to the younger group.

Pearson's coefficients (r) between teeth and fingerprints are presented in Table 3. Highlighted in yellow background and bold text are the significant correlations between dental trait MD and dermatoglyphic characteristic RD (ulnar, radial and proximal) at $p < 0.05$. Overall, the correlations between teeth and fingerprints are low, but the RD in the ulnar area emerged with the highest coefficients with MD diameter of the maxillary and mandibular dentition in both sexes.

Correlation coefficients were calculated within groups of dental and dermatoglyphic variables at $p < 0.05$. All MD diameters taken from different tooth types were positively correlated to each other in the primary teeth (0.31–0.95). Only some MD measurements (71 of 231 in males, 119 of 231 in females) were positively correlated with each other in the permanent teeth (0.40–0.84), and more significant values were observed in females than males. Meanwhile, only some RD counts from different fingers and areas were positively correlated to each other (312 of 435 in young males and 252 of 435 in young females, 147 of 435 in old males and 112 of 435 in old females), with more significant values in males and the young cohort. Greater r values were observed in the old cohort (0.35 to 0.75) compared to the young cohort (0.19 to 0.59).

4 DISCUSSION

The degree and patterning of sexual dimorphism in the dentition varies according to tooth type. Our observation of the permanent dentition showing more pronounced sexual dimorphism than primary

dentition agrees with previous findings [1,2]. The permanent lower canines displayed the largest sexual dimorphism in MD measurements, similar to the results of Garn *et al*. [3] and Ribeiro *et al*. [12] who pointed out that dental development might occur under fairly high levels of testosterone influence, and this could explain the differences in sexual dimorphism between primary and permanent teeth of same individuals.

The degree and patterning of sexual dimorphism in the dermatoglyph varies according to the finger area and finger type. In this study, there was no observed sexual dimorphism in the 8 to 10 year old group, while fingerprints of the 13 to 16 year old group displayed sexual dimorphism in the ulnar and radial areas of the index finger, and radial and proximal areas of the little finger. Few studies have investigated subadult fingerprints, and our results could be preliminary empirical evidence that friction ridges expand as individuals grow and develop, and possibly more so in males than females. It seems that sexual dimorphism in dermatoglyphic development commences during puberty, when a testosterone surge occurs in males [18].

There are three surges of testosterone that occur in normal male development. The first surge begins at around the 7th to 9th week of pregnancy, following testicular differentiation, and the testosterone level is at its highest around the 14th week [19,20]. The second surge occurs after birth due to the reduction of oestrogen produced by the placenta [18]. The third surge, as previously mentioned, occurs during puberty.

Primary dentition starts to develop at around 4 to 6 weeks in utero [6] and continues until around one year after birth. Permanent dentition begins to form 14 weeks in utero and continues to develop until at around 14 years of age [21]. Meanwhile, primary ridge formation begins at around 10 to 16 weeks and ends on the 17th week, then secondary ridges form until the 24th week in utero [7]. Our results suggest that the first two testosterone surges have a critical role in the sexual dimorphism of both the primary and permanent dentitions, while the third testosterone surge influences the sexual dimorphism of the fingerprints.

Human development is a complex adaptive process [8] and the human body is a complex adaptive system. This study has shown that both teeth and fingerprints are interconnected, yet they still have a degree of autonomy. They share a similar embryological origin and epithelial-mesenchymal interactions [6], yet they develop and interact with epigenetic and environmental factors differently. The interactions may be unpredictable, with no central control, but they are not random, as regularities and patterns emerge to find the best fit with the environment.

This research is the first to study both human dental and dermatoglyphic traits. Although a number of studies have been conducted on human dentition and dermatoglyphs separately, no attempt has been made previously to explore possible correlations between the two. This research furthers the investigation on the complex mechanisms and interactions occurring during dental, dermatoglyphic and general development with mesiodistal (MD) diameters of the teeth and ridge density (RD) counts of the fingerprints. In the future, more dental and dermatoglyphic traits could be studied together.

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Original Research

Sex variation in fingerprint ridge counts in Filipinos

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ABSTRACT

Objective: The aim of this research was to derive probability formulae based on ridge counts (RC) that could be used to contribute to sex determination in human identification. **Methods:** A modified technique of obtaining RC that is not influenced by finger patterns was employed. RC from fingerprints of 200 male and 200 female Filipinos aged 18-57 years were collected and analyzed statistically. **Results:** Males had lower RC compared to females, and there were differences in RC per digit as well. Odds for sex discrimination were obtained for the thumb (15 or less is more likely to be male; 20 or more is more likely to be female), index finger (20 or less is more likely to be male, 22 or more is more likely to be female), middle finger (20 or less is more likely to be male; 23 or more is more likely to be female), ring finger (18 or less is more likely to be male; 22 or more is more likely to be female), little finger (20 or less is more likely to be male; 24 or more is more likely to be female), and when the digit was unknown (19 or less is more likely to be male; 21 or more is more likely to be female). **Conclusion:** Given the overall range of probabilities ($P = 0.60$-1.00), the formulae based on RC may be used to assist in sex determination of unidentified fingerprints in the Philippine setting.

KEY WORDS: Forensic anthropology, forensic sciences, Dermatoglyphics, fingerprints, human identification,ridge count, sex determination, sexual dimorphism

INTRODUCTION

Fingerprints are used widely for human identification because they are both unique and persistent [1]. Ridge counts (RC) are often used when analyzing fingerprint data, as they are objective traits that can be used to characterize fingerprints and can be obtained quantitatively. In RC, a method developed by Bonnevie [2] and furthered by Holt [3] involving counting the number of ridges that touch a straight line between two-fixed points, i.e., two triradii, or a triradius and a core has been used extensively. This method is easily applicable to loop patterns as they contain a core and a triradius, but it is harder to apply for whorl patterns that contain two triradii. This difficulty is even more marked with arch patterns that have no core or triradius. Because of the different dermatoglyphic patterns, RC may not always be feasible, with arch patterns ending up having a score of zero. Cummins and Midlo [4] have suggested counting along a 1 cm line placed at right angles to ridges as this method may overcome the problem.

The degree of sex differences varies in different ancestral groups. Therefore, dermatoglyphic research on sexual dimorphism has focused on pattern and metric variation among different geographic populations [5]. Sexual differences in fingerprints have been observed in total RC in Portuguese [6], British [7], French [8], Swedish [9], Parsi Indian [10], European Australians [11], Polish [12], Easter Islanders [13], Middle Eastern Jews [14], Kenyans and Tanzanians [15], Rengma Nagaland Indians [16], Tunisians [17], and Muzeina Bedouins [18], with males having higher RC than females.

However, the RC method employed in these studies was largely dependent on the fingerprint pattern. For example, the absence of a triradius in arch patterns would always lead to an RC of zero. Therefore, the true nature of sexual dimorphism was not disclosed.

It has been observed that females have fine epidermal ridges, while males have coarser ridges [19-21]. Acree [22] has substantiated quantitatively that females have finer ridge detail with higher ridge density, and therefore, higher RC, compared to males.

The only forensic research on sex determination using fingerprints of Filipinos is the study by Taduran *et al*. [23] which derived probability formulae from ridge density and white line counts. The aim of the current research was to derive probability formulae based on RC. This could contribute to sex determination in human identification.

MATERIALS AND METHODS

Fingerprint samples of 200 males and 200 females aged 18-57 years were gathered and scanned in the Philippine National Police (PNP) Crime Laboratory Fingerprint Division located in Camp Crame, Quezon City, Philippines. A fingerprint sample is a single-standard ten-print card containing all-inked fingerprint impressions of an individual obtained when applying for police clearance. Inclusion criteria included full-finger rolling for all ten impressions, and no scarred patterns for any of the ten fingerprints. This research underwent the required ethical, legal, and procedural scrutiny before being approved by PNP officials.

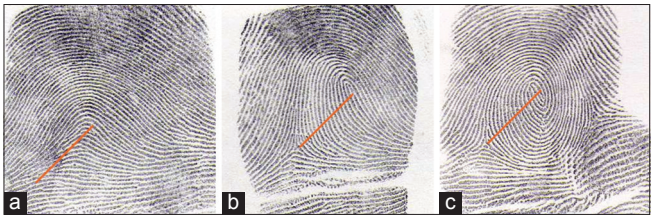

Figure 1: Sample locations of ridge count areas in fingerprint type (a) arch, (b) loop, and (c) whorl

Table 1: Descriptive statistics of fingerprint RC of Filipinos

Sex	RC		
	n	Mean±SD	CV
Males	2000	19.43±2.97	0.15
Females	2000	21.44±3.30	0.15
Combined	4000	20.44±3.30	0.16

SD: Standard deviation, CV: Coefficients of variation, RC: Ridge counts

A modified method of obtaining RC that is not influenced by finger patterns was employed as described by Cummins and Midlo [4]. Image J was used to aid the researchers in RC. The triradius was first identified for each fingerprint. Then, a 1 cm line from the triradius toward the core was drawn, and the number of ridges that touched the line was counted. For prints without a triradius, i.e., those with an arch pattern, a strategic ridge was chosen, as long as the line was perpendicular to the ridges. For prints with more than one triradius, i.e., those with a whorl pattern, the triradius with the higher RC was chosen. Lines that were part of a fork or an eye were counted separately. Island ridges and dots were counted as well.

Data were analyzed statistically using XLSTAT [24] statistical software. Descriptive statistics were calculated, including mean values, standard deviations, and coefficients of variation. Student's *t*-test was used to determine if there were significant differences in RC between the two sexes while the analysis of variance (ANOVA) was used to determine whether RC values differed significantly among fingers. Probability inferences of sex, based on RC, were made through calculating the likelihood ratio (LR) based on Bayes' theorem. The odds were computed based on the following equation:

$$LR = \frac{\text{Probability of observing a given ridge count if the donor was male (C)}}{\text{Probability of observing a given ridge count if the donor was female } (C^{1})}$$

RESULTS

Intra- and inter-operator repeatability tests were performed on 100 samples. The initial and repeated measures were done a day apart, and results (0.97 and 0.93, respectively) showed that methodological errors were negligible and unlikely to bias the data. Descriptive analysis of the data showed that in the sample population, males had lower RC mean values compared to females [Table 1].

Table 2: Descriptive statistics of fingerprint ridge count (RC) per finger in Filipinos

Finger	Males						Females					
	Right			Left			Right			Left		
	n	Mean±SD	CV	*n*	Mean±SD	CV	*n*	Mean±SD	CV	*n*	Mean±SD	CV
Thumb	200	17.46±2.76	0.16	200	18.27±2.81	0.15	200	18.21±2.78	0.15	200	19.72±2.60	0.13
Index	200	19.68±3.40	0.17	200	19.87±2.82	0.14	200	22.31±3.33	0.15	200	22.02±3.01	0.14
Middle	200	20.47±2.57	0.13	200	20.14±2.61	0.13	200	22.70±2.86	0.13	200	22.09±2.80	0.13
Ring	200	19.13±2.73	0.14	200	18.83±2.88	0.15	200	21.07±2.90	0.14	200	21.18±3.00	0.14
Little	200	20.88±2.47	0.12	200	19.61±2.89	0.15	200	23.20±3.12	0.13	200	21.94±3.42	0.16

SD: Standard deviation, CV: Coefficients of variation, RC: Ridge counts

Table 2 shows RC mean values per finger. There were left-right differences observed, as indicated in bold font, in the thumb and little finger in males, and in the thumb, middle, and little finger in females. Overall, when comparing sexes based on side and digit type, males had lower RC mean values compared to females.

In Table 3, the frequency distribution of RC mean values is presented. There were more males who had lower mean RC compared to females and more females who had higher mean RC compared to males.

Shown in Table 4 is the frequency distribution of RC per finger, with both left and right sides combined. More males had lower RC, some even being <12, while more females had higher RC, some reaching more than 30, depending on digit type.

Student's *t*-test was used to determine variations in RC per finger between sexes. Significant differences, as indicated by $P < 0.05$, were found between RC of males and females for all digit types.

ANOVA was used to examine differences in RC mean values among fingers in males and females [Table 5]. There were significant differences in RC among digits indicated by $P < 0.05$, except for the following combinations: In females, index and middle finger, index and little finger, and middle and little finger; in males, middle and little finger.

Probability densities and LR were calculated based on the frequencies of RC per finger in Table 4. Assuming prior probabilities of 50%, the odds were then obtained. Table 6 through 10 show computed probability densities, LR, and odds for sex discrimination per digit, namely, thumb [Table 6], index finger [Table 7], middle finger [Table 8], ring finger [Table 9], and little finger [Table 10].

In the thumb, as shown in Table 6, an RC of 15 or less is more likely to be male ($P = 0.62$-1.00) while an RC of 20 or more is more likely to be female ($P = 0.66$-1.00).

Table 7 shows that in the index finger, an RC value of 20 or less is more likely to be male ($P = 0.60$-1.00), while an RC value of 22 or more is more likely to be female ($P = 0.64$-1.00).

In the middle finger, as presented in Table 8, an RC of 20 or less is more likely to be male ($P = 0.64$-1.00), while an RC of 23 or more is more likely to be female ($P = 0.61$-1.00).

Table 9 shows that in the ring finger, an RC of 18 or less is more likely to be male ($P = 0.63$-1.00), while an RC of 22 or more is more likely to be female ($P = 0.68$-1.00).

Table 3: Frequency distribution of mean fingerprint RC of Filipinos

RC	Males	Females
<17	14	0
17-17.99	19	4
18-18.99	47	22
19-19.99	44	26
20-20.99	44	32
21-21.99	13	42
22-22.99	16	27
23-23.99	2	21
24-24.99	1	15
>25	0	11
Total	200	200

RC: Ridge count

Table 4: Frequency distribution of fingerprint RC per finger in Filipinos

RC	Thumb		Index		Middle		Ring		Little	
	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females
<12	5	0	8	0	1	0	4	0	1	0
12	5	3	2	0	1	0	4	1	1	0
13	10	8	4	0	1	0	3	0	4	2
14	24	8	7	3	2	0	9	0	2	0
15	32	20	8	4	5	3	16	7	10	4
16	50	37	20	7	10	6	31	10	16	8
17	57	39	26	11	33	10	48	22	24	16
18	55	47	41	22	41	11	56	33	43	16
19	62	56	57	22	55	32	65	47	46	26
20	32	63	57	38	65	37	57	60	72	31
21	22	41	59	54	63	52	40	53	51	41
22	25	35	39	68	50	61	22	47	45	52
23	10	24	31	43	32	51	24	31	41	50
24	8	11	22	34	15	40	11	34	24	39
25	2	4	14	34	20	40	4	21	11	34
26	1	2	5	24	3	31	3	18	4	33
27	0	1	0	20	1	11	3	9	4	23
28	0	1	0	8	1	8	0	4	1	12
29	0	0	0	3	1	5	0	2	0	7
>30	0	0	0	5	0	2	0	1	0	6
Total	400	400	400	400	400	400	400	400	400	400

RC: Ridge count

Table 5: ANOVA results (*P* values)

Finger	Male				
	Thumb	Index	Middle	Ring	Little
Female					
Thumb	0	<0.05	<0.05	<0.05	<0.05
Index	<0.05	0	<0.05	<0.05	<0.05
Middle	<0.05	0.29	0	<0.05	0.75
Ring	<0.05	<0.05	<0.05	0	<0.05
Little	<0.05	0.08	0.42	<0.05	0

Table 6: Probability densities and likelihood ratios of RC in thumb finger of Filipinos

RC (Thumb)	Probability density		Likelihood ratio		Odds	
	Male (C)	Female (C^1)	C:C^1	C^1:C	Male	Female
<12	0.013	0.000	-	-	1.00	0.00
12	0.013	0.008	1.667	0.600	0.63	0.38
13	0.025	0.020	1.250	0.800	0.56	0.44
14	0.060	0.020	3.000	0.333	0.75	0.25
15	0.080	0.050	1.600	0.625	0.62	0.38
16	0.125	0.093	1.351	0.740	0.57	0.43
17	0.143	0.098	1.462	0.684	0.59	0.41
18	0.138	0.118	1.170	0.855	0.54	0.46
19	0.155	0.140	1.107	0.903	0.53	0.47
20	0.080	0.158	0.508	1.969	0.34	0.66
21	0.055	0.103	0.537	1.864	0.35	0.65
22	0.063	0.088	0.714	1.400	0.42	0.58
23	0.025	0.060	0.417	2.400	0.29	0.71
24	0.020	0.028	0.727	1.375	0.42	0.58
25	0.005	0.010	0.500	2.000	0.33	0.67
26	0.003	0.005	0.500	2.000	0.33	0.67
>27	0.000	0.005	-	-	0.00	1.00

RC: Ridge count

Table 7: Probability densities and likelihood ratios of RC in index fingers of Filipinos

RC (index)	Probability density		Likelihood ratio		Odds	
	Male (C)	Female (C^1)	C: C^1	C^1:C	Male	Female
<14	0.035	0.000	-	-	1.00	0.00
14	0.018	0.008	2.333	0.429	0.70	0.30
15	0.020	0.010	2.000	0.500	0.67	0.33
16	0.050	0.018	2.857	0.350	0.74	0.26
17	0.065	0.028	2.364	0.423	0.70	0.30
18	0.103	0.055	1.864	0.537	0.65	0.35
19	0.143	0.055	2.591	0.386	0.72	0.28
20	0.143	0.095	1.500	0.667	0.60	0.40
21	0.148	0.135	1.093	0.915	0.52	0.48
22	0.098	0.170	0.574	1.744	0.36	0.64
23	0.078	0.108	0.721	1.387	0.42	0.58
24	0.055	0.085	0.647	1.545	0.39	0.61
25	0.035	0.085	0.412	2.429	0.29	0.71
26	0.013	0.060	0.208	4.800	0.17	0.83
>27	0.000	0.050	-	-	0.00	1.00

RC: Ridge counts

In the little finger, as shown in Table 10, an RC value of 20 or less is more likely to be male (P = 0.70-1.00), while an RC value of 24 or more is more likely to be female (P = 0.62-1.00).

Probability densities and LR were calculated based on the frequency distribution of RC in Table 3, which pooled together all RC in the sample. Assuming prior probabilities of 50%, the odds were then obtained. Table 11 shows computed probability densities, LR, and odds for sex discrimination, which can be used when the digit is unknown. An RC of 19 or less is more likely to be male (P = 0.63-1.00), while an RC of 21 or more is more likely to be female (P = 0.76-1.00).

Table 8: Probability densities and likelihood ratios of RC in middle finger of Filipinos

RC (middle)	Probability density		Likelihood ratio		Odds	
	Male (C)	Female (C^1)	C: C^1	C^1:C	Male	Female
<15	0.013	0.000	-	-	1.00	0.00
15	0.013	0.008	1.667	0.600	0.63	0.38
16	0.025	0.015	1.667	0.600	0.63	0.38
17	0.083	0.025	3.300	0.303	0.77	0.23
18	0.103	0.028	3.727	0.268	0.79	0.21
19	0.138	0.080	1.719	0.582	0.63	0.37
20	0.163	0.093	1.757	0.569	0.64	0.36
21	0.158	0.130	1.212	0.825	0.55	0.45
22	0.125	0.153	0.820	1.220	0.45	0.55
23	0.080	0.128	0.627	1.594	0.39	0.61
24	0.038	0.100	0.375	2.667	0.27	0.73
25	0.050	0.100	0.500	2.000	0.33	0.67
26	0.008	0.078	0.097	10.333	0.09	0.91
27	0.003	0.028	0.091	11.000	0.08	0.92
28	0.003	0.020	0.125	8.000	0.11	0.89
29	0.003	0.013	0.200	5.000	0.17	0.83
>30	0.000	0.005	-	-	0.00	1.00

RC: Ridge counts

Table 9: Probability densities and likelihood ratios of RC in ring finger of Filipinos

RC (ring)	Probability density		Likelihood ratio		Odds	
	Male (C)	Female (C^1)	C: C^1	C^1:C	Male	Female
<15	0.050	0.003	20.000	0.050	0.95	0.05
15	0.040	0.018	2.286	0.438	0.70	0.30
16	0.078	0.025	3.100	0.323	0.76	0.24
17	0.120	0.055	2.182	0.458	0.69	0.31
18	0.140	0.083	1.697	0.589	0.63	0.37
19	0.163	0.118	1.383	0.723	0.58	0.42
20	0.143	0.150	0.950	1.053	0.49	0.51
21	0.100	0.133	0.755	1.325	0.43	0.57
22	0.055	0.118	0.468	2.136	0.32	0.68
23	0.060	0.078	0.774	1.292	0.44	0.56
24	0.028	0.085	0.324	3.091	0.24	0.76
25	0.010	0.053	0.190	5.250	0.16	0.84
26	0.008	0.045	0.167	6.000	0.14	0.86
27	0.008	0.023	0.333	3.000	0.25	0.75
>28	0.000	0.010	-	-	0.00	1.00

RC: Ridge counts

DISCUSSION

Acree [22] confirmed sex differences in fingerprint ridges using quantitative data, with females having finer details, hence, a higher ridge density. Our data show that female Filipinos have higher RC than males regardless of digit type. These results support the idea of sexual dimorphism in human fingerprints in general, and more specifically in RC and breadths.

Mundorff *et al*. [5] observed significant interfinger differences in mean ridge breadths. We have noted significant differences

Table 10: Probability densities and likelihood ratios of RC in little finger of Filipinos

RC (little)	Probability density		Likelihood ratio		Odds	
	Male (C)	Female (C^1)	C: C^1	C^1:C	Male	Female
<15	0.020	0.005	4.000	0.250	0.80	0.20
15	0.025	0.010	2.500	0.400	0.71	0.29
16	0.040	0.020	2.000	0.500	0.67	0.33
17	0.060	0.040	1.500	0.667	0.60	0.40
18	0.108	0.040	2.688	0.372	0.73	0.27
19	0.115	0.065	1.769	0.565	0.64	0.36
20	0.180	0.078	2.323	0.431	0.70	0.30
21	0.128	0.103	1.244	0.804	0.55	0.45
22	0.113	0.130	0.865	1.156	0.46	0.54
23	0.103	0.125	0.820	1.220	0.45	0.55
24	0.060	0.098	0.615	1.625	0.38	0.62
25	0.028	0.085	0.324	3.091	0.24	0.76
26	0.010	0.083	0.121	8.250	0.11	0.89
27	0.010	0.058	0.174	5.750	0.15	0.85
28	0.003	0.030	0.083	12.000	0.08	0.92
>29	0.000	0.033	-	-	0.00	1.00

RC: Ridge counts

Table 11: Probability densities and likelihood ratios of finger RC of Filipinos

RC (thumb)	Probability density		Likelihood ratio		Odds	
	Male (C)	Female (C^1)	C: C^1	C^1:C	Male	Female
<17	0.070	0.000	-	-	1.00	0.00
17	0.095	0.020	4.750	0.211	0.83	0.17
18	0.235	0.110	2.136	0.468	0.68	0.32
19	0.220	0.130	1.692	0.591	0.63	0.37
20	0.220	0.160	1.375	0.727	0.58	0.42
21	0.065	0.210	0.310	3.231	0.24	0.76
22	0.080	0.135	0.593	1.688	0.37	0.63
23	0.010	0.105	0.095	10.500	0.09	0.91
24	0.005	0.075	0.067	15.000	0.06	0.94
>25	0.000	0.055	-	-	0.00	1.00

RC: Ridge counts

in RC per finger as well, and this suggests the need for digit identification to enable more precise sex discrimination. Arranging the digits from lowest to highest RC, the general order in both sexes was thumb < ring < index < middle < little. The thumb has the lowest RC, while the little finger has the highest RC. This may help in digit identification since it follows a similar trend regardless of sex.

Table 11 shows a similar trend in RC regardless of digit type, and further emphasizes sexual dimorphism based on this fingerprint characteristic in Filipinos. This may help in sex discrimination in forensic cases when prints are of unknown source and finger. However, it should be used with caution because RC mean values of the thumb are much lower compared to the other fingers, which could lead to misclassification of a female as a male.

Although previous studies of other ancestries have indicated higher RC in males, the different methodology that we used may account for the difference in our results. Earlier RC studies used a technique dependent on fingerprint pattern [2-4,6-18]. This procedure would automatically designate the RC for arches as zero and, since females are known to have a higher frequency of arches [14,16,25-27], higher RC in males would be expected as a result. What these earlier studies showed was more about the sex difference in fingerprint patterns than the nature of fingerprint ridges. We employed the method suggested by Cummins and Midlo [4] and overcame the problems encountered with arch pattern types when counting ridges. RC is the most consistent and reliable measurement for familial investigations and is an inherited metrical character [25]. Its quantitative nature allows for objective characterization of fingerprints, which may be helpful in identification matching.

The probability densities and LR derived in this study using RC may assist in sex discrimination based on unidentified fingerprints, such as in forensic cases with no possible suspect, or in victim profiling, or in large-scale disasters with high mortality rates as in airplane crashes or typhoons. Other fingerprint characteristics where sexual dimorphism may occur, such as ridge breadths, pattern type concordances, and left-right asymmetries, should be explored further. The results of these studies, as well as the study previously done on ridge density and white line counts by Taduran *et al*. [23], may be correlated with one another in order to come up with a more precise sex discrimination algorithms specific for Filipinos that are based on different fingerprint components. It may be possible to increase the accuracy of sex determination by combining fingerprint techniques and other anthropometric techniques, such as Taduran's [28] formulae from teeth dimensions.

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TWO COMPLEX ADAPTIVE SYSTEMS IN HUMAN DEVELOPMENT: FURTHER STUDIES OF DENTAL AND FINGERPRINT PARAMETERS

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ABSTRACT

This paper reports further results and an extension of the study presented at Complex Systems 2016. Human teeth and fingerprints both arise from genetic/epigenetic/environmental interactions and have embryological pathways with epithelial–mesenchymal interactions. The aims of this study were to determine the nature and extent of sexual dimorphism in teeth and fingerprints of twins at two different ages and to explore whether both systems display the features of complex adaptive systems. Buccolingual (BL) measurements from both primary and permanent teeth and ridge breadth (RB) measurements from fingerprints of the same set of Australian twins (28 males and 31 females aged 8 to 10 years, and aged 13 to 16 years, respectively) were collected and analysed. Sexual dimorphism was observed in both the primary and permanent dentitions, with the latter showing greater differences than the former. There was no observed sexual dimorphism in the fingerprints at 8 to 10 years. However, a few fingers (left index, left ring, and right middle) at 13 to 16-years exhibited significant differences, suggesting that friction ridges expand over time. It is concluded that both the dentition and dermatoglyphics display sexual dimorphism and characteristics of complex adaptive systems.

Keywords: buccolingual, complex adaptive system, dentition, dermatoglyphics, fingerprints, human development, ridge breadth, sexual dimorphism, tooth size

1 INTRODUCTION

Sexual dimorphism is the difference between sexes of the same biological species in phenotype or appearance. Some researchers have proposed that sexual differences are regulated by sex chromosomes [1, 2], but there are some who have suggested that hormonal influences are also important [3, 4]. Sexual dimorphism in human dentition and dermatoglyphs have been studied separately, and results are fairly consistent: males have larger tooth crown diameters than females [5, 6], sexual dimorphism is greater in permanent than in primary teeth [6, 7] and adult males have fewer finger ridges than females [8, 9].

Human development is a complex adaptive process that is influenced by genetic, epigenetic and environmental factors [10]. Genes interact with epigenetic and environmental elements and create complex networks within cells, and from this process the higher level tissues are formed. During embryonic growth, patterning, or the establishment of groups of cells in the proper relationship to each other and to surrounding tissues, occurs. Patterning is a longitudinal event that eventually leads to differentiation of cells to assume specialised functions and shapes.

The development of the human dentition and dermatoglyphs has similar embryological origin from epithelial–mesenchymal interactions [11]. Primary teeth commence development around 4 to 6 weeks in utero [10], while ridged skin on the fingers starts to form around 10 to 16 weeks in utero [12]. Once the patterns have been stabilised, their unique and persistent morphology makes them valuable models in studying sexual dimorphism. Only one study has explored possible correlations between the human dentition and dermatoglyphs in sub-adult Australian twins, and sexual dimorphism was observed in both primary and permanent teeth

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but not in fingerprints [13]. This study aimed to determine the nature and extent of sexual dimorphism in teeth and fingerprints of twins and explore whether both systems display the features of complex adaptive systems.

2 MATERIALS AND METHODS

Twin samples were acquired from the ongoing longitudinal research of the Craniofacial Biology Research Group in the Adelaide Dental School at the University of Adelaide [14], which is one of the four most extensive studies of its type in the world [15]. Serial casts of primary and permanent teeth, and rolled ink fingerprints of individuals aged 8 to 10 years and 13 to 16 years from a single cohort of monozygotic and dizygotic Australian twins (28 males and 31 females) were gathered and analysed. Dental casts showing wear, caries, or restorations and ten-prints with smudged ink and scarred patterns in any of the fingerprints were excluded.

Buccolingual crown diameter (BL) was measured as the breadth or distance between the buccal/labial and lingual surfaces of the crown [16, 17] by using a 2D imaging system. Using an adjustable stage, dental casts were orientated to obtain the correct plane or angle before obtaining images and calibrated Image J [18] software was used to digitise landmarks (Fig. 1). Measurements were obtained for central incisors (I1), lateral incisors (I2), canines (C), first molars (M1) and second molars (M2) of primary and permanent teeth.

Ridge breadth (RB) was determined by measuring the distance of 10 parallel ridges with no obstruction such as scars or white creases and/or interfering minutiae such as bifurcations, ridge endings, and short ridges. Measurements began and ended with valleys, or the spaces before the first ridge and after the tenth ridge (Fig. 2). This method is independent and not influenced by fingerprint pattern type and finger area [19].

Data were statistically analysed using XLSTAT statistical software. Descriptive statistics including means, standard deviations (SD) and coefficients of variation (CV) were computed

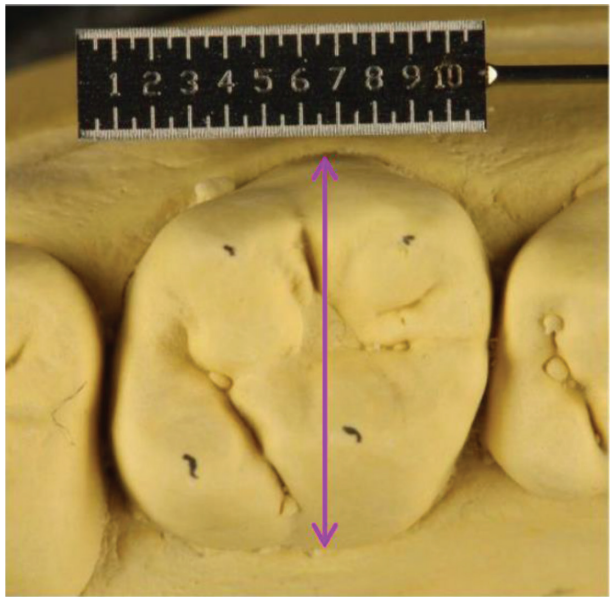

Figure 1: Buccolingual (BL) measurement of a permanent upper first molar from the occlusal view.

Figure 2: Sample of Ridge Breadth (RB) measurement.

for BL and RB variables. Differences between sexes and sides were calculated using Student's unpaired t-test. RB differences between age groups were compared with paired t-tests, and differences among fingers were examined with analysis of variance (ANOVA). Pearson's correlation coefficient was calculated to examine the strength of associations between the variables.

3 RESULTS

BL and RB measurements were found to be normally distributed, and results of intra- and inter-operator repeatability tests determined that errors in measurements were negligible and not likely to bias the results. Shown in Table 1 are the mean values, SD and CV of buccolingual (BL) measurements of primary and permanent teeth.

Highlighted in yellow are the sexually dimorphic dental measurements, where mean values are different between sexes at $p < 0.05$. Mean values of BL crown sizes of males were consistently greater compared to females in all types of teeth. Permanent dentitions showed greater sexual dimorphism compared to primary dentitions. There were no left-right differences observed in BL measurements of all primary and permanent teeth.

Shown in Table 2 are the mean values, SD and CV of ridge breadth (RB) of fingerprints of 8 to 10 year-old cohort and 13 to 16 year-old cohort.

All mean values of RB were statistically different to each other at $p < 0.05$. Highlighted in blue are the RB means that were found to be statistically different on both sides. More left-right differences were observed in the younger (8 to 10 years old) cohort. Most fingers were asymmetric in both sexes, except for the index fingers and thumbs in males and index fingers in females. It was observed that fingers on the right side consistently have greater RB, which indicates thicker finger ridges.

Table 1: Descriptive statistics for buccolingual (BL) measurements of primary and permanent teeth of Australian twins.

	Males								**Females**							
	Right				**Left**				**Right**				**Left**			
	n	**Mean**	**SD**	**CV (%)**	**n**	**Mean**	**SD**	**CV (%)**	**n**	**Mean**	**SD**	**CV (%)**	**n**	**Mean**	**SD**	**CV (%)**
								Primary								
								Maxillary								
i1	28	5.07	0.33	6.44	28	5.12	0.33	6.38	31	4.92	0.34	6.97	31	4.96	0.36	7.25
c	28	6.20	0.42	6.81	28	6.18	0.42	6.87	31	6.10	0.39	6.41	31	6.08	0.38	6.23
m1	28	8.79	0.43	4.88	28	8.76	0.42	4.77	31	8.55	0.34	3.96	31	8.54	0.34	4.01
m2	28	10.00	0.48	4.76	28	9.96	0.43	4.37	31	9.68	0.40	4.12	31	9.64	0.39	4.02
								Mandibular								
i1	28	3.88	0.30	7.62	28	3.83	0.25	6.40	31	3.72	0.27	7.30	31	3.71	0.24	6.58
i2	28	4.40	0.33	7.48	28	4.38	0.31	6.99	31	4.28	0.29	6.71	31	4.29	0.28	6.60
c	28	5.65	0.36	6.40	28	5.65	0.36	6.32	31	5.58	0.38	6.90	31	5.58	0.35	6.29
m1	28	7.09	0.38	5.31	28	7.17	0.37	5.16	31	6.86	0.40	5.77	31	6.94	0.37	5.29
m2	28	8.72	0.38	4.36	28	8.72	0.38	4.35	31	8.38	0.40	4.82	31	8.41	0.37	4.36
								Permanent								
								Maxillary								
I1	28	7.27	0.56	7.69	28	7.29	0.55	7.55	31	7.04	0.55	7.75	31	7.04	0.56	7.93
C	28	8.32	0.56	6.73	28	8.41	0.61	7.28	31	7.91	0.54	6.81	31	7.97	0.56	6.96
M1	28	11.79	0.56	4.79	28	11.73	0.54	4.60	31	11.22	0.53	4.75	31	11.16	0.50	4.48
M2	28	11.95	0.70	5.88	28	12.07	0.84	7.00	31	11.18	0.69	6.14	31	11.07	0.61	5.48
								Mandibular								
I1	28	6.19	0.46	7.41	28	6.13	0.51	8.34	31	5.93	0.46	7.74	31	5.97	0.43	7.23
I2	28	6.47	0.53	8.23	28	6.41	0.55	8.51	31	6.25	0.53	8.41	31	6.28	0.47	7.47
C	28	7.66	0.65	8.50	28	7.66	0.65	8.45	31	7.20	0.48	6.64	31	7.29	0.57	7.77
M1	28	10.54	0.47	4.48	28	10.56	0.50	4.70	31	9.99	0.48	4.78	31	10.07	0.48	4.77
M2	28	10.70	0.58	5.39	28	10.64	0.61	5.70	31	10.01	0.61	6.12	31	10.07	0.57	5.68

Highlighted in yellow are the sexually dimorphic RB measurements, where mean values are different between sexes at $p < 0.05$. Left index, right middle and left ring fingers were observed to exhibit male-female differences in the older cohort (13 to 16 years old), with greater mean values for RB in males, which indicates thicker friction ridges. Based on paired t-test, all mean values of RB are different between age groups at $p < 0.05$, with the older cohort having greater RB values compared to the younger group.

Table 2: Descriptive statistics for ridge breadth (RB) of fingerprints of Australian twins.

	Males								Females							
	Right				Left				Right				Left			
	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)	n	Mean	SD	CV (%)
8–10 years old																
Thumb	28	4.24	0.54	12.66	28	4.21	0.57	13.59	31	4.32	0.58	13.39	31	4.07	0.46	11.24
Index	28	3.98	0.45	11.21	28	3.97	0.60	15.19	31	3.98	0.46	11.58	31	3.94	0.48	12.22
Middle	28	3.92	0.51	13.07	28	3.76	0.49	13.15	31	3.93	0.50	12.77	31	3.69	0.50	13.65
Ring	28	3.83	0.54	14.09	28	3.49	0.45	12.98	31	3.83	0.44	11.46	31	3.46	0.45	13.16
Little	28	3.80	0.54	14.23	28	3.61	0.48	13.37	31	3.82	0.47	12.24	31	3.67	0.42	11.39
13–16 years old																
Thumb	28	4.69	0.54	11.58	28	4.68	0.55	11.79	31	4.61	0.59	12.90	31	4.55	0.52	11.39
Index	28	4.40	0.55	12.60	28	4.62	0.56	12.19	31	4.36	0.65	15.00	31	4.30	0.53	12.29
Middle	28	4.29	0.60	13.99	28	4.05	0.41	10.07	31	4.03	0.39	9.72	31	3.89	0.50	12.77
Ring	28	4.12	0.52	12.57	28	3.88	0.45	11.72	31	3.94	0.51	12.87	31	3.64	0.43	11.72
Little	28	4.16	0.53	12.64	28	4.06	0.51	12.48	31	4.09	0.38	9.28	31	3.95	0.40	10.22

Pearson's coefficients (r) between teeth and fingerprints are presented in Table 3. Highlighted in yellow are the statistically significant correlations between dental characteristic, BL, and dermatoglyphic trait, RB at $p < 0.05$. In general, the correlations between teeth and fingerprints are statistically significant but low in magnitude.

Correlation coefficients were calculated within groups of dental and dermatoglyphic variables with significance set at $p < 0.05$. All BL measurements taken from different tooth types were positively correlated to each other in the primary teeth (0.32 to 0.92). Meanwhile, only some BL diameters (128 of 306 in males, 226 of 306 in females) were positively correlated to each other in the permanent teeth (0.36 to 0.94), and more significant values were observed in females than males. On the other hand, only some RB measurements from different fingers were positively correlated to each other (90 of 90 in young males and 83 of 90 in young females, 64 of 90 in old males and 40 of 90 in old females), with more significant values in males, and all values are significant in the young cohort males. Greater r values were observed in RB at an older age (0.39 to 0.76) compared to the younger age (0.21 to 0.67).

Table 3: Pearson correlation coefficients of BL (buccolingual width) and RB (ridge breadth).

	Primary		Permanent	
Ridge Breadth	**Maxillary**	**Mandibular**	**Maxillary**	**Mandibular**
Males	0.28	0.30	0.25	0.35
Females	0.28	0.29	0.24	0.37

4 DISCUSSION

The degree and patterning of sexual dimorphism in the dentition varies according to tooth type. Our observation of the permanent dentition showing more pronounced sexual dimorphism than the primary dentition agrees with previous findings [4, 13]. The permanent molars displayed the largest sexual dimorphism in BL measurements, similar to previous studies [20, 21]. It has been suggested that dental development might occur under relatively high levels of testosterone influence [4], and this could explain the differences in sexual dimorphism between primary and permanent teeth of same individuals.

The degree and patterning of sexual dimorphism in the dermatoglyphs varies according to finger type and side. In this study, there was no observed sexual dimorphism at the age of 8 to 10 years, while fingerprints at 13 to 16 years of age displayed sexual dimorphism in the left index and ring fingers, and right middle finger. Our results are consistent with our previous study and support the idea that friction ridges expand as individuals grow and develop, probably more in males than females [13]. Sexual dimorphism in dermatoglyphic development seems to be initiated during puberty, when a testosterone surge occurs in males [22].

In normal male development, three surges of testosterone occur: the first surge happens at around the 7th to 9th week of pregnancy, and the testosterone level is highest around the 14th week following testicular differentiation [23, 24]; the second surge initiates after birth because of the reduction of oestrogen produced by the placenta [22]; and the third surge occurs during puberty. Meanwhile, primary teeth begin to form at around 4 to 6 weeks in utero [11] until around one year after birth. Permanent teeth commence development 14 weeks in utero and around 14 years of age [25]. On the other hand, primary ridges start to form at around 10 to 16 weeks and end on the 17th week, then secondary ridges develop until the 24th week in utero [12]. Our results are consistent with our previous study [13] and further support the idea that the first two testosterone surges have a critical role in the sexual dimorphism of both the primary and permanent teeth, while the third testosterone surge strongly influences the sexual dimorphism of fingerprints.

The human body is a complex adaptive system, and human development is a complex adaptive process [10]. This research has shown that both teeth and fingerprints are interconnected, yet they still have a degree of autonomy. They share a similar embryological origin and epithelial–mesenchymal interactions [11], yet they develop and interact with epigenetic and environmental factors differently. The interactions may be unpredictable, with no central control, but they are not random, as regularities and patterns emerge to find the best fit with the environment.

This research furthers the investigation on the complex mechanisms and interactions occurring during dental, dermatoglyphic and general development with buccolingual (BL) measurements of the teeth and ridge breadth (RB) measurements of the fingerprints. It is our second attempt to study both human dental and dermatoglyphic traits. Most studies have been conducted on the human dentition and dermatoglyphs separately, and no effort has been made to explore possible correlations between the two.

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