Foot Posture in School Children from the Western Cape: Differences between footwear use, gender and race

Elizabeth Mathewson

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Supervisor: Prof R Venter

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DECLARATION

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E Mathewson

SUMMARY

The feet of children are sensitive to external forces as the ligaments, muscles and bones are still in the process of maturing. The arch develops naturally within the first ten years of life. This research study reports on the factors affecting foot posture and plantar pressure parameters by describing the differences between boys and girls, age groups, and race in South-Africa, as well as the differences between South-African and German children.

A cross-sectional descriptive study where quantitative data were collected was used as the primary research method for this research study. Stratified randomised samples were selected consisting of 516 South-African children and 214 German children between the ages of six to eighteen years old. Testing equipment utilised include a manufactured foot calliper, as well as an EMED-SF® pressure plate. A barefoot scale was used to quantify the footwear habits of participants. A physical activity questionnaire developed specifically for older children (PAQ-C) and for adolescence (PAQ-A), were used to evaluate the physical activity level of the participants.

Within the South-African sample, no significant differences were found in foot posture between boys and girls. Younger children had significantly lower arches in terms of the dynamic arch index (DAI) (younger than ten: 1.045 (0.030), older than ten: 1.041 (0.026)) ($p = 0.025$), as well as increased pliability values. Children younger than ten years old presented with greatest peak pressure under the medial heel, while children older than ten years old presented with greatest peak pressure under the big toe. When comparing the DAI of white South-African children (0.171 (0.069)) (p = 0.000) to that of mixed race South-African children (0.196 (0/067)), it is clear that the mixed race children have flattened arches compared to the white children. Mixed race children presented with more pliable feet (1.050 (0.030)) compared to white children (1.040 (0.026)) (p = 0.000), as well as a decreased contact area in all regions of the foot, except for the medial midfoot, as they have greater medial midfoot contact (p < 0.05).

South African children had greater peak pressure in the medial forefoot and medial midfoot, as well as the big toe and toes two to five compared to German children (p < 0.05). Maximum force, was significantly greater for South-African children in all regions of the foot compared to German children except for the medial and lateral midfoot as well as the lateral forefoot (p < 0.05).

The most significant differences were observed between children of different races. Mixed race children presented with lowered arches, more pliable feet and more dispersed peak pressures. With regards to the intercontinental results, South-African children load their feet more medially with increased gripping of the toes. The increased pressure-time integral in German children puts them at an increased risk of developing foot pain.

Keywords: foot posture, plantar pressure parameters, foot development

OPSOMMING

Die voete van kinders is sensitief teen eksterne kragte wat daarop inwerk. Die ligamente, spiere en bene in die voet is nog in die proses van ontwikkeling en nog nie ten volle volwasse nie. Die voetbrug ontwikkel spontaan binne die eerste tien jaar. Hierdie navorsingsstudie rapporteer die verskille in voetstruktuur en druk onder die voet tussen seuns en meisies, tussen verskillende ouderdomsgroepe en rasse in Suid-Afrika, sowel as verskille tussen Suid-Afrikaanse en Duitse kinders.

Die studie is ‘n deursnee-studie waar kwantitatiewe data ingesamel is. ‘n Gestratifiseerde ewekansige steekproef van 516 Suid-Afrikaanse en 214 Duitse kinders tussen die ouderdom van ses en agtien jaar was gebruik. Die toerusting wat gebruik is, sluit ‘n vervaardigde meetpasser sowel as ‘n EMED-SF® druk platvorm in. ’n Kaalvoet vraelys is aan die deelnemers gegee, waar hul gewoontes van skoene dra aangedui word. ‘n Fisiese aktiwiteitsvraelys wat spesifiek vir ouer kinders (PAQ-C) en vir adolessente (PAQ-A) ontwikkel is, was gebruik om die kinders se fisiese aktiwiteitsgewoontes te bepaal.

In die Suid-Afrikaanse steekproef, was geen beduidende verskille gesien in voetstruktuur tussen die seuns en die meisies nie. Kinders jonger as tien jaar oud het beduidend laer voet brûe met ‘n brug-indeks van 0.257 (0.021) en ‘n dinamiese brug-indeks van 0.188 (0.066), sowel as meer buigsaamheid (1.045 (0.030)). Kinders jonger as tien jaar oud, toon die hoogste piek druk onder die mediale hak, terwyl kinders ouer as tien jaar die hoogste piek druk onder die groottoon aandui. Wanneer die Suid-Afrikaanse wit kinders met die Suid-Afrikaanse gemende ras kinders vergelyk word, is daar bepaal dat gemende ras kinders laer voet brûe getoon het in die dinamiese brug-indeks ((0.196 (0/067))(p = 0.000) in vergelyking met wit kinders (dinamiese brug-indeks: 0.171 (0.069))). Gemengde ras kinders het meer buigsaamheid getoon (1.050 (0.030))(p = 0.000) in vergelyking met wit kinders (buigsaamheid: 1.040 (0.026)), sowel as minder piek druk in al die areas van die voet, behalwe die mediale midvoet, want hul het 'n groter kontakoppervlak van die mediale midvoet.

Wanneer die Suid-Afrikaanse kinders met die Duitse kinders vergelyk is, was dit duidelik dat die Suid-Afrikaanse kinders hoër druk onder die mediale voorvoet en mediale midvoet, sowel as die druk onder die groottoon en die tweede tot vyfde toon ondervind het ($p < 0.05$). Maksimum druk was beduidend hoër vir Suid-Afrikaanse kinders in alle areas van die voet behawe die laterale en mediale midvoet en die laterale voorvoet, in vergelyking met Duitse kinders ($p < 0.05$).

Die mees beduidende verskil in die Suid-Afrikaanse steekproef was tussen die twee rasse. Kinders van gemengde ras het laer voetbrûe getoon, meer buigsaamheid en meer verspreide piek druk waardes. Met betrekking tot die interkontinentale resultate, was getoon dat Suid-Afrikaanse kinders hul voete meer mediaal belaai. Hul gebruik ook hul tone meer vir 'n beter greep. Verhoogde druk-tyd intergaal in die Duitse kinders kan lei tot 'n groter risiko vir die ontwikkeling van voetpyn.

Sleutelwoorde: voetstruktuur, druk onder voet, voetontwikkeling

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LIST OF ABBREVIATIONS

AHI	Arch height index
BMI	Body mass index
cm	centimetre
DAI	Dynamic arch index
DEXA	Dual-energy X-ray absorptiometry
EMG	Electromyography
FL	Foot length
FW	Foot width
MFPDI	Manchester foot pain and disability index
MLA	Medial longitudinal arch
mm	millimetre
MTP	Metatarsophalangeal
ICC	Intraclass correlation coefficient
PAQ	Physical activity questionnaire
PAQ-A	Physical activity questionnaire for adolescents
PAQ-C	Physical activity questionnaire for older children
SEAL	Sea Air and Land
SD	Standard deviation
WB	Weight bearing

CHAPTER ONE: INTRODUCTION

1.1 Background

The foot serves as the base of support for the body. Alterations in foot posture can affect the entire kinetic chain, affecting the knees, hips and lower back (Bird & Payne, 1999; Barwick, Smith & Chuter, 2012). The foot is a very complex structure that has to function as a rigid lever during the push-off phase of locomotion. In contrast, the foot needs to be pliable for shock absorption. The interaction that creates functional adaptability is accomplished by means of alignment of the bones, muscles and tendons. The foot bones move in a triplanar direction to accomplish the locking and unlocking of the foot structure (Caravaggi, Pataky, Goulermas, Savage & Crompton, 2009). The complexity of the foot makes the investigation thereof challenging.

There is no definitive method to quantify foot posture. Direct measurements include radiographic measurements, anthropometric measurements, as well as ultrasound evaluation. Indirect measurements include ink footprints, plantar pressure parameters and photographic techniques (Stavlas, Grivas, Michas, Vasiliadis & Polyzois, 2005). Field studies need a cost-effective, simple and non-invasive method to evaluate foot posture. Measurements should be taken in a static and dynamic fashion, as static foot measurement will not give an accurate, comprehensive view of the foot during movement (Menz, 1998).

It is known that many intrinsic and extrinsic factors influence the development of the foot. These factors include age, gender, ethnicity, body weight, activity level and footwear habits (Lin, Lai, Kuan & Chou, 2001; Echarri & Forriol, 2003; Pfeiffer, Kotz, Ledi, Hauser & Sluga, 2005; Chen, Chung & Wang, 2009; Mauch, Grau, Krauss, Maiwald & Horstmann, 2009; Jiménez-Ormeño, Aguado, Delgado-Abellán, Mecerreyes & Alegre, 2013).

Children's feet differ from that of adults (Walther, Herold, Sinderhauf & Morrison, 2008). Babies are born with flat feet, with the presence of a plantar fat pad (Spitzy's fat pad) under the foot. This fat pad diminishes with age. The arch forms at about ten years of age. Children present the greatest peak pressure under the hindfoot, and with an increase in age this peak pressure measurement shifts to the forefoot as seen in adult populations (Bosch, Nagel, Weigend & Rosenbaum, 2009). During the process of foot development, the feet are very sensitive to external forces. The feet are very pliable structures, for example during the 12th century, the feet of Chinese girls were bound up to create feet that are about ten centimetre (cm) in length (Cummings, Ling & Stone, 1997). It is therefore crucial that the shoes children wear, if any, fit properly (Staheli, 1991; Echarri & Forriol, 2003; Mauch *et al.*, 2009).

Most literature focuses on the differences between the foot posture of habitually barefoot populations and habitually shod populations. Investigations into this topic have been around for more than a century. Earlier investigations have found barefoot populations to have greater foot width (FW), creating space between the toe which is necessary for gripping (Hoffmann, 1905). In more recent years, researchers have found the highest incidence of flatfeet in shoe-wearing populations, less flatfeet in populations wearing flip-flops, and the smallest incidence of flatfeet in barefoot populations (Rao & Joseph, 1992). Investigations specifically focussing on children's shoes report that restrictive footwear leads to foot deformity, loss of mobility, weakness of the intrinsic foot muscles and less spreading of the toes (Staheli, 1991).

In a recent study assessing the kinematic influence of wearing shoes, it is reported that shoes have a splinting effect on the motion of the midfoot and the first metatarsophalangeal (MTP) joint, and that it reduces foot torsion, as well as the efficiency of the windlass mechanism (Wegener, Greene, Burns, Hunt, Vanwanseele & Smith, 2015).

A great amount of research has been done comparing barefoot- and shod populations; however, the ethnicity of the participants was not recorded. When comparing the foot structure between habitually barefoot- and habitually shod individuals, it is important to keep the ethnicity consistent (D'Août, Pataky, De Clercq & Aerts, 2009). Ethnicity has an influence on the laxity of joints (Lin *et al.*, 2001; Chen *et al.*, 2009) and may affect foot posture as well.

1.2 Motivation

There is a plethora of literature on the factors affecting foot posture; however, there is little academic support on the feet of children in static and dynamic conditions, while controlling for confounding factors. In the literature, there is no standard method to quantify foot posture, and the variety and diversity of the research questions and specific aims, made comparing results across studies a challenging task. Within the South-African sample, the current study aims to investigate the differences in foot posture between girls and boys, children younger and older than ten years of age, as well as between different races. These children were exposed to the same climate and footwear habits; however, they differed in race. Furthermore, this study also aims to investigate the differences between white South-African children and German children, with specific reference to gender and age. Race was kept as consistent as possible and it was assumed that different footwear habits were present as result of the difference in climate.

1.3 Research aims and objectives

The primary aim of this study was to investigate differences in foot posture and plantar pressure parameters of children between the ages of six and eighteen years old, within a South-African sample. The secondary aim was to determine how the plantar pressure parameters of South-African children differ from that of German children.

In support of the research aims the following objectives guided the research:

Within the South-African sample, to determine differences in terms of arch height index (AHI), dynamic arch index (DAI), pliability of the feet, as well as areas of peak pressure between:

(1) children from six to ten years old and children from eleven to eighteen years old.

(2) boys and girls.

(3) children from different races.

(4) children with different physical activity levels.

To compare the South-African children to the German children in terms of:

(5) peak pressure.

(6) pressure-time integral.

(7) force-time integral.

(8) maximum force.

(9) contact area.

(10) contact time.

(11) DAI.

(12) coefficient of spreading.

1.4 Significance of the research

Foot disorders are prevalent in apparently healthy individuals. The foot is a very pliable structure and wearing ill-fitting footwear has a negative effect on foot development. It is known that women's footwear is based on a scaled down version of a men's last. Little research has focused on the shoe design for different populations. As foot posture is influenced by age, gender, race, body stature and living habits, normative data is necessary that describes foot shape, and proportions for specific populations. Wearing restrictive footwear leads to decreased arch height and pliability of the foot, a narrower forefoot, as well as possible toe deformities. Altered foot posture can increase injury risk to the lower extremity, pelvis and lower back. It is worthy to investigate the differences in foot posture in a static and dynamic fashion in order to describe a "healthy" foot and the factors leading to variations in foot posture. Outcomes can be valuable for the shoe industry to provide greater variation in shoe dimensions to ensure a good fit. Knowledge of foot shape is and function is important for shoe design and clear that shoe dimensions is not a "fit all".

1.5 Scope of the study

This study is a cross-sectional descriptive study where quantitative data were collected. The testing took place during a single visit to schools, during school time. The sample consisted of 516 South-African children and 214 German children. Boys and girls between the ages of six to eighteen years old participated in the study. Randomised stratified sampling was used for data collection. The testing consisted of height and body mass measurements, static foot measurements, as well as plantar pressure measurements. Foot measurements were taken in a seated and standing position by means of a manufactured calliper with a resolution of one millimetre (mm). An EMED-SF® Pressure plate (Novel GmbH, Munich, Germany) system was used to collect plantar pressure data. All participants could voluntarily take part in the study if they completed an assent form, and if a consent form was completed by a parent or legal guardian. A barefoot questionnaire (Appendix F and Appendix G), a physical activity questionnaire for older children (PAQ-C) (Appendix I), and a physical activity questionnaire for adolescents (PAQ-A) (Appendix H) were completed by the participants. The children were asked to indicate their race at the end of a PAQ form (Appendix H and Appendix I). All questionnaires were available in English and Afrikaans to accommodate different language preferences. Children were excluded from the study if they had any current lower limb injuries, foot or toe deformities or clearly altered gait patterns. Children with a history of neuromuscular disease were also excluded as they have an increased risk for injury. Ethical clearance has been obtained from the Human Research (Humanities) Ethics committee for the study "Moving Feet" (HS1153/2014, Appendix A). The Western Cape Department of Education gave permission for the study to be conducted in the participating schools (Reference: 20160128-7123, Appendix B).

1.6 Structure of thesis

The thesis is presented in research article format. The two research articles (Chapter 3 and Chapter 4) were prepared according to the guidelines of different journals. Consequently the referencing style used in the different chapters of this dissertation will differ. The chapter and content analysis applicable to this research study are the following:

Chapter Two

This chapter gives a theoretical background on the function and anatomy of the foot. It focusses on the injuries associated with altered foot posture. This chapter describes the factors influencing foot posture and includes information related to age, gender, body mass, ethnicity and footwear use.

Chapter Three

The first article is compiled under the guidelines of the Journal *The Foot*. This article describes the foot posture of South-African school children in static and dynamic conditions by investigating differences between genders, age groups, as well as different ethnicities. This article addresses objectives (1), (2) and (3) as described in the section involving the aims of the study.

Chapter Four

The second article is compiled under the guidelines of the Journal *Gait and posture*. This article reports on the differences in plantar pressure parameters between German and South-African school children. This article addresses objectives (5), (8), (9) and (10) as discussed in the section involving the aims of the study.

Chapter Five

The fifth chapter provides a general discussion of the data by addressing each objective of the study, and it provides a general comprehensive conclusion regarding the main differences in foot posture and plantar pressure parameters in South-African children as well as when compared to German children. In addition, the limitations of the study and future research studies are discussed in this chapter.

CHAPTER TWO: THEORETICAL CONTEXT

2.1 Introduction

The following section will describe what is meant by foot posture in literature. The functional anatomy of the human foot and the importance of the medial longitudinal arch (MLA) will be explained as well as the measurement techniques of foot posture. Thereafter the factors influencing foot posture will be concisely reviewed from literature. These factors include age, gender, body mass, activity level, ethnicity as well as footwear use.

2.2 Foot posture

Although a lot of research has been published on foot posture, the term has not been clearly defined in literature. For the purpose of this manuscript, the terms foot structure and foot posture are not interchangeable. Foot structure refers to the anatomical dimensions of the foot and can be measured one dimensionally. Foot function refers to the dynamic, functional capacity of the foot and needs to be measured three dimensionally. Three dimensional measurements of the foot in motion are very difficult and needs expensive equipment. Foot posture refers to a combination of static and dynamic measurements of the foot in order to describe the foot in an overarching fashion, relating the static foot measurements with the dynamic foot function (Redmond, Crosbie & Ouvrier, 2006). Foot posture is therefore related to the anatomy of the foot as well as the functional role the foot has to fulfill.

2.3 Functional role and anatomy of the human foot

The foot has a complex functional role. Locomotion demands the body moving its centre of mass over a static foot, where the foot acts as a rigid lever. The most efficient way of locomotion is by making use of an inverted pendulum, moving the centre of mass in a relatively straight line, over the stationary foot. During locomotion, the foot needs to be pliable for shock absorption during early midstance and act as a rigid lever during push-off (Zifchock, Davis, Hillstrom & Song, 2006; Onodera, Sacco, Morioka, Souza, Sá & Amadio, 2008).

In foot biomechanics and locomotion, the medial longitudinal arch (MLA) plays an important role in terms of the alignment of bones, muscles, tendons and ligaments to create locking and unlocking of the foot structure for functional adaptability (Zifchock *et al.*, 2006; Onodera *et al.*, 2008). The foot needs to adapt to different terrains and act as a shock absorber. The foot also needs to act as a rigid lever for push-off (Kirby, 2000). The motion of the midtarsal and intertarsal joints leads to pronation and supination of the subtalar joint that make the conversion between stability and pliability possible.

With heel strike, linear momentum of the body is converted into angular momentum creating internal rotation of the whole lower limb. As the pronation of the foot allows for shock absorption, this conversion of momentum is very important for decreasing impact during walking (Kirby, 2000). For smooth ambulation, at late midstance, the whole lower limb should be slightly externally rotated. This allows the centre of mass to move smoothly to the contralateral limb. External rotation is initiated on the ground, where the subtalar joint supinates with activation of the gastrocnemius and soleus muscles. If subtalar supination does not occur, the foot needs to move into an externally rotated position. Subtalar joint supination aids in the structural potential of the foot to resist the dorsiflexion moments on the metatarsal heads during push-off, making the foot a more rigid lever. Insufficiency of this mechanism, as a result of increased pronation, will produce weakness during propulsion (Kirby, 2000).

During locomotion, the line of centre of force moves along the plantar surface of the foot. This increased force runs from the heel along the lateral surface of the foot. Thereafter, it runs along the heads of the metatarsals in a transverse motion until it leaves the big toe during push-off. This motion is needed for correct gait, and by altering the alignment of the foot and ankle complex, can lead to dynamic functional change (Echarri & Forriol, 2003).

Altered foot function can lead to muscle imbalances, balance problems or gait abnormalities, as well as decreased efficiency and effectiveness of the foot (Onodera *et al.*, 2008; Wegener *et al.*, 2015). Abnormal lower limb alignment can also lead to pathologies in the ankles, knees, hips and even the spine (Villarroya, Esquivel, Concepción, Buenafé & Moreno, 2008). Understanding the anatomy of the foot is important in order to understand its complex functional role.

The foot is divided into three regions, namely the hindfoot, midfoot and forefoot (Figure 2.1). The hindfoot consists of the talus and calcaneus, creating the subtalar joint. The midfoot consists of the navicular, cuboid and cuneiforms forming the transverse tarsal joints (talonavicular and calcaneocuboid) and the distal intertarsal joints (cuneonavicular, cuboidnavicular, intercuneiform and cuneocuboid complex).

The metatarsals and phalanges together with the tarsometatarsal-, intermetatarsal-, metatarsophalangeal-, and interphalangeal joints form the forefoot (Neumann, 2010).

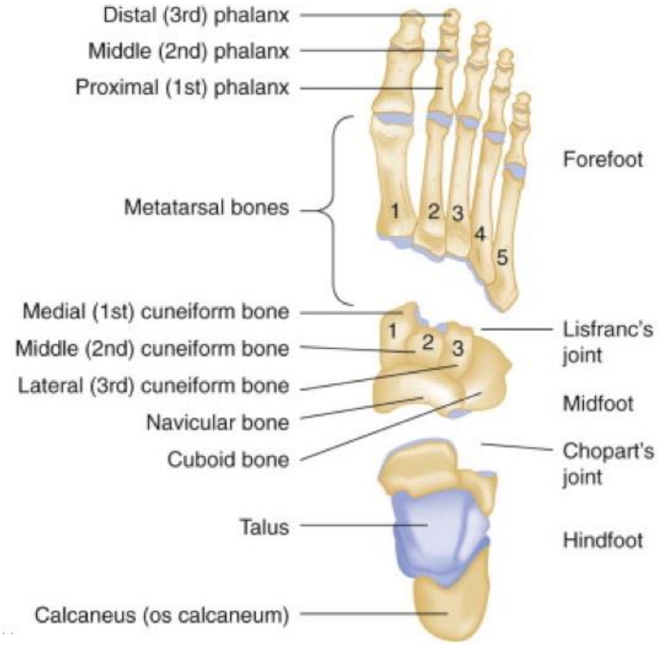

Figure 2.1: The three regions and bones of the foot

(Court-Brown, Heckman, McKee, McQueen, Ricci & Tornetta, 2012)

Bones and joints in the midfoot create the medial longitudinal arch (MLA). The MLA is important to create the locking and unlocking of the foot during locomotion in order to adapt to different functions.

The MLA is supported by active (muscles) and passive (bones and ligaments) structures (Figure 2.2). During standing, the MLA is mostly supported by passive structures where the plantar fascia contributes to roughly 25% of arch stiffness (Kaufman, Brodine, Shaffer, Johnson & Cullison, 1999). However, during periods of heavy loading and dynamic activity, the muscles play a more pronounced role in arch stabilisation. If the tarsal bones are poorly aligned, more load is carried by the muscles, which could lead to arch collapse (Kaufman *et al.*, 1999). The following section will discuss the active and passive supporting structures.

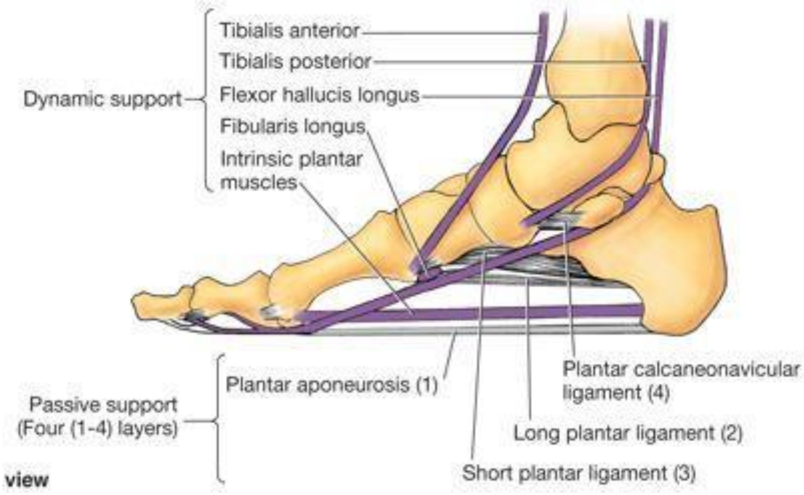

Figure 2.2: Active and passive support of the arch

(Studyblue© (www.studyblue .com) / Neale's Disorders of the Foot, Lorimer, French, O'Donnell, Burrow, Wall, Copyright Elsevier, (2006))

The tibialis anterior muscle runs from the upper two thirds of the lateral surface of the tibia to the medial surface of the first cuneiforms and the base of the first metatarsal bones. The cuneiform articulates with the navicular anteriorly. The posterior tibialis muscle originates from the lateral aspect of the posterior surface of the tibia and inserts on the navicular tuberosity, and extends with fibrous expansions to the calcaneus, cuneiforms, cuboids, as well as the base of the second, third, and fourth metatarsals. The muscles play a protective role in terms of the stabilisation of the joint, while the skeletal interactions are needed for shock absorption (Delacerda, 1980; Neumann, 2010).

Another important muscle is the tibialis posterior, which originates at posterior aspect of the tibia, fibula and interosseous membrane. It then runs posteriorly and medially around the ankle, in a groove next to the medial malleolus and inserts on the area of the navicular tuberosity in the midfoot (Beals, Pomeroy & Manoli, 1999). The tibialis posterior functions as a plantar flexor of the ankle and an invertor of the subtalar joint. Dysfunction of the posterior tibialis is the most common cause of flatfoot deformity in adults and children (Beals *et al.*, 1999; Ringleb, Kavros, Kotajarvi, Hansen, Kitaoka & Kaufman, 2007).

The plantar calcaneonavicular (spring) ligament stretches from the sustentaculum talus of the calcaneus to the medial-plantar surface of the navicular and forms the floor and medial wall of the talonavicular joint. This ligament is wide and supports the head of the talus in a body weight loading position, thus keeping the shape of the arch in a weight bearing position (Neumann, 2010). Cutting this ligament would lead to arch collapse (Taniguchi, Tanaka, Takaura, Kadono, Maeda & Yamamoto, 2003). Minimising the support of the tibialis posterior, will lead to stretching of the spring ligament, lowering the arch, and decreasing the effectiveness of push-off (Taniguchi *et al.*, 2003). The plantar aponeurosis stores potential energy as the toes dorsiflex (in late stance) and the plantar aponeurosis is stretched around the metatarsal heads. This action is responsible for raising the arch and is known as the windlass mechanism (Caravaggi *et al.*, 2009).

The windlass mechanism is the raising of the arch that follows when extending the toe. When the toe extends, it pulls the plantar pad anteriorly, which then pulls on the attachment of the plantar aponeurosis. The plantar aponeurosis is now tightened and shortened, thereby lifting the arch. The tarsal bones now move into a supinated stable position. Rising of the arch is caused by the position of the bones and ligaments (Hicks, 1954; Caravaggi *et al.*, 2009)

The foot needs both active and passive structures to keep the integrity of the arch. Muscles, bones and ligaments work together through the different phases of the gait cycle to ensure optimal foot function. If the integrity of the arch is compromised, risk of injury is increased.

2.4 Arch height and injury risk

There is an association between foot structure and lower extremity dysfunction where the structure of the foot is normally classified by determining the height of the arch. Altered foot mechanics can be linked to lower limb dysfunction and thus contribute to pathologies of the ankles, lower legs, knees, hips and lower back (Barwick *et al.*, 2012). Contradicting literature is found on the relationship between arch height and injury patterns (Barnes, Wheat & Milner, 2008; Buldt, Murley, Butterworth, Levinger, Menz & Landorf, 2013). This is due to the lack of methodological consistency in terms of foot classification methods and injury classifications (Barnes *et al.*, 2008; Buldt *et al.*, 2013).

Within the adult population it was clear that there is a correlation between foot characteristics, specifically arch height, and lower limb overuse injuries. Kaufman *et al.* (1999) also investigated the correlation between arch height and injury rate. They studied 449 Navy Sea, Air and Land (SEAL) trainees between the ages of 18 to 29 years old from different ethnical backgrounds (88.5% White, 5.7% Hispanic, 2.0% Black, 1.5% Native American, and the remaining were combinations of other ethnicities). It was found that both extremes of arch height (high and low) increased the risk of lower limb injuries (Kaufman *et al.*, 1999).

With regards to runners, Williams, McClay and Hamill (2001) proposed a trend that high arches increase the risk for bone injuries, as well as lateral structural injuries and foot problems such as ankle injuries and stress fractures of the tibia. Low arched individuals were at greater risk for soft tissue injuries, and likely to develop medial structures such as medial tibial stress syndrome or knee pain.

The above-mentioned trend might be related to the flexibility of the foot (Zifchock *et al.*, 2006). The low arched foot will be more flexible and thus prone to soft-tissue injury. Abnormal joint coupling or joint rotation may be to blame (Buldt *et al.*, 2013), whereas the high arched foot will be more rigid and stress fractures could result from less mobility and shock absorption properties. The above mentioned studies were done on adults, and the link between arch height and injury might differ for children.

In preschool children, the significance of flexible flatfoot was investigated in a study on preschool children in Taiwan (Lin *et al.*, 2001). Feet were graded subjectively on appearance of the arch. If the arch appeared normal upon raising the heel, children were classified as having a flexible flatfoot. The normal and mild arch groups were compared to the moderate and severe flatfoot groups. Gait analysis was performed by means of a motion analysis system, and variables included kinetics, kinematics and spatio-temporal parameters. The children were also asked to perform various physical activity tasks while grading their performance. It was reported that children with flexible flatfoot walk slower, toe-out slightly, and a degree of valgus was seen in both the ankle and knee joint. These children also scored lower muscle performance scores. The researchers concluded that flexible flatfoot has a negative influence on physical performance as a result of laxity of the supporting ligaments. The research involved a very young target population, whose arches were not fully developed and that will undergo structural changes with maturation (Lin *et al.*, 2001). The feet of primary school children will be fully developed by the age of ten years old (Lin *et al.*, 2001; Onodera *et al.*, 2008; Chen *et al.*, 2009). The current study investigates the foot posture in primary school and high school children.

Only one study was done involving primary school children. No altered function was reported in children who presented with flexible flatfoot. Demographic data, as well as participants' age, gender, height and weight were collected. Generalised laxity was evaluated by using the Beighton scoring system (Beighton, Solomon & Soskolne, 1973), where nine indicates a maximum score. Children that scored five and more were classified as hypermobile. The MLA was subjectively evaluated in a standing position. The foot was classified as being flexible if the arch appeared normal when lifting the heel or during hyperextension of the toe. The children were divided into four groups, namely "normal", "mild flatfoot" "moderate flatfoot" and "severe flatfoot", as described by Lin *et al.* (2001). Groups were clustered by combining the "normal" and "mild flatfoot" groups, as well as the "moderate flatfoot" and "severe flatfoot" groups. Static footprints were also recorded with a Harris and Beath mat, thereby calculating the arch index by dividing the width of the arch of the foot by the width of the heel. The foot progression angle was also calculated from the footprint by getting the angle between the long axis of the foot and the line of progression. It was reported that flexible flatfoot does not lead to any degree of disability (El, Akcali, Kosay, Kaner, Arslan, Sagol, Soylev, Iyidogan, Cinar & Peker, 2006).

In 1999, it was suggested that not only the lower limbs are at greater risk for injury with altered foot motion, but also proximal structures. A study by Ogon, Aleksiev, Pope, Wimmer and Saltzman (1999) investigated the effect of arch height on the forces acting on the back during running. It was found that low arched feet are at greater risk for low back pathology. This claim is also supported by more recent literature.

Kirby (2000) explained that pronation leads to the joint axis being medially deviated where supinations tends to lead to a laterally deviated effect. A change as little as two millimetres in the position of the joint axis can cause imbalance of the moments acting on the subtalar joint in such a way that foot function is impaired. Excessive pronation leads to decreased supination at late midstance (just before push-off) thus producing decreased external rotation of the lower limb, which is needed for smooth ambulatory transition. As the normal range of external rotation of the lower limb is not achieved, a compensatory external rotation of the foot in relation to the ground or an abductory twist as the heel lifts will appear (Kirby, 2000).

Flat-arched individuals presented with significantly greater internal rotation of the rearfoot, as well as increased plantarflexion and greater abduction of the forefoot. More eversion at the rearfoot relates to the lowering of the arch as seen on the X-rays, indicating internal rotation of the talus and calcaneus (Levinger, Murley, Barton, Cotchett, McSweeney & Menz, 2010).

It was concluded in a review that excessive pronation of the foot leads to internal rotation of the whole lower limb (Barwick *et al.*, 2012). Placing the knee in a valgus position and the pelvis in an anterior tilt, results in the dysfunction of the muscles in the hip and pelvic region, and places increased stress on the lower back (sacroiliac and lumbosacral joints) (Bird & Payne, 1999; Barwick *et al.*, 2012).

Specifically in primary school children, Twomey and McIntosh (2012) investigated the effects of low arched feet on lower limb gait kinematics. The children were categorised in normal- and low arched groups based on static (footprint arch index) and dynamic (navicular height in the sagittal plane during walking) foot posture parameters. Groups consisted of 12 participants each. A motion analysis system was used to determine kinematic parameters. Greater external rotation at the hip and a more externally rotated foot progression angle was found in the low arched group, especially during the stance phase. Data on electromyography (EMG) activity was not collected and could have been helpful to explain whether the abnormal foot kinematics influence the proximal structures or if the altered pelvic muscle activation influences foot mechanics.

The majority of the research indicates that both extreme deviations in foot structure and arch height, whether it be high or low, will increase the risk of injury to certain structures in the foot, lower limbs, as well as pelvic and hip musculature. It is therefore very important to investigate the factors influencing foot posture, as altered foot function can be a health concern. Foot pain or injuries, affection the whole kinetic chain, as a result of altered arch height can be disabling and limit your physical capacity.

Discrepancies in literature may be due to differences in testing protocols, measurement techniques, data collection and aims of the studies (Williams & McClay, 2000). Differences in methodology of the studies make comparing results difficult. The following section will discuss the different techniques of measuring foot posture.

2.5 Measurement of foot posture

As discussed earlier, the MLA is a critical variable in determining foot posture. There is no single definitive method used in literature to evaluate foot posture (Stavlas *et al.*, 2005). Direct measurements include somatometric measurements, radiographic- or ultrasound evaluation. Indirect measurements include using footprints created by ink or a pressure plate, as well as photographic techniques. Clinical assessment can also be used to determine defects although this can be very subjective (Stavlas *et al.*, 2005). Disagreement in literature regarding arch structure and foot type classification, make it difficult to compare findings across studies (Menz & Munteanu, 2005; Barnes *et al.*, 2008). Standardised measurement techniques are needed in order to compare findings across studies. The assessment of arch height for field research requires an inexpensive, simple, non-invasive, reliable and valid method (McPoil, Cornwall, Vicenzino, Teyhen, Molloy, Christie & Collins, 2008). The following discussion will focus on the development of different techniques to accessing foot posture.

2.5.1 Footprint

The “arch index”, originally described by Cavanagh and Rodgers (1987), is used in literature to evaluate foot posture based on the footprint method. It was proposed that the arch index is defined as a ratio of the midfoot area relative to the total area of the foot excluding the toes. This is then classified into three groups: high arch, normal arch and flat arch. A large arch index corresponds with a flat arch and a low arch index to a high arch (Cavanagh & Rodgers, 1987). The basic concept is that a higher MLA produces a narrower isthmus (Stavlas *et al.*, 2005). It is generally believed that there is a relationship between foot structure and foot shape. However, in overweight and obese individuals this will not be accurate, as they have increased plantar fat mass that increases the contact area of the footprint (Wearing, Hills, Byrne, Hennig & McDonald, 2004; Billis, Katsakiori, Kapodistrias & Kapreli, 2007).

Other indexes based on plantar footprints include the Chipaux-Smirak Index, Alpha angle, and the Staheli Index. However, for the purpose of this research study, these indexes were not further investigated (Onodera *et al.*, 2008).

Footprint measurements are based upon the angle on the plantar surface of the foot. Although it will give an indication of arch height, measuring the bony aspect of the MLA will be more accurate for determining the true height of the MLA.

2.5.2 Navicular height

The navicular has a prominent tuberosity on its medial surface, in an adult it is about 2.5 centimetre (cm) away from the medial malleolus, and serves as one of the several attachments of the tibialis posterior muscle (Neumann, 2010). Information with regards to measuring the height of the navicular tuberosity from the supporting surface (Cowan, Jones, Robinson & Reed, 1993), as well as determining the vertical displacement of the navicular from a subtalar congruent position to a relaxed position

(Delacerda, 1980; Brody, 1982), can be found in literature. However, it has been found that measurement of the navicular tuberosity had poor-to-moderate intra-tester and inter-tester reliability. Difficulties arise with the small numerical values, as well as inconsistencies with placing the subtalar joint in a “neutral” position or a subtalar “congruent” position. Clinical experience helps to improve the reliability of the measurements (Menz, 1998).

2.5.3 Arch height index (AHI)

AHI was developed by Williams and McClay (2000) in attempt to eliminate the anatomical variability and difficulty palpating the navicular tuberosity. The AHI is defined as measuring the linear height of the arch at 50% of the total foot length (FL) by means of a manufactured foot calliper. It is then normalised to either the total FL or the truncated (the length of the foot without the toes) FL, as the absolute arch height cannot be used for comparison (Williams & McClay, 2000). Either the total FL or truncated FL could be used to calculate the AHI, depending on the population (McPoil *et al.*, 2008; Teyhen, Stoltenberg, Collinsworth, Giesel, Williams, Kardouni, Molloy, Goffar, Christie & McPoil, 2009). There will however be a numerical difference and the values will not be interchangeable. Using truncated FL will be more suited when analysing individuals with toe deformities such as hallux valgus or claw toes (McPoil *et al.*, 2008); however, total FL is predominantly used in literature. A manufactured caliper with a resolution of 1mm has been used in previous literature to determine foot dimensions (Kadambande, Khurana, Debnath, Bansal & Hariharan, 2006; Zifchock *et al.*, 2006; McPoil *et al.*, 2008; Teyhen *et al.*, 2009). Teyhen and colleagues demonstrated excellent reliability as well as an association between arch height measured statically with a caliper and dynamic plantar pressure measures

(Teyhen *et al.*, 2009).

Low or high arches are classified by an AHI being greater than 1.5 standard deviations (SD) from the mean (Teyhen *et al.*, 2009). The AHI is a valid and reliable method of clinically measuring the height of the arch and is used considerably in research; however, limited information is received from this measurement (Teyhen *et al.*, 2009).

When measuring the arch height there are some important factors to note. Firstly, the measurement must take into account bone landmarks, as soft tissue plays a role in the size and shape of the foot. Secondly, flexibility of the foot must be accessed, as static arch height is a poor predictor of dynamic foot function (Menz, 1998).

2.5.4 Pliability

Foot posture can be characterised in terms of AHI and arch stiffness (Zifchock *et al.*, 2006). The arch height is defined as the height of the arch at 50% of FL normalised to total FL, measured in both a sitting and standing position. Arch stiffness is defined as the amount of deformity per unit of load. It can be measured my determining the difference in arch height between standing and sitting (Zifchock *et al.*, 2006). It is assumed that the weight on the foot during sitting is 10% of the body weight and during bipedal standing, each foot will be loaded with 50% body weight. The load difference between sitting and standing will then be equal to 40%. Arch stiffness was calculated by dividing 40% of the bodyweight by the difference between the seated arch height and the standing arch height.

Kadambande, Khurana, Debnath, Bansal and Hariharan (2006) evaluated foot pliability by dividing the maximum weight bearing FL and the maximum weight baring foot width by the maximum non-weight bearing FL and the maximum non-weight bearing FW. This formula does not take body weight into account.

2.5.5 Plantar pressure

As described above, the AHI was found to be a valid and reliable method of classifying the arch. Teyhen *et al.* (2009) however found the information received to be very limited, therefore plantar pressure parameters were added. Plantar pressure measurements enabled functional assessment of arch height, as well as determining the roll-over and peak pressure areas, which presents a broader picture. It was reported that the dynamic arch index (DAI) correlates linearly with the static AHI when measured manually with a manufactured calliper.

Müller, Carlsohn, Müller, Baur and Mayer (2012) stated that static footprint measurements are not sufficient for predicting foot function. It was proposed that by measuring static and dynamic foot characteristics, it will be possible to achieve comprehensive view of foot structure and function (foot posture). Static foot measurements are FL and FW, which was achieved by placing the foot on a manufactured calliper. Dynamic foot measurements were achieved by having the participants walk over a pressure plate, built into a wooden walkway, thereby analysing their normal gait during barefoot walking. Data on the contact area, peak pressure, and force-time integral was used, as well as a calculation of the DAI, by dividing the contact area of the midfoot by the total contact area (forefoot, midfoot and hindfoot). This gave an indication of the arch height. A large DAI represents a low arch, while a small DAI represents a high arch (Müller *et al.*, 2012).

Jonely *et al.* (2011) determined which static foot measurement relates best with plantar pressures on the medial aspect of the foot. Their sample consisted of 92 participants who attended a local gymnasium. The participants consisted of 42 females and 50 males between 18 - 35 years old with a mean body mass of 27.9 and a SD of 16.7. The static clinical tests included an AHI, navicular drop, and navicular drift. The AHI refers to the dorsal height of the foot at 50% of the FL, normalised to the truncated FL, while the subject stands in a 90% weight bearing position. Navicular drop is a measurement of the amount of vertical movement of the navicular from a subtalar neutral position to a natural, relaxed position, while the subject is in a bilateral stance. Navicular drift describes the amount of horizontal movement of the navicular from a subtalar neutral to a normal relaxed stance. A Teskan® insole pressure system was used for plantar pressure parameters. It was stated that arch height, navicular drop and navicular drift measurements are significantly related to changes in the medial peak plantar pressures for standing and walking (Jonely *et al.*, 2011).

In summay, foot posture measurement based on footprints alone, are not sufficiently comprehensive (Menz, 1998). Static foot measurements need to include bone measurements, as soft tissue can influence the shape of the foot. It is useful to relate static measures to dynamic function and therefore include foot pliability measurements, as well as plantar pressure parameters (Teyhen *et al.*, 2009).

2.5 Factors influencing foot posture

Foot posture is affected by various internal and external factors. Five predominant factors that influence the development of the foot, namely age, gender, footwear habits, loading (bodyweight), physical activity habits and ethnicity are found in literature (Lin *et al.*, 2001; Echarri & Forriol, 2003; Pfeiffer *et al.*, 2005; Chen *et al.*, 2009; Mauch *et al.*, 2009; Jiménez-Ormeño *et al.*, 2013). The factors influencing foot posture is the focus of the current study. The following section will provide a summary of the literature on each of the factors influencing foot posture.

2.6.1 Age-related developmental changes

Birth to toddlers

Babies are born with foot supination and forefoot adduction. Once the child begins to walk, the talus and calcaneal bones start to grow faster on the medial side as a result of increased tension, and the rear foot moves to an upright position. This leads to the bones of the midfoot (cuboid, navicular and cuneiform bones) being moved from supination to a pronated position. As the child continues to walk and experience mechanical loads, the muscles and collagen fibres are strengthened to keep the foot in an upright position (Walther *et al.*, 2008). Babies have a prominent “sandal gap” (big toe standing away from the other toes). They have limited plantar flexion with a great range of dorsiflexion, as the toes can touch the shin (Walther *et al.*, 2008). Their supporting structures, such as tendons and ligaments which are necessary for development of the feet, are not yet developed to maintain the arch and is still very soft and elastic (Walther *et al.*, 2008).

Babies are born with high arches filled with a fat pad (Spitzy's fat pad) which in turn leads to flat feet, as commonly observed amongst preschool children. Müller, Carlsohn, Müller, Baur and Mayer (2012) agreed by stating that the feet of one-year-old toddlers are flat (great contact area). However, this may be due to the Spitzy's fat pad that diminishes with age, as six to seven-year-olds presents with significantly higher dynamic arch index.

Toddlers to ten-year-olds (Arch development)

Low arched feet seen in children younger than ten years old are due to laxity of the immature ligaments. Better muscle and balance control are expected with an increase in age as the child's central nervous system matures, thereby improving lower limb control and normalised stance. Maturation of the nervous system is complimented by gradual ossification of the bones to improve stabilisation of the arch during weight bearing (Echarri & Forriol, 2003; Stavlas *et al.*, 2005).

During the period of foot growth and maturation of the arch, the feet of children (toddlers to ten-year-olds) are more sensitive to external loads and compressions. Their feet are not physically strong and solid yet, and therefore it is of utmost importance for children to wear the correct fitting shoe, if any (Staheli, 1991; Echarri & Forriol, 2003; Mauch *et al.*, 2009). The shoe should have similar internal space and dimensions to the foot wearing it.

The arch should develop naturally within the first ten years of life (Lin *et al.*, 2001; Pfeiffer *et al.*, 2005; Onodera *et al.*, 2008; Walther *et al.*, 2008; Chen *et al.*, 2009). Discrepancies are found in literature as to at what age the arch is completely formed

(Villarroya *et al.*, 2008). Volpron (1994) reports that arch contours develop between the ages of two to six years old. Some researchers claim that the arch would be formed by six years of age (Riddiford-Harland, Steele & Baur, 2011). Staheli (1991) found that the MLA develops during the first six to eight years of life. Onodera *et al.* (2008) however, studied the growth and development of the arch and found that the foot is in a significant linear growth phase up to six years of age, thereafter maturation continues, but at a slower pace up to ten years of age. At the ages of seven to eight years old, the arch is classified as “low”. Only after the age of nine years old the arch can be classified as “normal”. The theory that the arch is completely developed at nine years of age is supported by literature (El *et al.*, 2006; Villarroya *et al.*, 2008).

As the feet of the child undergo structural and soft tissue changes, there are also changes in plantar pressure loading patterns (Hennig, Staats & Rosenbaum, 1994). By making use of a pressure distribution platform (EMED-SF® F01 system, Novel GMBH, Munchen, Germany) data were collected from 125 children (64 boys and 61 girls) between the ages of six to ten years old. Measurements were only taken on the right foot of the subjects. The results were compared to a previous study that was conducted on 111 adults with the same protocol. It was noted that a load shift occurs from lateral to medal between the ages of six to seven years old. Genu valgum is common in young children and is associated with pronated feet. As the child develops into an adult posture and gait pattern, the valgus will disappear, if the child is not overweight. This normally occurs between the ages of six to seven years old (Hennig *et al.*, 1994).

Bosch *et al.* (2009) also investigated the age-related differences in plantar pressure patterns. A total of 104 participants were divided into four different age groups, namely toddlers (mean age: 1.3; SD: 0.4), seven-year-olds (mean age: 7.0; SD: 0.4), adults (mean age: 31.9; SD: 2.1) and seniors (mean age: 68.7; SD: 3.2). All participants were instructed to walk at a comfortable pace over an EMED-SF® pressure plate in order to keep the gait as natural as possible.

The toddlers showed significantly lower peak pressure under the total foot, as well as under the hindfoot compared to the other age groups, and reached their peak pressure under the hallux during the roll-over process. The midfoot contact area was significantly higher amongst toddlers (29.49% of total contact area) when compared to the seven-year-olds (15.21%). Toddlers had a significantly higher DAI (0.36) compared to seven-year-olds (0.18), thus indicating flat feet (which may be as a result of Spitzy’s fat pad). This increase in contact area under the midfoot may explain the decrease in pressure values (Bosch *et al.*, 2009).

The seven-year-olds showed the highest peak pressure under the hindfoot compared to other age groups. The hindfoot was also the area with the greatest pressure under the total foot area. The seven-year-olds reached their peak pressure at heel contact. Within the first 12 months of walking, the peak pressure shifts away from the hallux and this is recognised as a very important developmental stage of the foot (Bosch *et al.*, 2009).

Adults

After formation of the arch, around the age of ten years old, the feet of children have similar dimensions to those of young adults (Onodera *et al.*, 2008). With a further increase in age, more changes occur in foot posture and plantar pressures as seen in a study comparing younger adults to the elderly (Scott, Menz & Newcombe, 2007). Older adults were not investigated within the ambit of this study. However, when compared to children, peak pressure under the total foot, forefoot and toes increased significantly with age. It was assumed that the increase in peak pressure is as a result of the changes in the elasticity of the supportive tissue involved with the ageing process. Adults and seniors showed the highest peak pressure under the forefoot. Adults and seniors also showed significantly longer contact time of the total foot (Bosch *et al.*, 2009).

2.6.2 Gender

Results on gender differences in children found in literature are somewhat contradictory. Some research indicate that girls show a higher incidence of flat foot (El *et al.*, 2006). This was hypothesised to be as a result of increased joint hypermobility in girls. On the contrary, other researchers report that boys or men are at greater risk of flat foot (Pfeiffer *et al.*, 2005; Stavlas *et al.*, 2005; Mickle, Steele & Munro, 2008; Chang, Wang, Kuo, Shen, Hong & Lin, 2010). These researchers speculated that the arch of boys probably develops slower than that of girls. Barisch-Fritz, Schmeltzpfenning, Plank, Hein and Grau (2013) also report that the AHI, FW and girth are greater in boys. Accordingly, other studies report that females tend to have narrower feet in the forefoot and heel region. Males present a longer heel-to-ball length of the foot (Krauss, Grau, Mauch, Maiwald & Horstmann, 2008) compared to females with the same FL. For the purpose of this study, foot dimensions were not investigated.

2.6.3 Body mass index (BMI)

Over the past decade, the rate of obesity in children has increased dramatically worldwide. This can lead to pathology in the lower limbs and especially the feet, as they are exposed to increased mass. The structures in children's feet are not adequately developed and matured to support high loads as with overweight and obesity (Onodera *et al.*, 2008). The increased load on the feet of the children may lead to changes in the ligamentous and structural tissue and therefore leads to a collapse of the MLA (Jiménez-Ormeño *et al.*, 2013). It is clear from literature that obese children tend to have broader, taller, thicker and flatter feet than their normal weight counterparts (Pfeiffer *et al.*, 2005; Mauch, Grau, Krauss, Maiwald & Horstmann, 2008; Chen *et al.*, 2009; Riddiford-Harland *et al.*, 2011; Jiménez-Ormeño *et al.*, 2013).

A recent study investigated the foot posture, range of motion, as well as the plantar pressure characteristics in obese and non-obese individuals (Butterworth, Urquhart, Landorf, Wluka, Cicuttini & Menz, 2015). The sample consisted of 68 participants (47 females and 21 males) that were classified into obese (BMI > 30.0 kg/m^2) (n=31) and non-obese (BMI < 30.0 kg/m^2) (n=37) individuals. Individuals had to indicate their degree of pain by means of the Manchester foot pain and disability index (MFPDI). Foot posture was calculated by making use of the foot posture index. Their degree of hallux valgus was also determined by using the Manchester scale. Arch structure was measured by the DAI - the contact area of the middle third to total contact area of the foot, excluding the toes (Cavanagh & Rodgers, 1987). High DAI correlates with a flat foot, thus <0.21 are classified as a high arch, 0.21-0.28 would be a normal arch, while >0.28 is regarded as a low arch. A goniometer was used to measure ankle inversion and eversion range of motion. Results indicate that obese individuals have a higher tendency to foot pain, pronated foot posture, flatter feet, as well as decreased ankle inversion. With regards to plantar pressure loading patterns, weight was significantly and independently associated with increased loading of the foot, especially the forefoot and midfoot, after accounting for foot structure and walking speed (Butterworth *et al.*, 2015).

Although the study by Butterwoth *et al.* (2015) was very thorough, it had one major limitation, as fat free mass and the level of physical activity were not taken into account. It might be useful to differentiate between obesity and muscular individuals as one will assume that with the same weight on the feet of the individuals, the feet of the muscular individuals would be better developed to handle that load.

2.6.4 Activity level

There are no studies, to the author's knowledge, that describe the influence of physical activity on the development of children's feet. However, some studies investigate physical activity on bone density in children.

Lean muscle mass was used as a total mediator of muscular fitness on bone health in a study conducted by Torres-Costoso, Gracia-Marco, Sánchez-López, García-Prieto, García-Hermoso, Díez-Fernández and Martínez-Vizcaíno (2014). A sample of 132 children of the same age (between eight and ten years old) and gender was used. Muscular fitness was determined by means of a handgrip test and a standing long jump, normalised to body weight. The children were also asked to wear an accelerometer monitor for seven days, only removing it with water-based activities. Their bone mineral density and bone mineral content were measured by means of a dual energy X-ray absorptiometry (DEXA) scan. It was reported that children with a good handgrip had higher bone mineral density and bone mineral content in a number of body regions. Children with good standing long jump scores had surprisingly less bone mineral density and bone mineral content in a number of body regions. Children with a high lean body mass had increased bone mineral density and bone mineral content in all the body regions tested. Therefore, lean body mass is a full mediator in the relationship between muscle fitness and bone mass (Torres-Costoso *et al.*, 2014). This study by Torres-Costoso *et al.* (2014) had a relatively small sample size.

2.6.5 Ethnicity

In literature it is stated that genetics can have an effect on arch height. It is difficult to fully confirm this statement without genetic testing. Evaluating different ethnical groups may be an alternative method. Many investigators have tried to specify the differences between different populations and different ethnical groups.

Stolwijk, Duysens, Louwerens, van de Ven and Keijsers (2013) noticed that foot problems are more prevalent in Western populations compared to African populations. They investigated foot geometry, plantar pressure patterns, and roll-over of the foot between Dutch and Malawian adults with no history of foot pathologies. A three-step method (third step measured) was used as participants walked over a pressure plate. Variables received include the mean pressure per sensor, peak pressure per sensor, pressure time integral per sensor, as well as the trajectory of the centre of pressure and the velocity of the centre of pressure. All variables were normalised to the FL and FW as indicated in earlier literature (Keijsers, Stolwijk, Nienhuis & Duysens, 2009). The DAI was calculated as described by Cavanagh and Rogers (1987). Low arches were classified as a value of 0.26 or more and high arches as a value of 0.21 and lower.

Significant differences were found between Dutch and Malawian feet in terms of medial angle (the angle between the centre of the medial malleolus, the navicular tubercle, and the medial centre of the first metatarsal head), navicular height-to-foot-length ratio, as well as navicular height. A lower MLA was represented by the Malawian group as they had a smaller medial angle and navicular height-to-foot-length ratio. They also reported on DAI data from the plantar pressure measurements and found the Malawian population to have a higher incidence of low arches, whereas the Dutch group tends to fall in the high arch category. The lower MLA of the Malawian population creates a larger loading area and more loading under the midfoot, thereby shortening the loading time of the forefoot during roll-off. More equal plantar pressure distributions were the proposed reason for less foot problems in the African population (Stolwijk *et al.*, 2013). Stolwijk *et al.* (2013) did not take into account the footwear habits and physical activity status of the participants, which could be confounding factors.

Race has an influence on laxity. It has been shown that Asian children have a higher laxity index than Caucasian children. It is still unclear if they also have an increased incidence of flat feet (Lin *et al.*, 2001; Chen *et al.*, 2009). Beighton *et al.* (1973) investigated the articular mobility in 1081 Tswana community members of the

Western Transvaal by means of a series of movements that classify the mobility on a scale from 0 to 9, with 9 being most flexible. The somatotype and pathologic symptoms were evaluated for each individual. They found females to be more hypermobile than males at all ages. It was suggested that hypermobile individuals have a higher risk of orthopaedic disorders such as joint degeneration, dislocations and muscular pains. The results were not compared to other populations and can therefore not be generalised. Other studies using the Beighton scale to evaluate flexibility, describing the incidence of flatfoot in primary school children. It was found that flexible flatfoot correlated with hypermobility in children, and dynamic arch height differed statistically significant between hypermobile and non-hypermobile children (El *et al.*, 2006).

Chen *et al.* (2009) compared their research to similar studies done on different racial groups, to evaluate ethnical differences. They report that Taiwanese boys between five to eight years old showed a flatfoot incidence of 43%, while the nine to twelve year old group showed an incidence of 30%. The results were compared to boys of the same age from a Congolese population. The Congolese boys presented with 49% and 25% respectively (Echarri & Forriol, 2003). Taiwanese children between the ages of six to twelve years old were also compared to Turkish children of the same age, and results indicate the prevalence of flatfoot to be 28% for Taiwanese children and 17% for Turkish children. It is very difficult to compare racial differences, as a standard protocol and variables were not put in place. Footwear habits were also not taken into account and can be a confounding factor.

These differences between population groups can be attributed to ethnical differences such as genetics, as well as environmental differences such as weather that affect the shoe-wearing habits of the individuals (Mauch, Mickle, Munro, Dowling, Grau & Steele, 2008). Evaluating different ethnical groups with the same climate and footwear habits are necessary to identify true differences.

Comparing the results of the studies is difficult as different testing equipment was used and the researchers were working towards different objectives. It is clear however, that some differences exist between different ethnical groups.

2.6.6 Footwear habits

The complexity of the foot makes investigation and understanding of the subject very challenging. However, research on the influence of footwear on the foot structure, has been done since the early twentieth century.

It is important to note that as the foot is a highly plastic structure. Wearing footwear from early childhood, will have an influence on the shape and dynamic function of the foot. It was then proposed that the Western foot is not “natural” anymore, and current knowledge of the foot is based on an already “deformed” foot as opposed to the biologically “normal” foot (D’Août *et al.*, 2009).

As early as 1905, it was demonstrated that shoes lead to irreversible damage to the forefoot. The “modern” shoe was seen as too tight, thus decreasing the wide shape of the forefoot and the space between the toes (Hoffmann, 1905). Hoffman speculated that common foot problems are as a result of using inadequate footwear on a daily basis.

A literature review investigated the effects of habitual footwear use, as well as the most appropriate type of footwear for children (Staheli, 1991). It was concluded that foot development occurs optimally in barefoot conditions and that shoes should be primarily used for protecting the foot against infection or injury. It was furthermore found that stiff and compressive footwear leads to foot deformity, weakness, and loss of mobility as the application of external force leads to deformity. Barefoot subjects tend to have greater mobility of the foot, as well as fewer deformities. In barefoot individuals, thickening of the plantar skin was observed with creases on the plantar and dorsum of the foot as a result of the flexibility in the midfoot. Increased pliability in the feet was also noted during weight bearing as subjects' toes spread more. It was also stated that compressive footwear leads to deformity, weakness and a stiffer foot and that children should wear shoes based on the barefoot model. They found the plantar skin of barefoot walkers to be thickened. In addition, they found creases on the plantar and dorsum of the foot due to the flexibility of the midtarsal joints.

The feet of Indian barefoot individuals were compared to Welsh shod individuals by means of anthropometric analysis. The sample consisted of 50 male and 50 female participants per group. The Indian group did not wear closed shoes, but simple protective footwear like flip-flops. All individuals had a healthy BMI range, were between the ages of 25 to 35 years old and had no lower limb injuries or deformities. Foot pliability was measured by determining the foot dimensions in a standing or sitting position. Forefoot intrinsic muscle function was measured by using a force gauge. No statistically significant difference was found between the force gauge measurements, thus wearing shoes does not inhibit function of the forefoot intrinsic muscles. However, it was found that unshod feet are more pliable than shod feet, thus concluding that wearing shoes restricts the natural splay of the forefoot and the MLA may lead to a stiffer foot as the feet of unshod Indians were more pliable than the feet of the shod Welsh population (Kadambande *et al.*, 2006).

The effects of footwear habits and the influence thereof on the foot shape and size relative to stature and body weight was investigated by Ashizawa, Kumakura, Kusumoto and Narasaki (1997). The researchers evaluated 103 male and 126 female East Javanese subjects that do not make use of any footwear. Filipinas subjects consisted of 34 women between the ages of 19 to 55 years old, who wore only sandals. Japanese subjects consisted of 300 boys and 325 girls between the ages of 6 to 18 years old, as well as 40 female and 107 male adult workers, wearing sneakers or leather shoes. Foot length and width were measured, as well as body weight and stature to determine BMI. It was found that the Javanese group had significantly longer and wider feet relative to their body weight compared to the Japanese group. According to Ashizawa *et al.* (1997), the barefoot population of East Java still represents the prototype human foot, whereas the modern Japanese foot is deformed as a result of the restraining footwear.

The predominant amount of literature report on studies involving adults, with feet is already completely developed. It is important to investigate whether the same trends are seen during the developmental stages on children. Children between the ages on six to thirteen are also the focus of the current study.

In 1992, a study was done by Rao and Joseph (1992) to investigate the influence of footwear on the feet of children between four and thirteen years old. A large sample of 1237 boys and 1063 girls were used. All children had the same ethnicity. Footprints were taken by means of a Harris and Beath mat. The footprints were classified into flat-, normal-, or high arched. They also classified their groups into habitually shod individuals and 745 participants were barefoot. Rao and Joseph (1992) noticed that flatfoot is very common in America and Europe, but not in India. They stated that children from farming- or manual labour communities do not present with flat feet. The "toe raise test" was done to determine if the child has flat feet or normal feet. They found flat foot to be most common in children wearing shoes habitually, less common in children wearing flip-flops, and least common in barefoot walkers. They concluded that wearing rigid shoes during the developmental stages of childhood can negatively affect the development of the MLA (inverse relationship) (Rao & Joseph, 1992).

The influence of wearing shoes was also investigated by Echarri and Forriol (2003), describing the development in footprint morphology in children. They divided the sample (1851 Congolese children of three to 12 years old) into two different socio-economic groups by targeting urban and rural areas, assuming that the urban children will be predominantly shod, whereas the rural children are predominantly barefoot. They made use of footprints to obtain data and also indicated the bodyweight of the child. Indexes such as the Chippaux-Smirak's index, Staheli's index and Clark's angle were used to quantify the foot morphology. They found a greater proportion of flat feet in the urban (shod) environment. The shod girls also showed significantly flatter feet compared to the barefoot girls across all the age groups investigated. There were however discrepancies depending on which variable they used (which index) (Echarri & Forriol, 2003).

The above-mentioned studies all focused on the anthropological measurements assessing the structure of the foot. Kinematic aspects were not taken into account.

Two-hundred-and-fifty-five subjects were included from three different ethnical backgrounds. From South India, 70 habitually barefoot and 137 habitually shod individuals made up the “Barefoot Indian” and “Shod Indian” groups respectively. The last group consisted of 48 Belgium individuals and was classified as the “Western” group. Foot measurements, plantar pressure parameters, as well as video analyses of foot kinematics were collected. The results show that barefoot individuals have significantly wider feet and a decreased peak pressure under the foot. This decreased the risk for injury, especially during physical activity (D’Août *et al.*, 2009).

Shoes have a splinting effect on the foot. Studies done on the kinematics involved with barefoot and shod walking include the research done by Wegener *et al.* (2015). It was reported that wearing shoes reduces the motion of the first metatarsophalangeal joint and midfoot during walking. More specifically, reducing the foot torsion, forefoot pronation and pliability of the arch, thus reduce plantar flexion of the midfoot during locomotion. This reduction was similar for individuals wearing flexible shoes; however, it was not consistent for individuals wearing flip-flops. This splinting effect of the shoe affects the function of the children’s feet. It may decrease the release of stored elastic energy through the windlass mechanism of the plantar aponeurosis. This decrease in windlass mechanism effectiveness may decrease the efficiency of running and jumping. Children will compensate for the decrease in midfoot plantar flexion by increasing ankle plantar flexion during shod walking (Wegener *et al.*, 2015).

A study on the anatomical evidence for the history of human footwear use was done by Trinkaus and Shang (2008). It was described that the basic pattern of ground reaction force during walking will not be greatly altered by wearing shoes. Where the peak ground reaction force during the stance phase will be at heel-strike, through the calcaneus and with heel-off through the MTP joints, then toe-off through the hallux with the lateral toes having little role in propulsion is used more for grip and traction during midstance to heel-off. Wearing shoes will affect the bending forces at the hallux, spreading it across the medial midfoot. A rigid sole will also decrease the amount of grip of the lateral toes (Trinkaus & Shang, 2008).

Mauch *et al.* (2008) investigated the differences in foot structure between the feet of German and Australian children. For the 505 Australian children (3 – 12 years old), feet were measured by means of 10 anthropometric measurements, while the feet of the German sample (matched for age, gender, height and BMI) were measured with a 3-D foot scanner. For both samples a pedograph was used to retrieve footprint information. They speculated that the dimensions of the children’s feet differ as a result of the warmer climate in Australia, which leads to different lifestyle habits such as predominantly walking barefoot or with sandals. They however did not take the ethnicity of the children into account. Firstly, German preschool children had significantly longer feet than the Australian children when matched according to age, gender, height and BMI. This trend however does not continue with older primary school individuals and might be explained by the increase in time spent wearing shoes in school. German children had significantly longer ball-of-foot length (from the heel to the first metatarsophalangeal protrusion). German preschool children had significantly higher dorsal arch height when normalised to FL, although they have flatter feet in terms of the contact area recorded on footprints. However, the Australian primary school children had significantly higher dorsal arch height compared to their German counterparts (Mauch, *et al.*, 2008).

The predominant amount of research on the influence of foot posture did not control for ethnical differences. When investigating the influence of footwear use on foot structure and foot function, ensuring that the individuals are from the same ethnical background is important as foot structure differs between ethnical groups (D'Août *et al.*, 2009). However, it is clear from literature that the foot develops optimally in barefoot conditions. The feet of children are in a maturation process and its plasticity makes it sensitive to external forces. Shoes have a splinting affect, thereby decreasing muscle function. The restrictive nature of footwear limits the natural splay of the foot.

2.7 Summary

The foot is a very complex structure. Enabled to function as a rigid lever, as well as a pliable adapter to different surfaces, joints in the foot need to lock and unlock on demand. This is made possible by the cooperation of ligaments and tendons pulling the joints into place (Kaufman *et al.*, 1999). Severe high arches or low arches may lead to alerted foot function and predispose individuals to injury (Williams *et al.*, 2001; Zifchock *et al.*, 2006; Buldt *et al.*, 2013). The measurement of height, as well as determining plantar pressure parameters, can quantify foot posture. Arch height can be measured by means of the AHI, dividing the height of the arch at 50% of the FL by the total FL (McPoil *et al.*, 2008; Teyhen *et al.*, 2009). Plantar pressure parameters are also good measurements of foot posture in a dynamic fashion (Keijsers *et al.*, 2009).

From the literature it is clear that arch development in children is crucial for developing healthy feet. An extreme variance in arch height may lead to foot pathology, as well as problems further up in the kinetic chain, influencing the knee, hip and lower back. It is therefore important to evaluate variables that can have an influence on arch development. Literature reports that factors influencing the arch height include age, gender, body weight (load on feet), physical activity habits footwear status, and genetics.

Babies are born with flat arches. The arch develops naturally up to the age of ten years old, as a result of maturation of the ligaments and tendons, as well as ossification of the bones, creating stability. As the foot structure of the developing child changes, the plantar pressure parameters change as well. At the age of ten years old the arch structure and plantar pressure parameters represent those of adults. With a further increase in age it is proposed that the supporting structures of seniors lose its elasticity and therefore further changes occur in the plantar pressure parameters.

Flatter arches are reported with increased body weight. The reason being that the ligaments and tendons are not capable to handle the increased load placed on the arch. Another reason proposed by literature is the presence of a thickened plantar flat pad, thereby increasing the plantar contact area of the foot, mimicking a fallen arch. As most studies focus on BMI as a mediator, muscle mass was not accounted for.

Little evidence is found on the influence of being physically active or fit on foot structure. Further investigation is therefore necessary to evaluate if the arch would be better developed to handle the increased load in individuals with the same BMI, one having excess fat, the other being physically fit and muscular.

With regards to footwear status, there are no contradictions in literature. The foot optimally develops in barefoot conditions. The shoe has a splinting effect on the foot and will decrease the activity of intrinsic foot muscles. The feet are extremely pliable structures. The shoe is seen as an external force and has the ability to change the form of the foot, if not fitting correctly. The narrower the shoe, the more it will restrict the natural splay of the forefoot.

Lastly, genetic differences are seen in different populations. Populations differ with regards to the shape of their feet, as well as the mobility thereof. It is important to take into account that different populations might also have different footwear status as a result of different climates. Investigating different populations in the same climate and footwear status is very important.

This research study will investigate the factors effecting foot posture in school children. Differences in foot posture and plantar parameters will be described between children older and younger than 10 years old, different genders, ethnicities, activity levels, as well as footwear use. For the purpose of this study, the influence of BMI was not investigated independently; however, it was added as a confounding factor in the analysis.

CHAPTER THREE: ARTICLE ONE

This article is compiled according to the author guidelines of the Journal *The Foot* (Appendix J). To provide a neat and well-rounded final product for this dissertation, the article has been edited to present an actual published article as it would appear in the Journal. This does not imply that the article has been accepted or will be accepted for publication.

Foot posture and plantar pressure parameters in South-African school children

Mathewson, Elizabeth.[1], Hollander, Karsten.[2], Venter, Ranel.[1]

[1] Department of Sport Science, Stellenbosch University, Suidwal Road, Coetzenburg, South Africa

[2] Department of Sports and Exercise Medicine, Institute of Human Movement Science, University of Hamburg, Turmweg 2, 20148 Hamburg, Germany

Corresponding Author: Elizabeth Mathewson

Lizmat008@gmail.com

Department of Sport Science
Room 329
Suidwal Road, Coetzenburg
Matieland, 7601
South Africa

Abstract

Introduction: Altered foot posture may increase the risk of injury. Quantifying deviation in foot posture is difficult as a great amount of variability exists in the posture of the human foot. Factors influencing variations in foot posture include age, gender and race. These factors were investigated within a sample of South-African school children.

Methods: Static foot posture and dynamic plantar pressure parameters were measured in 583 South-African school children between the ages of six to 18 years old. A manufactured foot calliper and an EMED-SF® pressure plate were used for data collection. The influence of age, gender and race was investigated by means of a multivariate analysis of variance.

Results: Differences between genders were not significant. Older children had significantly ($p = 0.00$) lower arches in terms of the arch height index (0.257 (0.021)) and dynamic arch index (0.188 (0.066)) compared to younger children (arch height index: 0.264 (0.020), dynamic arch index: 0.166 (0.074)). Younger children presented with greatest peak pressure in the medial hindfoot, where older children had greatest peak pressure in the big toe. Mixed race children presented with greater dynamic arch index values (0.196 (0/067))($p = 0.01$) as well as pliability (1.050 (0.030))($p = 0.00$) compared to white children (dynamic arch index: 0.171 (0.069)) (pliability: 1.040 (0.026)). Mixed race children also had significantly ($p < 0.05$) lowered peak pressure in all regions of the foot except for the medial and lateral midfoot as well as lateral and central forefoot.

Conclusion: The most significant differences were seen between children of different races. Mixed race children presented with lowered arches, more pliable feet, and more dispersed peak pressures.

Keywords: Foot posture, Foot development, Race, South-African population

1. Introduction

The foot serves a complex functional role. The foot has to be rigid to carry the body with stability, it has to be pliable to adapt to different supporting surfaces, and it needs to balance the play-off between static and dynamic tasks [1]. Altered function of the foot will increase the risk of injury to the whole lower limb as well as the pelvis and low back [2,3]. Different foot types has been shown to predispose people to different injuries [4,5]. High arches increase the risk for bone injury to the lateral structures, while low arched individuals are more prone to soft tissue injuries to the medial structures [4,6,7]. Ill-fitting shoes is associated with pathological foot disorders such as hammer toes, hallux valgus as well as pes planus, thereby increasing the prevalence of flatfoot [1]. Shoes with a good fit are extremely important for maturing feet of children and should not interfere with the maturation of muscles and ligaments as well as the ossification of bones [1].

Difficulty exists with quantifying altered foot posture as a great amount of variability is present in the feet of humans. Variations in foot posture can be link to intrinsic and extrinsic factors such as age, gender, body mass, genetics as well as footwear habits [8–13].

Babies are born with flat feet due to the presence of a plantar fat pad [14]. Spitzy’s plantar fat pad diminishes with age. Within the first ten years of life, the medial longitudinal arch develops naturally [10,12–15]. The feet of children mature gradually in terms of soft tissue structures, bone ossification as well as central nervous system function in order to create stabilization during movement. As structural and soft-tissue changes occur, plantar pressure parameters change as well [16,17]. The feet of children therefore differ compared to the feet of adults and is more sensitive to external loads [1,11,18].

During the developmental stages of children's feet it has been reported that both genders follow the same trend, however values may differ [1,19]. Females tend to have narrower feet in the forefoot and heel region. Males present with longer heel-to-ball length of the foot [1,20] compared to females with the same foot length. Results on gender differences found in literature are somewhat contradictory. Some research indicate that girls show a higher incidence of flat foot [21]. This was hypothesised to be a result of increased joint hypermobility in girls. On the contrary, other researchers report that boys or men are at greater risk for flat foot [10,19,22,23]. These researchers speculate that the arch of boys possibly develop slower than that of girls.

In foot posture, there is a genetic factor in play as well. It is however very difficult to substantiate this statement without doing genetic testing. A more appropriate investigation may be the difference between racial groups. Different races have various ranges of joint laxity [12,13]. It has been shown, for example, that Asian children have a higher laxity index than Caucasian children [12,13]. Several studies have focused on the differences of foot posture between different races [12]. Significant differences were found between different races; however the difference in climate could affect their footwear habits.

Understanding differences in foot posture and function can provide insight into injury risk for different specific populations. Therefore, this article aims to provide insight into the factors influencing foot posture, namely age, gender and race in a population exposed to the same climate and attending the same schools. No studies, to the author’s knowledge, have investigated these factors in a South African population. This study will contribute to the body of knowledge on the growth and development of children’s feet and the factors that could lead to variations in foot posture.

2. Materials and methods

This research represents a cross-sectional, descriptive, study that was conducted at selected schools in the Western Cape. A total of 516 children completed the testing during a single visit to the school and included 257 boys and 259 girls between the ages of six to eighteen years old. A randomised stratified sample of schools in the Western Cape was selected and all learners could voluntarily participate. Children with any current lower limb injuries or illness that would prevent them from completing the full protocol were excluded from the study. Children with a history of neuromuscular disease were also excluded as they posed a risk of injury.

Ethical clearance was obtained from the Human Research (Humanities) Ethics committee for the study Moving Feet (HS1153/2014). Western Cape Department of Education gave permission for the data to be collected in the participating schools (Reference: 20160128-7123). The participants had the opportunity to voluntarily partake in the study and could stop at any time during the testing process. Prior to testing, children received the informed consent forms that had to be completed and signed by themselves and by a parent or legal guardian.

Stature and body mass was taken on the day of testing and the body mass index (BMI) was calculated by dividing the body mass by stature squared (kg.m-2). Foot posture was measured based on bony landmarks by a manufactured foot calliper (Figure 3.1) with a resolution of one millimetre (mm), as described by Teyhen 2009 [24]. All foot posture measurements were taken in a 10% and 50% weight bearing position as described in the literature [4,24]. Pliability was calculated by dividing the seated foot length and width, by the standing foot length and width $\left(\frac{\text{Seated foot length x Seated foot width}}{\text{Standing foot legth x Standing foot width}}\right)$ [25].

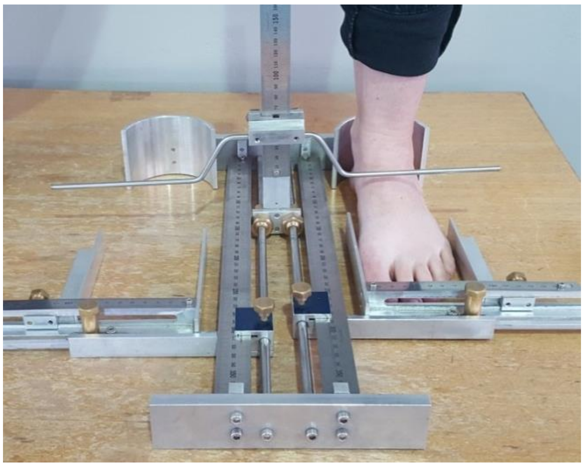

Figure 3.1: Manufactured foot calliper used for static measurements

(Photo by E Mathewson)

Dynamic plantar pressure parameters were determined by the EMED-SF® c50 pressure plate (Novel GmbH, Munich, Germany). Built into a wooden walkway, the pressure plate positioned in the middle and countersunk to be flush with the walkway with a width of 61 cm and a length of 480 cm. After verbal instruction and demonstration, the participants were allowed at least two practice trials until they felt comfortable. They were instructed to walk over the pressure plate at a self-selected pace while looking straight ahead, only stopping at the end of the walkway. The two-step method, where the second stride strikes the pressure plate, was used as it is an easy and consistent method to use with children [24,26]. The procedure was repeated until a minimum of three valid trials were recorded for each foot. Variables from the pressure plate included peak pressure and the dynamic arch index. The foot was divided into nine areas of interest using Novel software masks (Novel GmbH, Munich, Germany). Regions of the foot included the lateral hildfoot, medial hindfoot, lateral midfoot, medial midfoot, lateral forefoot, central forefoot, medial forefoot, big toe and toes two to five.

Race, age and gender were determined by the each individual child responding to questions on the score sheet.

Statistical analysis

Descriptive statistics were used to summarise demographic data of the sample. A multivariate analysis of variance was used to determine the differences in means between the age groups, genders and races. The foot (left or right) was set as a fixed factor. Cohen's effect sizes were calculated to determine small, medium and large practical significance (0.15, 0.40 and 0.75, respectively) [27] . Inter-rater reliability for the foot caliper was determined by using 10 subjects (20 feet) during a single visit, and intra-rater reliability was done measuring the feet of 22 children (44 feet) on two separate visit to the school. Reliability was then calculated via intraclass correlation coefficient (ICC), (Model 3, 1) Two-way mixed with absolute agreement.

ICC for single measures [28]. Data were analysed by using SPSS 23.0 (SPSS inc, Chicago, IL) software.

3. Results

The demographic data of the sample is summarised in table 3.1.

Table 3.1: Summary of demographic data of the participants

		Age (years)		Weight (kg)		Height (m)		BMI (kg.m^{-2})	
		Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
White	Male	13 (3)	6 – 18	56.6 (19.4)	21.3 – 111.7	1.62 (0.19)	1.19 – 1.97	20.9 (3.9)	14.7 – 36.7
	Female	12 (3)	6 – 18	49.1(17.2)	19.5 – 108.7	1.53 (0.16)	1.15 – 1.79	20.3 (4.2)	13.9 – 37.0
Mixed race	Male	11 (3)	6 – 18	42.8(19.7)	20.1 – 89.3	1.48 (0.18)	1.13 – 1.81	18.7 (4.3)	13.8 – 32.4
	Female	11 (4)	6 – 18	41.2 (14.3)	15.7 – 76.8	1.44 (0.16)	1.10 – 1.67	19.1 (3.8)	12.6 – 28.5
Total	Male	12 (3)	6 – 18	53.8 (20.6)	20.1 – 111.7	1.58 (0.19)	1.13 – 1.97	20.6 (4.2)	13.8 – 36.7
	Female	13 (3)	6 – 18	47.3 (16.5)	15.7 – 108.7	1.51 (0.16)	1.10 – 0.79	20.0 (4.0)	12.6 – 37.0

Table 3.2: ICC reliability of foot caliper measurements

Intra-rater Measurement	Value	Inter-rater Measurement	Value
Foot length (FL)	0.990	**Foot length (FL)**	0.997
Foot width (FW)	0.930	**Foot width (FW)**	0.972
Arch height	0.847	**Arch height**	0.986

Table 3.3: Comparison of peak pressure between different races

Peak Pressure	White (n = 363)	Mixed race (n = 98)	p ; Effect size
Total Object	444.74 (164.89)*	381.41 (163.07)	p = 0.00; $d = 0.37^S$
Big Toe	348.02 (168.07)*	275.10 (143.57)	p = 0.00; $d = 0.43^M$
Toes 2-5	171.06 (74.50)*	132.32 (59.41)	p = 0.00; $d = 0.55^M$
Lateral Hindfoot	280.17 (72.16)*	232.53 (66.64)	p = 0.00; $d = 0.66^M$
Medial Hindfoot	308.60 (89.41)*	256.50 (96.02)	p = 0.00; $d = 0.56^M$
Lateral Midfoot	89.51 (34.53)	89.41 (33.84)	p = 0.77; $d = 0.02^N$
Medial Midfoot	69.23 (30.33)	78.70 (30.40)*	p = 0.02; $d = 0.30^S$
Lateral Forefoot	274.05 (128.76)	251.46 (107.44)	p = 0.18; $d = 0.17^S$
Central Forefoot	285.41 (136.91)*	264.08 (148.02)	p = 0.27; $d = 0.14^N$
Medial Forefoot	229.35 (109.41)*	188.21 (87.47)	p = 0.00; $d = 0.38^S$

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 3.4: Comparison of peak pressure between girls and boys

Peak Pressure	Girls (n = 233)	Boys (n = 228)	p ; Effect size
Total Object	439.42 (174.36)	423.84 (160.98)	p = 0.16; *d* = 0.13^N
Big Toe	350.81 (182.07)	317.83 (151.46)	p = 0.07; *d* = 0.22^S
Toes 2-5	164.07 (74.62)	161.29 (72.02)	p = 0.79; *d* = 0.05^N
Lateral Hindfoot	271.72 (74.61)	267.76 (73.88)	p = 0.97; *d* = 0.10^N
Medial Hindfoot	302.94 (101.09)	293.27 (90.63)	p = 0.70; *d* = 0.15^S
Lateral Midfoot	89.95 (36.53)	90.65 (32.78)	p = 0.49; *d* = 0.02^N
Medial Midfoot	71.48 (30.75)	72.36 (30.99)	p = 0.79; *d* = 0.02^N
Lateral Forefoot	270.33 (121.67)	271.45 (131.80)	p = 0.56; *d* = 0.01^N
Central Forefoot	288.10 (147.17)	276.12 (133.90)	p = 0.12; *d* = 0.12^N
Medial Forefoot	219.34 (105.98)	221.01 (108.99)	p = 0.86; *d* = 0.01^N

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 3.6: Comparison of peak pressure between different age groups

Peak Pressure	Younger than 10 (n = 140)	Older than 10 (n = 321)	p ; Effect size
Total Object	338.81 (93.49)	472.28 (176.88)*	p = 0.00; *d* = 0.88^L
Big Toe	257.34 (95.69)	367.91 (181.42)*	p = 0.00; *d* = 0.71^M
Toes 2-5	149.02 (58.29)	168.68 (78.30)	p = 0.17; *d* = 0.27^S
Lateral Hindfoot	250.40 (74.25)	278.20 (72.67)*	p = 0.00; *d* = 0.37^S
Medial Hindfoot	282.13 (89.40)	305.06 (98.05)*	p = 0.02; *d* = 0.23^S
Lateral Midfoot	75.69 (28.11)	96.71 (35.35)*	p = 0.00; *d* = 0.67^M
Medial Midfoot	63.58 (28.12)	75.59 (31.31)*	p = 0.00; *d* = 0.44^M
Lateral Forefoot	200.56 (76.86)	301.77 (132.04)*	p = 0.00; *d* = 0.89^L
Central Forefoot	201.86 (61.88)	317.26 (150.83)*	p = 0.00; *d* = 0.90^L
Medial Forefoot	160.39 (56.57)	246.43 (113.84)*	p = 0.00; *d* = 0.88^L

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 3.7: DAI and Static measurements of boys and girls

	Girls (n = 244)	Boys (n = 240)	p ; Effect size
AHI	0.257 (0.020)	0.261 (0.021)*	p = 0.03; *d* = 0.19^{S}
DAI	0.177 (0.070)	0.185 (0.067)	p = 0.94; *d* = 0.08^{N}
Pliability	1.041 (0.028)	1.043 (0.027)	p = 0.73; *d* = 0.07^{N}

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 3.8: DAI and Static measurements of white and mixed race children

	White (n = 379)	Mixed race (n = 105)	p ; Effect size
AHI	0.260 (0.020)	0.257 (0.022)	p = 0.20; *d* = 0.14^{N}
DAI	0.171 (0.069)	0.196 (0.067)*	p = 0.01; *d* = 0.35^{S}
Pliability	1.040 (0.026)	1.050 (0.030)*	p = 0.00; *d* = 0.36^{S}

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 3.9: DAI and Static measurements of younger and older than ten years old

	Younger than 10 (n = 150)	Older than 10 (n = 334)	p ; Effect size
AHI	0.264 (0.020)*	0.257 (0.021)	p = 0.00; *d* = 0.42^{M}
DAI	0.166 (0.074)	0.188 (0.066)*	p = 0.00; *d* = 0.40^{S}
Pliability	1.045 (0.031)	1.041 (0.026)	p = 0.19; *d* = 0.17^{S}

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

The following provides a summary of the results presented in the tables. No interaction effect was seen for AHI, DAI, Pliability, or peak pressures in terms of age, gender, and race. Therefore only main effects were reported.

Arch height index

Results show that boys have a significantly higher arch height index than girls (p = 0.03; *d* = 0.19^S). No significant difference was found between different races (p = 0.20; *d* = 0.14^N). Higher arch height index values were present for the group below ten years old (p = 0.00; *d* = 0.42^M) when compared to the group older than ten years old (Table 3.7 – 3.9).

Dynamic arch index

No significant difference was found between boys and girls (p = 0.94; *d* = 0.08^N) regarding the dynamic arch index. However, mixed race children had significantly higher arch index values (mean; 0.196; SD: 0.067) compared to white children (mean: 0.171; SD: 0.069) (p = 0.01; *d* = 0.35^S). Children above ten years old have significantly higher arch index values compared to children older than ten years old (p = 0.00; *d* = 0.40^S) (Table 3.7 – 3.9).

Pliability

No significant difference was found in pliability ratio values between boys and girls (p = 0.73; *d* = 0.07^N). Mixed race children presented with greater pliability ratio values compared to white children (p = 0.00; *d* = 0.36^S). No significant difference were found between the children from six to ten years old, compared to children from eleven to eighteen years old (p = 0.19; *d* = 0.17^S) (Table 3.7 – 3.9).

Peak pressure

In the children from six years to ten years old, the highest peak pressure was found under the medial hindfoot. From 11 years old and upwards, the peak pressure is positioned distally, to under the big toe (Table 3.6).

No statistical significant difference was found between the boys and girls ($p > 0.05$) (Table 3.4). Statistically significant differences in peak pressure were observed for the different races. The white children showed an increased peak pressure in most regions of the foot, i.e. the lateral hindfoot ($p = 0.00$; $d = 0.66^M$), medial hindfoot ($p = 0.00$; $d = 0.56^M$), medial forefoot ($p = 0.00$; $d = 0.38^S$), big toe ($p = 0.00$; $d = 0.43^M$) and toes two to five ($p = 0.00$; $d = 0.55^M$). A higher peak pressure in the medial midfoot was observed in mixed race children ($p = 0.02$; $d = 0.30^S$) (Table 3.3). No significant difference was reported for the lateral midfoot ($p = 0.77$; $d = 0.02^N$), lateral forefoot ($p = 0.18$; $d = 0.17^S$), and central forefoot ($p = 0.27$; $d = 0.14^N$).

4. Discussion

A manufactured caliper with a resolution of 1mm has been used in previous literature to determine foot dimensions [4,24,25,29]. Teyhen and colleagues demonstrated excellent reliability as well as an association between arch height measured statically with a caliper and dynamic plantar pressure measures [24]. Table 3.2 shows that all the static foot caliper measurements demonstrated an excellent intra-rater and inter-rater reliability.

This research study found higher arch height index values in the group younger than ten years old, compared to the older children. Children older than ten years presented with greater dynamic arch index values compared to the younger children, thus indicating a lowered arch in older children. These findings are contradictory to previous literature that reported that at the age of seven to eight years old, the arch is classified as “low”, and only after the age of nine, the arch is classified as “normal”

[15]. Other studies report that the medial longitudinal arch would be formed by the age of six years old [30,31]. In some schools, primary school children were allowed to attend school barefoot, while secondary school children were obligated to wear shoes. The wearing of restrictive footwear for longer periods of the day can influence the arch height of the feet.

For the children younger than ten years old, the current study found the greatest peak pressure to be present under the medial heel, whereas the children older than ten years old presented with the greatest peak pressure under the big toe. Similar findings were reported in a study investigating age-related differences in plantar pressure patterns [17]. Greatest peak pressure was present under the heel for the seven-year-old group, while the adults had the highest peak pressure under the forefoot [17]. It was clear that the peak pressure of the total foot increase with age, supporting the reports of Bosch *et al.* [17].

Furthermore, this research study found that the peak pressure in all areas of the foot was the same for boys and girls. No significant difference was reported in the dynamic arch index or pliability values between boys and girls.

A significantly higher arch height index was found in boys compared to girls. These findings are in line with findings of El *et al.* [21], who reported a higher tendency of flatfoot in girls, as they have increased hypermobility of joints. Findings are in contrast with a study done on the prevalence of flatfoot in Taiwanese school children, that reported males to be twice as likely to have flat foot [19]. The work of Pfeiffer *et al.* (2005) [10] also report boys to be more than twice as likely to have flatfoot compared to girls. Other studies also found males to be more at risk for flat foot and it was speculated that the medial longitudinal arch develops slower in boys [22,23].

The current study found mixed race children to have significantly lower arches in terms of contact area compared to white children. The mixed race children presented with a mean dynamic arch index value of 0.196, and 0.171 for the white children, with a small effect size. However, no difference was found between white and mixed race children in terms of dorsal arch height normalised to foot length (arch height index). These findings are in line with a study done on Dutch and Malawian adults [32]. It was found that the Dutch participants had greater dynamic arch index values (mean: 0.21), compared to the Malawian participants (mean: 0.28), where a higher value represents a lowered arch.

As race has an influence on flexibility or hypermobility, it could affect the pliability of the foot. The mixed race children showed greater pliability ratio values compared to the white children, indicating a greater amount of spreading of the foot with weight bearing. No other studies to the author’s knowledge investigated the influence of race on the pliability of the foot.

Some studies have reported on differences in foot dimensions between different races. Significant differences were reported in foot length and width, in different ratios for four different Thai communities [33]. The feet of Japanese and Korean males differ in terms of anterior margin angle to the long axis of the foot, compared to Caucasian American males [34]. Another study Comparing German children to Brazilian children, it was reported that German children had a wider forefoot and narrower rearfoot compared to Brazilian children [35]. It is clear that differences exist in foot structure between different races, which is important for shoe manufactures that supply different countries.

The current study found in terms of peak pressure, it is clear that mixed race children had decreased peak pressure in all regions of the foot, except for the medial and lateral midfoot, as well as the lateral and central forefoot. For the medial midfoot, the e mixed race children presented with greater peak pressure. The feet of mixed race children are more pliable and spread the load more evenly across all regions of the foot. Correspondingly, in a study investigating the differences in plantar pressure between Dutch and Malawian adults, it was found that the Malawian population had decreased peak plantar pressure in all regions of the foot; however, more loading was present under the midfoot compared to the Dutch participants [32].

In a multi-ethnic community of older adults it has been shown that a number of foot pathologies were more prevalent in certain racial groups independent of education and gender [36]. Although no clear cut reason were provided it was speculated that it could possibly be due to differences in access to health care, the prevalence of different chronic diseases, as well as possibly occupation [36]. Another study on older adults reported that pes planus is three times more common in African Americans compared to whites. Whites were five times more likely to have Tailor's bunion and pes cavus [37]. It was also reported that hallux valgus, hammer toes and overlapping toes were more prevalent in African Americans compared to whites [37].

The current study found differences in foot posture between children of different races. The white and mixed race participants attended the same schools and were exposed to the same climate. There was also no statistically significant difference in footwear habits reported between the white and mixed race children. The difference in foot posture can therefore be attributed to the difference in race.

Limitations to the study should be noted. Optimal foot posture and plantar pressure parameters could not be determined. The range of motion of the foot and ankle was not assessed. It cannot be concluded that altered plantar pressure parameters lead to an altered range of motion or gait abnormalities. Race classification is also a limitation as a subject of mixed race can have between 0% and 99.999% Caucasian ancestry.

5. Conclusion

Little differences were found between genders. It was clear that peak pressure increase with increased age. With an increase in age the peak pressure moves proximally from the heel region to the forefoot and big toe. It is clear that the foot underdoes functional changes with increase in age. Children's footwear should therefore be designed for specific age groups, and cannot be based on the dimensions of an adult shoe. The mixed race participants had significantly lower medial longitudinal arches and decreased peak pressure in the areas of the foot compared to the white population. The mixed race children showed greater pliability and arch deformity with weight bearing. Mixed race children spread the load more evenly under their feet during locomotion. This study found a great variability in foot posture and peak pressure of the foot. Studies reported differences in foot injury prevalence between different races in adults, independent of footwear use, gender and education. They speculated that the differences might be due to occupation or health care access. The current study found differences in foot posture between children from different races, who attends the same schools, and reported the same footwear habits. It is clear that differences exist in different populations, therefore shoe design should accommodate for a great variety in foot dimensions. This will ensure healthy foot development and decrease the risk of foot injuries.

Conflict of interest statement

There is no personal of financial conflict of interest.

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CHAPTER FOUR: ARTICLE TWO

This article is compiled according to the author guidelines of the Journal *Gait and posture* (Appendix K). To provide a neat and well-rounded final product for this dissertation, the article has been edited to present an actual published article as it would appear in the Journal. This does not imply that the article has been accepted or will be accepted for publication.

A comparison of plantar pressure parameters between German and South African children

Mathewson, Elizabeth.[1], Hollander, Karsten.[2], Venter, Ranel.[1]

[1] Department of Sport Science, Stellenbosch University, Suidwal Road, Coetzenburg, South Africa

[2] Department of Sports and Exercise Medicine, Institute of Human Movement Science, University of Hamburg, Turmweg 2, 20148 Hamburg, Germany

Corresponding Author: Elizabeth Mathewson

Lizmat008@gmail.com

Department of Sport Science
Room 329
Suidwal Road, Coetzenburg
Matieland, 7601
South Africa

Highlights

- It has been suggested that the feet of children develop optimally in barefoot condition.
- The differences between habitually shod German children and habitually barefoot South-African children were investigated.
- Although statistically significant differences exist in plantar pressure parameters between German children and South African children, it is of little practical significance.

Abstract

It has been suggested that a barefoot environment is ideal for foot development. The influence of footwear on the foot structure has previously been investigated. Main findings in literature report that restrictive footwear leads to narrower, less pliable feet and decreased arch height. Ill-fitting footwear can also lead to toe deformities. In the present research study, an EMED-SF® pressure plate was used to investigate the difference in plantar pressure parameters between German and South African children (6 - 18 years old). South African children had greater peak pressure in the medial forefoot and medial midfoot, as well as the big toe and toes two to five compared to German children ($p < 0.05$). Maximum force, was significantly greater for South-African children in all regions of the foot compared to German children except for the medial and lateral midfoot as well as the lateral forefoot ($p < 0.05$).

Keywords: Foot development, Barefoot, Foot posture

1. Introduction

Research suggests that the use of footwear can lead to foot problems [1]. More foot problems exist in the west, habitually shod population than in the African habitually barefoot population [2,3]. Particularly ill-fitting shoes lead to foot pathology and biomechanical dysfunction. Therefore it has been shown that the foot develops optimally in barefoot condition [4,5]. The feet of children are sensitive to restrictive footwear. An extreme example is that of Chinese girls that bound their feet, restricting the growth to achieve the infamous lotus feet [6].

More than a century ago, the discussion on barefoot development started. Hoffmann (1905) did a profound study on the differences of the feet between barefoot and shoe-wearing individuals. The main findings indicate that decreased forefoot width and space between toes are the result of the constrictive nature of “modern” shoes [7].

Staheli (1991) did a seminal review on footwear use for children about two decades ago. It was stated that the foot develops optimally in barefoot conditions, and that stiff and constraining footwear lead to deformity, weakness and loss of mobility in the foot [4]. Thereafter, studies report a high incidence of flat feet in habitually shod individuals, a moderate incidence of flat feet in individuals wearing flip-flops, and a low incidence in barefoot individuals [8].

More recently studies also report that the feet of barefoot populations are found to be more pliable [1] and wider [6] compared to shod populations. More pliable feet will result in decreased peak pressure under the foot [6]. Shoes have a splinting effect on the feet, influencing the motion of the first metatarsophalangeal joint, and decreasing the effectiveness of the windlass mechanism [9].

Differences in foot structure between children living in different countries were investigated by comparing German children to Australian children matched according to age, gender and body mass index (BMI) [10]. The German children were found to have longer and flatter feet compared to their Australian counterparts, with the Australian children presenting a forefoot that is more square in shape [10]. Evaluating the feet in a static condition does not provide sufficient information, and one therefore needs to consider the dynamic foot motion [11].

Making use of plantar pressure measurements can provide critical information on foot structure, foot function and general gait mechanics [12]. Pressure is the measure that analyses the distribution of forces across a surface area. Pes cavus, or high arched feet, will significantly lower plantar pressure under the medial arch and increased pressure under the heel and forefoot, compared to normal arched feet [13,14]. Contact area refers to the pressure that is applied to within each mask. Contact time is the amount of time in milliseconds that contact is pressure is present within a mask. Increased contact time within certain masks will lead to increased force-time integral and pressure-time integral and can thus contribute to risk of foot injuries [15].

Stolwijk *et al.* (2013) speculate that the reason why African populations have less foot problems might be due to differences in loading patterns. Clear differences were seen in loading patterns as the Malawian population showed a lowered medial longitudinal arch, as well as significantly lower plantar pressure under the heel and regions of the forefoot. It was also reported that the Malawian population showed increased time loading of the midfoot and decreased time loading the of forefoot during push-off [2]. The participants were adults and the difference in plantar pressures between African and European children in the period of foot development and maturation are unknown.

In evaluating differences between shod and barefoot individuals, it is important that the individuals are from the same ethnical background, as foot structure differs between ethnical groups [6]. Different ethnicities have different ranges of joint mobility [16–18]. Joint laxity has an influence on the arch height and foot pliability [17].

Habitual footwear use, from a young age, can be harmful as ill-fitting shoes can influence the normal developmental process of children, thereby altering the base of support creating pathologies of the feet, knees, hips and low [6,10]. Describing and understanding the variations in foot posture and function as well as the biomechanics of habitual barefoot walkers can be helpful to health professionals, podiatrists, paediatricians, anthropologists, applied scientists as well as shoe designers [6,10]. For optimal fit of a shoe, dynamic characteristics should be investigated [19]. Differences in foot posture and plantar pressure have been investigated between European and African or Australian people, in warmer climates; however, the ethnicity was not controlled for.

The aim of this study is to describe the differences in plantar pressure parameters between white South African children and German children including peak pressure, relative maximum force, contact area and contact time. It is assumed that the South African children walk barefoot or wear flip-flops for a greater amount of time per day, compared to German children. It is therefore hypothesised that the plantar pressure parameters of feet of children within the same race (because of the common European ancestry), will differ as a result of different footwear habits.

2. Methods

A cross-sectional, descriptive study design was used and quantitative data were collected from a randomised stratified sample of children in the Western Cape, South Africa and in Hamburg, Germany. The left and right foot of 437 South African children (boys: 228; girls: 209) and 214 German children (boys: 96; girls: 118), between the ages of six to 18 years old were assessed. Each participant completed the testing during a single visit to the school, in a school hall, during school hours.

Participants voluntarily took part in the study after consent was provided by the children and a parent or legal guardian. Participants were excluded if they had any current lower limb injuries or illness that would prevent them from completing the testing process, or if they had a history of neuromuscular disease. Ethical clearance has been obtained from the Human Research (Humanities) Ethics committee for the study “Moving Feet” (HS1153/2014). The Western Cape Department of Education gave permission for the study to be conducted in the participating schools (Reference: 20160128-7123).

Stature and body mass measurements were taken to calculate the body mass index

(BMI). Plantar pressure parameters were measured by the EMED-SF® c50 pressure plate (Novel GmbH, Munich, Germany). Built into a wooden walkway, the pressure plate was positioned in the middle and countersunk in order to be flush with the walkway. The walkway has a width of 61 centimetre (cm) and a length of 480 cm. After verbal instruction and demonstration, the participants were allowed at least two practise trials. They were instructed to walk over the pressure plate at a self-selected pace while looking straight ahead, only stopping at the end of the walkway. The two-step method was used, where the second stride strikes the pressure plate. The two-step method is an easy and consistent method to use with children [14,20]. The procedure was repeated until a minimum of three valid trials were recorded for each foot. Data on peak pressure, pressure-time integral, force-time integral, maximum force contact area and contact time were collected during this procedure.

Statistical analysis

Descriptive statistics assist in describing data and include mean, standard deviation and range data. The foot was divided into nine areas of interest using Novel software masks (Novel GmbH, Munich, Germany). Regions of the foot include the lateral hindfoot, medial hindfoot, lateral midfoot, medial midfoot, lateral forefoot, central forefoot, medial forefoot, big toe and toes two to five. Maximum force were normalised to body weight. The contact area was normalised to the contact area of the total object. A mixed model analysis of variance was used, with one fixed factor: Foot (left or right) and one random factor: Country (Germany or South Africa) The collected data was analysed by using SPSS 23.0 (SPSS inc, Chicago, IL) software.

3. Results

Table 4.1 describes the demographic data of the sample

Table 4.1: Summary of demographic data of the participants

	SA Mean (SD)	SA Range	GER Mean (SD)	GER Range
Age	12.6 (3.3)	6.0 – 18.0	13.9 (3.6)	6.0 – 18.0
Weight	53.8 (19.0)	20.1 – 111.7	54.1 (7.6)	18.6 – 110.1
Height	158.1 (17.8)	115.0 – 197.4	161.8 (17.6)	116.0 – 195.0
BMI	20.8 (4.1)	13.9 – 37.0	20.1 (3.8)	13.6 – 36.6

Table 4.2: Comparison of peak pressure between German and South African children

		Peak pressure	p ; Effect size
Total Object	SA	459.040 (176.242)	0.33 ; 0.03^N
	GER	464.180 (147.283)	
Big Toe	SA	350.305 (173.177) *	0.04 ; 0.10^N
	GER	332.737 (167.909)	
Toes 2 to 5	SA	170.435 (75.023) *	0.00 ; 0.23^S
	GER	153.008 (73.078)	
Lateral Hindfoot	SA	279.908 (76.699)	0.22 ; 0.04^N
	GER	283.078 (72.249)	
Medial Hindfoot	SA	309.148 (95.999)	0.45 ; 0.04^N
	GER	313.103 (86.269)	
Lateral Midfoot	SA	89.788 (33.927)	0.22 ; 0.03^N
	GER	88.657 (41.148)	
Medial Midfoot	SA	70.258 (30.553) *	0.00 ; 0.21^S
	GER	63.937 (29.887)	
Lateral Forefoot	SA	276.355 (129.834)	0.95 ; 0.18^N
	GER	299.340 (129.386)	
Central Forefoot	SA	289.127 (140.336)	0.23 ; 0.05^N
	GER	295.911 (128.860)	
Medial Forefoot	SA	229.732 (111.937) *	0.00 ; 0.18^N
	GER	210.441 (92.535)	

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 4.3: Comparison of relative maximum force (maximum force to body weight) between German and South African children

		Maximum force	p ; Effect size
Total Object	SA	109.960 (9.788) *	0.00 ; 0.71^{M}
	GER	103.397 (7.943)	
Big Toe	SA	22.312 (8.374) *	0.00 ; 0.32^{S}
	GER	19.619 (8.479)	
Toes 2 to 5	SA	8.854 (4.545) *	0.02 ; 0.20^{S}
	GER	7.961 (4.330)	
Lateral Hindfoot	SA	34.070 (5.645) *	0.00 ; 0.41^{M}
	GER	31.899 (4.739)	
Medial Hindfoot	SA	41.527 (6.930) *	0.00 ; 0.45^{M}
	GER	38.501 (6.308)	
Lateral Midfoot	SA	12.471 (7.845)	0.48 ; 0.03^{N}
	GER	12.209 (7.664)	
Medial Midfoot	SA	1.906 (1.999)	0.07 ; 0.20^{S}
	GER	1.511 (1.788)	
Lateral Forefoot	SA	38.058 (9.529)	0.80 ; 0.04^{N}
	GER	38.411 (9.575)	
Central Forefoot	SA	26.422 (5.584) *	0.00 ; 0.29^{S}
	GER	24.774 (5.621)	
Medial Forefoot	SA	25.567 (7.848) *	0.00 ; 0.62^{M}
	GER	20.937 (6.831)	

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 4.4: A comparison of relative contact area (contact area per region to total object contact area) between German and South African children

		Contact area	p ; Effect size
Big Toe	SA	0.086 (0.015)	0.21 ; 0.04^{N}
	GER	0.085 (0.016)	
Toes 2 to 5	SA	0.074 (0.021)	0.53 ; 0.08^{N}
	GER	0.075 (0.025)	
Lateral Hindfoot	SA	0.139 (0.013)	0.20 ; 0.02^{N}
	GER	0.139 (0.012)	
Medial Hindfoot	SA	0.138 (0.013)	0.02 ; 0.03^{N}
	GER	0.139 (0.012)	
Lateral Midfoot	SA	0.131 (0.054)	0.00 ; 0.08^{N}
	GER	0.136 (0.052)	
Medial Midfoot	SA	0.019 (0.015) *	0.03 ; 0.14^{N}
	GER	0.017 (0.015)	
Lateral Forefoot	SA	0.198 (0.020)	0.02 ; 0.08^{N}
	GER	0.199 (0.022)	
Central Forefoot	SA	0.097 (0.013)	0.00 ; 0.05^{N}
	GER	0.097 (0.013)	
Medial Forefoot	SA	0.117 (0.017) *	0.01 ; 0.30^{S}
	GER	0.112 (0.018)	

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Table 4.5: A comparison of relative contact time between German and South African children

		Relative contact time	p ; Effect size
Big Toe	SA	59.36 (13.60)	0.00 ; 0.60^{M}
	GER	67.26 (13.57) *	
Toes 2 to 5	SA	54.65 (13.00)	0.00 ; 0.64^{M}
	GER	63.40 (14.68) *	
Lateral Hindfoot	SA	55.94 (7.16) *	0.00 ; 0.25^{S}
	GER	54.01 (8.85)	
Medial Hindfoot	SA	56.77 (7.26) *	0.00 ; 0.29^{S}
	GER	54.52 (8.92)	
Lateral Midfoot	SA	58.46 (10.00) *	0.00 ; 0.28^{S}
	GER	55.43 (12.34)	
Medial Midfoot	SA	40.34 (12.88) *	0.00 ; 0.38^{S}
	GER	35.54 (13.78)	
Lateral Forefoot	SA	82.73 (5.04)	0.05 ; 0.12^{N}
	GER	83.34 (4.53)	
Central Forefoot	SA	79.76 (5.77)	0.00 0.26^{S}
	GER	81.19 (5.04) *	
Medial Forefoot	SA	75.45 (7.80)	0.03 ; 0.11^{N}
	GER	76.30 (7.66) *	

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

The following provides a summary of the results presented in the tables. No interaction effects were found, therefore the article only reports on the main effects.

Peak pressure: As shown in table 4.2, the South African children had a significantly greater peak pressure under the medial midfoot (p = 0.00 ; 0.21^{S}), and medial forefoot (p = 0.00 ; 0.18^{N}), as well as under the big toe (p = 0.04 ; 0.10^{N}) and toes two to five (p = 0.00 ; 0.23^{S}) compared to German children.

Maximum force relative to body weight: The South African children had significantly higher maximum force in all the regions of the foot, compared to the German children ($p < 0.05$), except for the lateral and medial midfoot and lateral forefoot ($p > 0.05$) as seen in table 4.3.

Relative contact area: South African children showed greater relative contact area with regards to the medial midfoot ($p = 0.03$; 0.14^N) and medial forefoot ($p = 0.01$; 0.30^S) compared to the German children. For all the other regions of the foot, no significant differences were found between the German and South African children ($p > 0.05$) (table 4.4).

Relative contact time: Table 4.5 shows that South African children had greater relative contact time in the medial and lateral hindfoot as well as the medial and lateral midfoot ($p < 0.05$). German children presented with greater relative contact time in the big toe, toes two to five as well as the lateral, central and medial forefoot ($p < 0.05$). Effect sizes are small and negligible, except for toes to to five as well as the big toe, that has a moderate effect size.

4. Discussion

The purpose of this study is to report on the main differences in plantar pressure parameters between German children and South African children. The climate of South Africa lends itself to being more of a barefoot or flip-flop wearing culture. The European children wear restrictive footwear year-round. It was speculated that the difference in footwear use would influence the function of the feet. The race was kept consistent as far as possible to eliminate this confounding variable.

Literature has reported differences in foot dimensions possibly as a result of different footwear habits. It was shown that German children present with longer and flatter feet compared to Australian children [8]. As well as that the forefoot of the Australian children are squarer in shape compared to German children [10]. Some literature reported that habitually shoe-wearing individuals had a greater prevalence of flatfoot compared to habitually barefoot populations [6,8,21]. Other literature also noted that bunions were unknown in Japan prior to Western footwear trends [22].

In terms of plantar pressure parameters, the current study found significant differences in peak pressure and relative maximum force between the German and South African children. South African children presented with greater peak pressure under the toes as well as medial midfoot and medial forefoot. South African children also presented with greater relative maximum force in total as well as under the toes, medial and lateral hindfoot, and central and medial forefoot. However no differences were reported in the relative maximum force under the midfoot regions. The South African children also had a greater contact area in the medial midfoot and medial forefoot compared to the German children. All the variables however, were of little of negligible practical significance.

Stolwijk *et al.* [2] report that Malawian participants have an increased loading area, more equal distribution of pressure, longer loading under the midfoot and more gripping of the toes during push-off compared to their European counterparts. In line with these findings, this research study found greater peak pressure under the big toe and toes two to five in South African children compared to that of German children.

Significant differences in plantar pressures were reported also between Indian habitually barefoot walkers and a shod Western population [6]. Barefoot walkers had more equally distributed peak pressures, whereas the habitually shod subjects had regions of very high or very low peak pressures. The Western subjects showed higher peak pressures at the heel, metatarsals and big toe.

It could be speculated that the above-mentioned trends were due to racial differences, rather than footwear habits.

Possible limitations to the study include altered foot motions might not be symptomatic, and was not evaluated. Range of motion of the foot and ankle was not assessed. It cannot be concluded that the altered plantar pressure parameters lead to an altered range of motion or gait abnormalities.

Future research could asses children while running or doing athletic tasks and also take the path of centre of center of pressure into account.

5. Conclusion

Although statistically significant differences exist in the peak pressure, relative maximum force, contact area and contact time, there was no practical significance. It could be concluded that the environmental factors such as footwear habits play a small role when subjects of the same race is compared. It could also be speculated that although the South African children walk barefoot habitually, some time is spent in footwear. This leads to their feet not being different enough from the feet of German children that wear shoes for the greatest part of the day.

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CHAPTER FIVE: DISCUSSION

5.1 Introduction

The biomechanics of the foot is the most poorly understood of any structure in the human body (D'Août *et al.*, 2009). It serves as the base for supporting the body, which is important during any weight bearing tasks. Deviations in foot posture may lead to altered gait and put an individual at an increased risk of injury. A great amount of variability is present when describing foot posture in literature. Factors attributing to the variability include age, gender, body mass, activity level, ethnicity, as well as footwear use. Establishing normative values for the foot posture of children, could be helpful in identifying a "normal" foot posture as well as plantar pressures (Kellis, 2001). The discussion in this chapter is presented in accordance to the specific research objectives in Chapter one.

5.2 Age

The current research study found, for the South African children, higher arch height index (AHI) values in the group younger than ten years old, compared to the older children. Children older than ten years presented with greater dynamic arch index (DAI) values compared to the younger children, thus indicating a lowered arch in older children. These findings are contradictory to previous literature that report that at the age of seven to eight years old, the arch is classified as "low", and only after the age of nine, the arch is classified as "normal" (Onodera *et al.*, 2008). Other studies report that the arch would be formed by the age of six years old (Volpron, 1994; Riddiford-Harland *et al.*, 2011). It could be hypothesised that for the South African population the arches will be fully matured and developed by the age of six years old, when they start to attend school. Faster maturing arches could possibly as a result of walking predominantly barefoot in early years (Sacco, Onodera, Bosch & Rosenbaum, 2015). A longitudinal study would be necessary to investigate arch maturation in South African children.

Children younger than ten years old had significantly greater foot pliability values compared to older children. In some schools, children in primary school were allowed to attend school barefoot, while in secondary school all children were obligated to wear shoes. The wearing of restrictive footwear for longer periods of the day can influence the pliability of the feet.

For the children younger than ten years old, the present research study found the greatest peak pressure to be present under the medial heel, whereas the children older than ten years old presented with the greatest peak pressure under the big toe. Similar findings were reported by Bosch *et al.* (2009) when investigating age-related differences in plantar pressure patterns. They found the greatest peak pressure to be present under the heel of the seven-year old group, while the adults had the highest peak pressure under the forefoot. From there research results it is clear that the peak pressure of the total foot increase with age (Bosch *et al.*, 2009). Older research also indicated that children from six to ten years old present with a third of the peak pressure present in adults (Hennig *et al.*, 1994).

5.3 Gender

The current research study found that peak pressure was the same for boys and girls in all areas of the foot. No significant difference was found in the DAI or pliability values between boys and girls.

A significantly higher AHI was found in boys compared to girls. These findings are in line with the findings of El *et al.* (2006), who reported a higher tendency to flatfoot in girls, as they have increased hypermobility of joints. Findings are in contrast with a study done on the prevalence of flatfoot in Taiwanese school children, as males are reported to be twice as likely to have flat foot (Chang *et al.*, 2010). The work of Pfeiffer *et al.* (2005) also report that boys are more than twice as likely to have flatfoot compared to girls. Other studies also found males to be more at risk for flat foot, and it is speculated that the MLA develops slower in boys (Stavlas *et al.*, 2005; Mickle *et al.*, 2008).

5.4 Activity level

No significant differences were observed between groups of different physical activity levels in terms of AHI, DAI or pliability (Appendix M, Table M.1). More research is needed in order to evaluate if children with the same BMI, but different fat mass and lean mass distributions, have different foot structures. It could be speculated that more muscular children should be able to handle the load on their feet in a better manner.

5.5 Race

Results of the present research study reported mixed race children had significantly lower arches in terms of contact area compared to white children. The mixed race children presented with a mean DAI value of 0.196, compared to 0.171 for the white children. However, no difference was found between white and mixed race children in terms of dorsal arch height normalised to FL (AHI). These findings are in line with a study done on Dutch and Malawian adults (Stolwijk *et al.*, 2013). Stolwijk *et al.* (2013) found that the Dutch participants had greater DAI values (mean: 0.21) compared to the Malawian participants (mean: 0.28), where a higher value represents a lowered arch. The same trends were seen for adults and children therefore emphasised that it is a genetic difference and does not occur over time. Effect sizes were small thus indicating little practical significance.

As race has an influence on flexibility and hypermobility, it could affect the pliability of the foot. In the current study, the mixed race children showed greater pliability ratio values compared to the white children, indicating a greater amount of spreading of the foot with weight bearing. According to the author's knowledge, there is no published literature on the influence of ethnicity on the pliability of the foot.

Some studies have reported on differences in foot dimensions between different races. The feet of Japanese and Korean males differ in terms of anterior margin angle to the long axis of the foot, compared to Caucasian American males (Hawes, Sovak, Miyashita, Kang, Yoshihuku & Tanaka, 1994). Significant differences were reported in foot length and width, in different ratios for four different Thai communities (Singh & Phookan, 1993). Another study reported that German children had a wider forefoot and narrower rearfoot compared to Brazilian children (Sacco *et al.*, 2015). It is clear that differences exist in foot structure between different races, which is important for shoe manufactures that supply different countries.

In terms of peak pressure, it is clear that mixed race children have decreased peak pressure in all regions of the foot, except for the medial and lateral midfoot, as well as the lateral and central forefoot. The feet of mixed race children are more pliable and spread the load more evenly across all regions of the foot. Correspondingly, in a study investigating the differences in plantar pressure between Dutch and Malawian adults, it was found that the Malawian population had decreased peak plantar pressure in all regions of the foot; however, more loading was present under the midfoot compared to the Dutch participants (Stolwijk *et al.*, 2013).

In a multi-ethnic community of older adults it has been shown that a number of foot pathologies were more prevalent in certain racial groups independent of education and gender. Although no clear cut reason were provided it was speculated that it could possibly be due to differences in access to health care, the prevalence of different chronic diseases, as well as possibly occupation (Dunn, Link, Felson, Crincoll, Keysor & KcKinlay, 2004). Another study on older adults reported that pes planus is three times more common in African Americans compared to whites. Whites were five times more likely to have Tailor's bunion and pes cavus (Golightly, Hannan, Dufour & Jordan, 2012). It was also reported that hallux valgus, hammer toes and overlapping toes were more prevalent in African Americans compared to whites (Golightly *et al.*, 2012).

The white and mixed race participants attended the same schools and were exposed to the same climate. There was also no statistically significant difference in footwear habits reported between the white and mixed race children (Appendix L, Table L.1). The difference in foot posture could therefore be attributed to the difference in race.

5.6 Footwear use

As a result of the plasticity of the foot, wearing shoes will minimally influence the shape and dynamic function of the foot (D'Aoút *et al.*, 2009). It is difficult to investigate bare feet, as it does not exist in Western populations, where the feet are deformed compared to a biologically "natural" foot.

The climate of South Africa lends itself to being a nation of habitually barefoot walkers, as well those that wear flip-flops. In specific primary schools, children are allowed to attend school barefoot. European children, on the other hand, wear restrictive footwear year-round. It is safe to assume that German children walk barefoot significantly less than South African children. When investigating footwear habits, it is important to keep ethnicity consistent (D'Août *et al.*, 2009). Therefore, for the purpose of this section, only children indicating their race to be white, were selected from the South African sample for comparison to German children.

A number of studies have been done on the differences in foot structure between habitually barefoot and shod individuals. However, scares research has been done on the differences in plantar pressure parameters between habitually barefoot and habitually shod populations. Evaluating plantar pressures can give valuable information on foot posture, weight distribution, as well as some gait parameters (Keijsers *et al.*, 2009). In this section, only plantar pressure parameters were analysed and are elaborated upon below.

Peak pressure

Pressure is the measure that analyses the distribution of forces across a surface area (Rosenbaum & Becker, 1997). South African children had significantly greater peak pressure under the medial midfoot ($p < 0.05$) and the medial forefoot ($p < 0.05$), as well as under the big toe ($p < 0.05$) and toes two to five ($p < 0.05$) compared to German children. The German children however had greater peak pressure under the lateral forefoot ($p < 0.05$). South African children carry their weight more medially and they have greater pressure under their toes. Stolwijk *et al.* (2013) report more distribution of pressure, thus lower pressure in all regions of the foot. They also report higher peak pressure under the big toe, as well as toes two to five, indicating more gripping of the toes (Stolwijk *et al.*, 2013).

Pes cavus, or high arched feet, show significantly lower plantar pressure under the medial arch and increased pressure under the heel and forefoot, compared to normal arched feet. (Burns *et al.*, 2005; Teyhen *et al.*, 2009). This trend was supported with reports that a lower MLA is associated with greater peak pressures under the medial midfoot and lower pressures in the medial forefoot. Higher arches are associated with greater peak pressure in the hindfoot and forefoot (Jonely *et al.*, 2011).

It could therefore be concluded that German children presented with more of a pes cavus foot shape compared to the South African children.

Pressure-time integral (Table N.1)

The pressure-time integral refers to the peak pressure for a specific frame, for the duration of one frame. The German children had greater pressure-time integral values compared to the South African children. An increased pressure-time integral is related to an increased risk of foot pain development (Burns *et al.*, 2005).

Differences in walking speed might have an influence, although it was not controlled for.

The pressure plate was used by Burns, Crosbie, Hunt and Ouvrier (2005) to investigate the correlation between pes cavus feet and foot pain. Pressure-time integral was calculated as the sum of the peak pressure in each frame of the foot contact, multiplied by the duration of foot contact. They concluded that increased pressure under the rear- and forefoot, compensating for a decreased contact area of the midfoot, is the reason for the increased pressure-time integral in the idiopathic pes cavus group. For the neurological group, the increased pressure-time integral may be as a result of decreased walking speed, thereby increasing the contact time. Burns *et al.* (2005) suggested that a pressure-time integral was the best indicator of loading characteristics when compared to individual parameters. When correlating foot pain with plantar parameters, it is not only the magnitude of pressure that is important, but also the rate at which pressure is loaded. A significant relationship was found between pressure-time integral and foot pain; however, the correlation accounted for 24% of the variance, indicating that there are other factors that also account for foot pain (Burns *et al.*, 2005).

The increased pressure-time integral seen in the German children could contribute to increased risk of developing foot pain in the future.

Force-time integral relative to body weight (Table N.2)

Force-time integral represents the area under the force-time curve (within the mask), could also be referred to as the impulse (Impulse = force x time). These values were normalised to the body mass of each participant. The German children presented significantly greater force-time integral values compared to the South African children, except for the midfoot in lateral and medial regions. Loading under each region of the foot was present for a longer period of time under each region of the foot. It could possibly lead to an increased risk of foot pain. Increased contact time under all regions of the foot was present. The German children possibly had a significantly slower walking speed; however, this was not controlled.

Walking speed was not controlled for, this may influence the time amplitude in the pressure-time integral and force-time integral (Keijsers, Stolwijk & Pataky, 2010).

Maximum force relative to body weight

South African children presented with significantly higher maximum force values in all regions of the foot, compared to the German children with the exception of the lateral midfoot and lateral forefoot.

Contact area relative to total foot contact area

Contact area refers to the pressure that is applied to within each mask. The contact area of each mask was normalised to the contact area of the total foot. South African children had a greater contact area of the medial midfoot and medial forefoot compared to the German children. All the other regions of the foot showed no significant difference between the South African and German children. This indicates greater weight bearing on the medial side of the foot, as well as possible greater pliability of the foot, spreading more medially compared to the German children.

Absolute contact time

Contact time is the amount of time in milliseconds that contact is pressure is present within a mask. In all regions of the foot, the German children presented with significantly longer contact time compared to the South African children (Table N.3). Greater contact time indicates a longer time spent in ground contact during roll-over. Similarly, a study investigating the influence of the shoe on plantar pressures, report greater contact time in all areas of the foot when the participants wore shoes compared to the barefoot trials (Nyska, McCabe, Linge, Laing & Klenerman, 1995). Again, walking speed could influence these values and was not controlled for.

Relative contact time

Here the contact time within the mask is normalised to the total contact time of the object. South African children had greater relative contact time in the medial and lateral hindfoot as well as the medial and lateral midfoot. German children presented with greater relative contact time in the big toe, toes two to five as well as the lateral, central and medial forefoot. The effect sizes however indicated small and negligible practical significance and can therefore be ignored. Toes two to five as well as the big toe show moderate effect sizes, which indicate a true difference. German children spend a larger percentage of roll-over on their toes.

Coefficient of Spreading

Coefficient of spreading is the forefoot width, relative to total FL. The South African children presented with greater coefficient of spreading compared to the German children (Appendix O, Table O.1). This indicates that the South African children have broader feet relative to foot length. This could be as a result of the German children spending more time in restrictive footwear, not allowing for splay of the metatarsal heads.

Dynamic arch index (DAI)

DAI is a ratio of the midfoot contact area divided by the total foot contact area, excluding the toes. No significant difference was observed in the DAI between the South African and German children. These findings are in contrast with findings from earlier studies that report that a higher incidence of flatfoot was present in shod populations compared to barefoot populations (Rao & Joseph, 1992; Echarri & Forriol, 2003). Another study comparing the foot structure of German and Australian children, reported the German preschool children to have flatter feet in terms of contact area, as well as greater dorsal arch height (Mauch, Mickle, *et al.*, 2008). This research study did not involve any measurement of pliability between the German and South African children (Appendix O, Table O.1). The author speculates that differences in pliability of the feet would be more prominent and possibly a better indication of foot health.

As children run and play for a great amount of time during the day, the influence of barefoot running should not be ignored. Literature indicate that habitually barefoot runners shows decreased ground reaction force (Hall, Barton, Jones & Morrissey, 2013) and present with significantly reduced impact transient compared to shod runners (Tam, Astephen Wilson, Noakes & Tucker, 2013). Habitual barefoot running is associated with a flatter foot at touchdown, thus creating a greater contact area for distribution of loads thereby decreasing the impact. With acute barefoot running however, the habitually shod runners showed very high impact peaks. It was then hypothesized that the change in foot mechanics as a result of barefoot running, is an acquired skill, not an immediate effect (Tam *et al.*, 2013). The influence of barefoot running on the feet of children has been investigated.

5.7 Limitations

According to the present research study, there are clear differences in foot posture and plantar pressure parameters between children from different races, as well as their country of origin. Race classification is a limitation as a subject of mixed race can have between 0% and 99.999% Caucasian ancestry. No indication of symptoms was evaluated, and altered foot motions might not be symptomatic. Range of motion of the foot and ankle, as well as the effect of the differences in foot posture on the proximal structures by means of motion analysis, were not assessed in this study. With regards to the pressure plate measurements, the walking speed was not controlled and could be a confounding factor.

5.8 Future research

Future research could investigate the foot posture and plantar pressure parameters of other races and countries to develop a better understanding of the differences between nationalities. Foot scanners could be used to better determine differences in foot structure for shoe design. More research is needed in order to understand the influence of a barefoot playing intervention on the feet of children with a habitually shod background with evaluation of the whole lower limbs. Plantar pressure parameters can be investigated during a variety of athletic tasks such as running, jumping or cutting.

5.9 Conclusion

Within the South African sample the greatest differences were seen between races. When evaluating foot posture and plantar pressure parameters, it is important to keep the race constant, or to evaluate different races separately. These children were exposed to the same climate and socio-economic status and it can therefore be assumed that the differences are a result of the genetic differences.

When keeping the race constant, significant differences between the German and South African children were found. Differences between these two groups are speculated to be as a result of differences in footwear use. German children presented with narrower forefeet, as well as less time spent in the midfoot during roll-over. The practical significance however, were small and negligible. It is evident that the great amount of time spent in restrictive footwear has somewhat altered the foot mechanics of children, however no practical influence.

The findings of the present study indicate that shoe dimensions should not be a universal constant for different populations, as a great amount of variability exists. Shoe companies should produce a range of dimensions finding the perfect fit for each gender, age groups race or specific country. Wearing proper fitting footwear during developmental ages will aid in healthy foot development and possibly decrease the amount of foot injuries to occur in later life.

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APPENDICES

List of Appendices

APPENDIX A

Research Ethics Committee: Human Research (Humanities) Approval

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Approval Notice

Stipulated documents/requirements

18-Feb-2015
De Villiers, Johanna JE

Proposal #: HS1153/2014
Title: Moving Feet – A Comparative Study between Habitually Barefoot And Shod School-Aged Children.

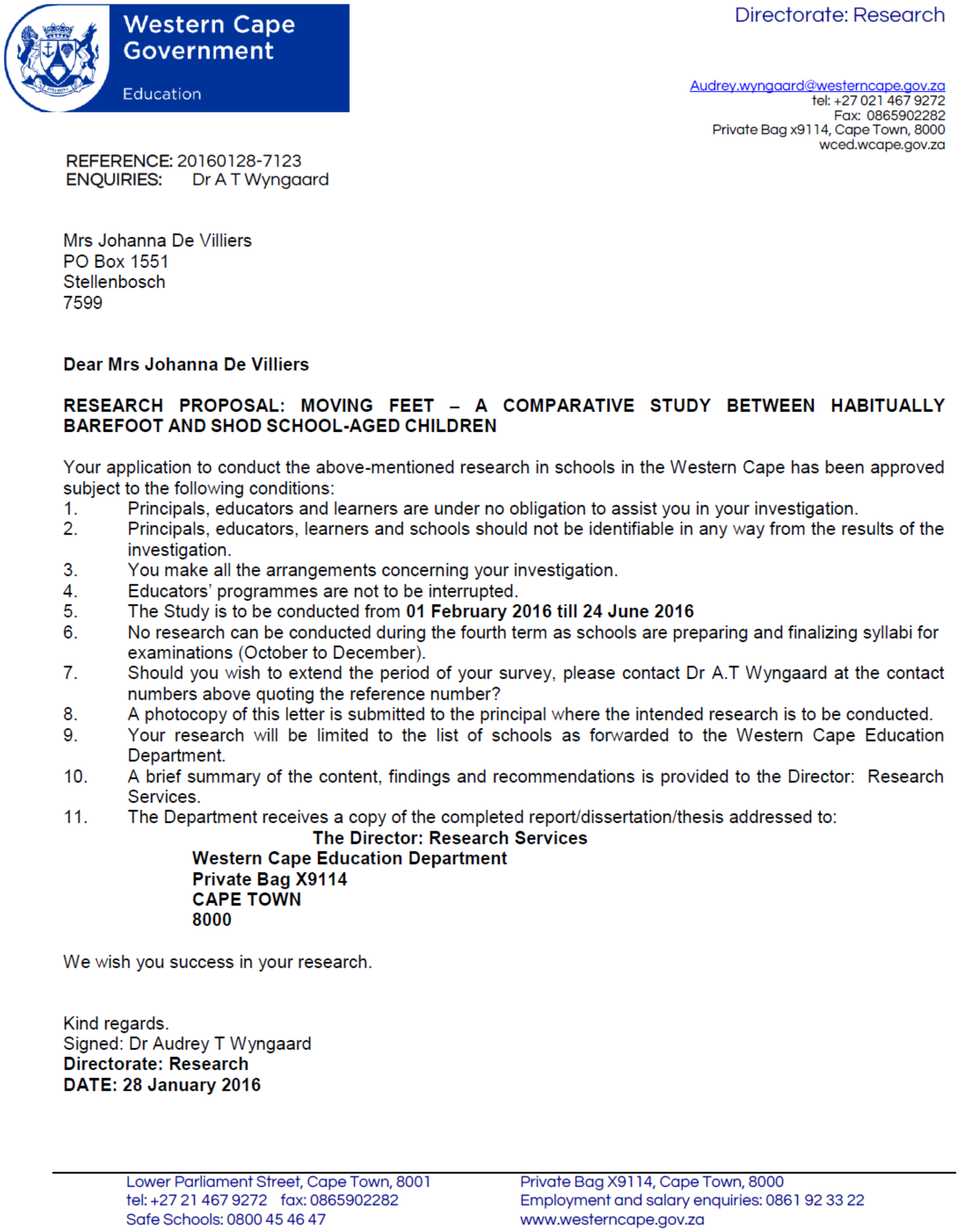
Dear Ms. Johanna De Villiers,

Your **Stipulated documents/requirements** received on **18-Feb-2015**, was reviewed by members of the **Research Ethics Committee: Human Research (Humanities)** via Expedited review procedures on **17-Feb-2015** and was approved.
Sincerely,

Clarissa Graham
REC Coordinator
Research Ethics Committee: Human Research (Humanities)

APPENDIX B

Approval from Western Cape Government Department of Education



Western Cape Government
Education

Directorate: Research

Audrey.wyngaard@westerncape.gov.za
tel: +27 021 467 9272
Fax: 0865902282
Private Bag x9114, Cape Town, 8000
wced.wcape.gov.za

REFERENCE: 20160128-7123
ENQUIRIES: Dr A T Wyngaard

Mrs Johanna De Villiers
PO Box 1551
Stellenbosch
7599

Dear Mrs Johanna De Villiers

RESEARCH PROPOSAL: MOVING FEET – A COMPARATIVE STUDY BETWEEN HABITUALLY BAREFOOT AND SHOD SCHOOL-AGED CHILDREN

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **01 February 2016 till 24 June 2016**
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Dr A.T Wyngaard at the contact numbers above quoting the reference number?
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

The Director: Research Services
Western Cape Education Department
Private Bag X9114
CAPE TOWN
8000

We wish you success in your research.

Kind regards.
Signed: Dr Audrey T Wyngaard
Directorate: Research
DATE: 28 January 2016

Lower Parliament Street, Cape Town, 8001
tel: +27 21 467 9272 fax: 0865902282
Safe Schools: 0800 45 46 47

Private Bag X9114, Cape Town, 8000
Employment and salary enquiries: 0861 92 33 22
www.westerncape.gov.za

APPENDIX C
Information and informed consent form sent to parents

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STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Moving feet – a comparative study of school children who normally wear shoes and those who normally walk barefoot

I am Elbé de Villiers (a PhD student in Sport Science) of the Department of Sport Science at Stellenbosch University. I would like to invite your child to participate in my research study. The results of the study will form part of the thesis for my doctoral degree in Sport Science. Your child has been chosen as a possible participant in the study because he/she is in one of the participant schools and also is of the right age.

1. PURPOSE OF THE STUDY

The main purpose of this study is to determine the effect that shoes have on the developing foot. I will also determine whether shoes influence children's ability to move.

2. PROCEDURES

If you agree that your child may take part in this study, your child will have to undergo the following tests and measurements:

Anthropometric measurement: Your child's height and weight will be measured.

Complete a questionnaire on physical activity: This is done to determine how active your child is.

Questionnaire on being barefoot: This will be done to determine how often your child is barefoot.

Walking, jogging and running for 20 metres: First your child will walk, then jog and then sprint for 20 metres. While doing this, he/she will be recorded on a video camera. They will be asked to do the sprinting twice. The video is just to determine how their feet land while running.

Balance tests: Your child will be asked to stand on one leg for 30 seconds. This will be done three times. Next they will be asked to walk backwards on 3 planks, each with a different width. This will also be done three times for each plank width.

Jumping: Your child will be asked to jump as far as they can with both feet together. The distance will be measured. He/she will do this jump three times.
They will also be asked to jump sideways as many times as possible in 15 seconds. They will do it twice.

Agility test: This test is done over 5 metres between two cones. Your child will run between the cones, touching the cone, 10 times. The time it takes your child to complete all 10 reps will be taken. They will also repeat the test and the best time will be used.

Foot shape: Your child will be asked to stand with both legs on a piece of paper and their foot's arch height, foot length and foot width will be measured by a calliper while they are standing and being seated.

3. POTENTIAL RISKS AND DISCOMFORT

Although some of the tests might be unknown to your child, they are simple tests. They should not make your child exceptionally tired or cause any discomfort.

4. POTENTIAL BENEFITS FOR STUDY PARTICIPANTS AND/OR SOCIETY

Your child will gain no direct benefit from the study.

The study does hold benefits for knowledge in the field of sport science, however, and specifically on the effect of shoes on children's feet and their ability to move. The results could possibly also provide shoe manufacturers with the necessary knowledge in the future to design shoes that are beneficial for the development of children's feet.

5. REMUNERATION FOR PARTICIPATION

Your child will not be paid for participation in this study.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that could reveal your child's identity will remain confidential and will only be revealed with your consent or if required by law. Confidentiality will be maintained by storing the data on a personal computer with a password. Only the researcher and the supervisor will be able to look at the data. The data will be dealt with anonymously at all times.

If the research should be published, the data will be discussed in general – in other words for the group as a whole.

7. PARTICIPATION AND WITHDRAWAL

You can decide whether or not your child may participate in this study. If you offer that your child may participate, you may still withdraw him/her from the study at any stage without this holding any negative consequences for your child. The researcher could also decide to remove your child from the study should circumstances require this.

8. DETAILS OF RESEARCHERS

If you have any questions on the research or if anything about it bothers you, you are welcome to contact us:
Elbé de Villiers (cell phone 084 515 7642; e-mail edup@sun.ac.za) or Dr Ranel Venter (cell phone 083 309 2894; e-mail rev@sun.ac.za)

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any stage and discontinue your child's participation, without any negative consequences. Your child will not waive any legal claims or rights by taking part in this research study. For any questions about your child's rights as a study participant, contact Ms Maléne Fouché at the Stellenbosch University Division for Research Development [mfouche@sun.ac.za; 021 808 4622].

SIGNATURE OF PARENT / GUARDIAN

I was given a copy of the letter with information.
I was given the opportunity to ask questions, and they were answered satisfactorily.

I consent that ________________________________ may participate in this study. I have received a copy of this form.

____
Name of parent/guardian

___________________________________ ________________
Signature of parent/guardian **Date**

Physical Address:

Street number and name:____
Area / Suburb: ____
Town / City: ____

APPENDIX D
Information and informed consent form for high school participants

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STELLENBOSCH UNIVERSITY
CONSENT TO PARTICIPATE IN RESEARCH

Moving feet – a comparative study of school children who normally wear shoes and those who normally walk barefoot

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The main purpose of this study is to determine the effect that shoes have on the developing foot. I will also determine whether shoes influence children's ability to move.

2. PROCEDURES

If you agree to take part in this study, you will have to undergo the following tests and measurements:

Anthropometric measurement: Your height and weight will be measured.

Complete a questionnaire on physical activity: This is done to determine how active you are.

Questionnaire on being barefoot: This will be done to determine how often you are barefoot.

Walking, jogging and running for 20 metres: First you will walk then jog and then sprint for 20 metres. While doing this, you will be recorded on a video camera. You will be asked to do the sprinting twice. The video is just to determine how you land with your feet while running.

Balance tests: You will be asked to stand on one leg for 30 seconds. This will be done three times. Next you will be asked to walk backwards on 3 planks, each with a different width. This will also be done three times for each plank width.

Jumping: You will be asked to jump as far as you can with both feet together. The distance will be measured. You will do this jump three times.
With the next jump, you will have to jump sideways as many times as possible in 15 seconds. The jumps will be counted and you will do it twice.

Agility test: This test is done over 5 metres between two cones. You will run between the cones, touching the floor, 10 times. The time it takes you to complete all 10 reps will be taken. You will also repeat the test and the best time will be used.

Foot shape: You will be asked to stand with both legs on a piece of paper and your arch height, foot length and foot width will be measured by a calliper while you are standing and being seated.

3. POTENTIAL RISKS AND DISCOMFORT

Although some of the tests might be unknown to you, they are simple tests. They should not make you exceptionally tired or cause any discomfort.

4. POTENTIAL BENEFITS FOR STUDY PARTICIPANTS AND/OR SOCIETY

You will gain no direct benefit from the study.

The study does hold benefits for knowledge in the field of sport science, however, and specifically on the effect of shoes on children's feet and their ability to move. The results could possibly also provide shoe manufacturers with the necessary knowledge in the future to design shoes that are beneficial for the development of children's feet.

5. REMUNERATION FOR PARTICIPATION

You will not be paid for participation in this study.

6. CONFIDENTIALITY

Any information that is obtained in connection with this study and that could reveal your identity will remain confidential and will only be revealed with your consent or if required by law. Confidentiality will be maintained by storing the data on a personal computer with a password. Only the researcher and the supervisor will be able to look at the data. The data will be dealt with anonymously at all times.

If the research should be published, the data will be discussed in general – in other words for the group as a whole.

7. PARTICIPATION AND WITHDRAWAL

You can decide whether or not you want to participate in this study. If you offer that you will participate, you may still withdraw from the study at any stage without this holding any negative consequences for you. The researcher could also decide to remove you from the study should circumstances require this.

8. DETAILS OF RESEARCHERS

If you have any questions on the research or if anything about it bothers you, you are welcome to contact us:
Elbé de Villiers (cell phone 084 515 7642; e-mail edup@sun.ac.za) or Dr Ranel Venter (cell phone 083 309 2894; e-mail rev@sun.ac.za)

9. RIGHTS OF RESEARCH PARTICIPANTS

You may withdraw your consent at any stage and discontinue your participation, without any negative consequences. You will not waive any legal claims or rights by taking part in this research study. For any questions about your rights as a study participant, contact Ms Maléne Fouché at the Stellenbosch University Division for Research Development [mfouche@sun.ac.za; 021 808 4622].

SIGNATURE OF PARTICIPANT

I was given a copy of the letter with information.
I was given the opportunity to ask questions, and they were answered satisfactorily.

I consent that I, ________________________________ will participate in this study. I have received a copy of this form.

____
Name of participant

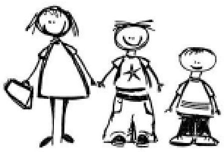
____________________________________ ________________
Signature of participant **Date**

APPENDIX E

Information and informed consent form for primary school participants

	STELLENBOSCH UNIVERSITY

PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



TITLE OF THE RESEARCH PROJECT:
Moving Feet – A Study where we compare school-aged children who normally walks barefoot to those who normally wear shoes.

RESEARCHER'S NAME: Elbé de Villiers

ADDRESS: Department of Sport Science, Stellenbosch University

CONTACT NUMBER: 021 808 4735 / 021 808 4735

What is RESEARCH?
Research is something we do to find **NEW KNOWLEDGE** about the way things (and people) work. We use research projects or studies to help us find out more about children and teenagers and the things that affect their lives, their schools, their families and their health. We do this to try and make the world a better place!

What is this research project all about?
During this project we want to see what effect your everyday shoes have on:
The way you walk
The shape of your feet
Your balance
The distance that you can jump
The time it takes you to run a short distance turns around and run back

Why have I been invited to take part in this research project?
You were invited because you are a pupil in one of the schools that was chosen for the study. You are healthy, do not have an injury and you are the right age.

Who is doing the research?
My name is Elbé de Villiers. I am a Biokineticist working at Stellenbosch University. My job is to help people get better after they had an injury, where in an accident or where very ill. We help them by doing specific exercises.

What will happen to me in this study?

During the study we will do a few tests.
First of all we will measure your height and weight.
Then we will do a warm-up (light jogging and stretches) to get you ready for the other tests.
We will ask you to walk a few metres while we record everything with a video camera. We will take measurements of your foot while you are standing and sitting
The balance test is next. You will need to stand on the one leg for 30 seconds. After that you will have to try and walk backwards on three different sized plank, 3 times.
You will be asked to jump forward as far as you can 3 times and jump sideways as many times as possible in 15 seconds. You will do this twice.
Next you will walk, jog and run 20 metres while being recorded by a video camera. We want to see how you put your foot down while running. Only the running will be done twice and the time it takes you to complete this will be taken.
Lastly we will record your time while you run 5 metres, turn around and run back 10 times

Can anything bad happen to me?

Nothing bad can happen to you during the study. You will only run short distances and jump three times. The only thing that might happen is that your muscles might feel uncomfortable.
We will show you how to do everything.

Will anyone know I am in the study?

Nobody have to know that you are part of the study. Your specific results will only be known by Elbé.

Who can I talk to about the study?

If you have questions or want to speak to someone about the study you can contact: Elbé de Villiers (cell phone: 084 515 7642; email: edup@sun.ac.za) or Dr Ranel Venter (cell phone: 083 309 2894; email: rev@sun.ac.za).

What if I do not want to do this?

No one can force you to be part of the study. If you do not want to do this, you do not have to. Even if your parents allowed you and signed the form, you still do not have to do it.
If you said that you want to be part of the study and decide later on that you do not want to do it any more, nothing will happen to you and you can just stop being part of it.

Do you understand this research study and are you willing to take part in it?

YES NO

Has the researcher answered all your questions?

YES NO

Do you understand that you can STOP being in the study at any time?

YES NO

____________________________	______________________
Signature of Child	Date

APPENDIX F

Barefoot questionnaire for high school participants

Name:

Vraelys oor hoe gereeld jy kaalvoet is
Questionnaire on how often you are barefoot

Omkring hoe baie jy kaalvoet loop by die skool:
Circle how often you are barefoot at school:

As dit warm is
When it is warm

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

As dit koud is
When it is cold

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

Omkring hoe baie jy kaalvoet is tydens sport:
Circle how often you are barefoot during sport activities:

As dit warm is
When it is warm

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

As dit koud is
When it is cold

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

Omkring hoe baie jy kaalvoet is in en om die huis:
Circle how often you are barefoot in and around the home:

As dit warm is
When it is warm

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

As dit koud is
When it is cold

Amper nooit *Almost never*	*Helfte van die tyd* *Half of the time*	*Amper altyd* *Almost always*

Omkring hoe baie jy kaalvoet was toe jy in die laerskool was:
Circle how often you were barefoot while at primary school:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet was tydens sport in die laerskool:
Circle how often you were barefoot during sport activities at primary school:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet was in en om die huis toe jy in die laerskool was:
Circle how often you were barefoot in and around the home while you were at primary school:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Baie dankie! Thank you!

APPENDIX G

Barefoot questionnaire for primary school participants

Name:

Vraelys oor hoe gereeld jy kaalvoet is
Questionnaire on how often you are barefoot

Omkring hoe baie jy kaalvoet loop by die skool:
Circle how often you are barefoot at school:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet is tydens sport:
Circle how often you are barefoot during sport activities:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Omkring hoe baie jy kaalvoet in en om die huis is:
Circle how often you are barefoot in and around the house:

As dit warm is
When it is warm

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

As dit koud is
When it is cold

Amper nooit	*Helfte van die tyd*	*Amper altyd*
Almost never	*Half of the time*	*Almost always*

Baie dankie! Thank you!

APPENDIX H
Physical activity questionnaire for adolescents (PAQ-A)

Name:

Subject #

Physical Activity Questionnaire (Secondary School)

We are trying to find out about your level of physical activity from the last 7 days (in the last week). These includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:

- There are no right and wrong answers — this is not a test.
- Please answer all the questions as honestly and accurately as you can — this is very important.

1. Physical activity in your spare time: Do you do any of the following activities in **a normal week**? If yes, how many times?

	No	1-2	3-4	5-6	7 times or more
Games/Skipping					
Walking for exercise					
Cycling					
Jogging and/or running					
Aerobics					
Soccer					
Rugby/Touch/7's					
Netball or basketball					
Hockey					
Cricket					
Rounders/Base-/softball					
Badmington/Tennis/squash					
Rowing/Canoeing					
Martial Arts					
Swimming					
Gymnastics					
Dance/Cheerleading					
Roller or inline skating					
Skateboarding					
Horse riding					
Sailing/windsurfing					
Ice skating					
Other:					

2. In a normal week, during your **Life Orientation (LO) classes**, how often are you very active (playing hard, running, jumping, throwing)? (Check one only.)

I don't do LO	
Hardly ever	
Sometimes	
Quite often	
Always	

3. In a normal week, what do you normally do at **break**? (Check one only.)

Sat down (talking, reading, doing schoolwork)	
Stood around or walked around	
Ran or played a little bit	
Ran around and played quite a bit	
Ran and played hard most of the time	

4. In a normal week, on how many days **right after school**, do you do sport, dance, or play games in which you are very active? (Check one only.)

None	
1 time last week	
2 or 3 times last week	
4 times last week	
5 times last week	

5. In a normal week, on how many **evenings** do you do sports, dance, or play games in which you are very active? (Check one only.)

None	
1 time	
2 or 3 times	
4 or 5 times	
6 or more times	

6. On a normal weekend, how many times do you do sports, dance, or play games in which you are very active? (Check one only.)

None	
1 time	
2 or 3 times	
4 or 5 times	
6 or more times	

7. Which one of the following describes you best? Read all five statements before deciding on the one answer that describes you.

All or most of my free time was spent doing things that involve little physical effort	
I sometimes (1 — 2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics)	
I often (3 — 4 times last week) did physical things in my free time	
I quite often (5 — 6 times last week) did physical things in my free time	
I very often (7 or more times last week) did physical things in my free time	

8. Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week.

	None	Little bit	Medium	Often	Very often
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					
Saturday					
Sunday					

9. Were you sick last week, or did anything prevent you from doing your normal physical activities?

Yes	No

If yes, what prevented you? ________________________________

10. Have you had any injuries recently? ________________________________

If yes, what kind and when? ________________________________

11. How would you describe yourself?

White	Brown	Black	Indian/ Asian

APPENDIX I

Physical activity questionnaire for older children (PAQ-C)

Name:

Subject #

Physical Activity Questionnaire (Elementary School)

We are trying to find out about your level of physical activity from **the last 7 days (in the last week).** These includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:

- There are no right and wrong answers — this is not a test.
- Please answer all the questions as honestly and accurately as you can — this is very important.

1. Physical activity in your spare time: Do you do any of the following activities in **a normal week** (last week)? If yes, how many times?

	No	1-2	3-4	5-6	7 times or more
Games/Skipping					
Walking for exercise					
Cycling					
Jogging and/or running					
Aerobics					
Soccer					
Rugby/Touch/7's					
Netball or basketball					
Hockey					
Cricket					
Rounders/Base-/softball					
Badmington/Tennis/squash					
Rowing/Canoeing					
Martial Arts					
Swimming					
Gymnastics					
Dance/Cheerleading					
Roller or inline skating					
Skateboarding					
Horse riding					
Sailing/windsurfing					
Ice skating					
Other:					

2. In **a normal week**, during your **Life Orientation (LO)** classes, how often are you very active (playing hard, running, jumping, throwing)? (Check one only.)

I don't do LO	
Hardly ever	
Sometimes	
Quite often	
Always	

3 & 4. In **a normal week**, what did you do most of the time at recess? (Check one only.)

Sat down (talking, reading, doing schoolwork)	
Stood around or walked around	
Ran or played a little bit	
Ran around and played quite a bit	
Ran and played hard most of the time	

5. In **a normal week**, on how many days right after school, do you do sport, dance, or play games in which you are very active? (Check one only.)

None	
1 time last week	
2 or 3 times last week	
4 times last week	
5 times last week	

6. In **a normal week**, on how many evenings do you do sport, dance, or play games in which you are very active? (Check one only.)

None	
1 time	
2 or 3 times	
4 or 5 times	
6 or more times	

7. On **a normal weekend**, how many times do you do sports, dance, or play games in which you are very active? (Check one only.)

None	
1 time	
2 or 3 times	
4 or 5 times	
6 or more times	

8. Which one of the following describes you best for the last 7 days? Read all five statements before deciding on the one answer that describes you.

All or most of my free time was spent doing things that involve little physical effort	
I sometimes (1 — 2 times last week) did physical things in my free time (e.g. played sports, went running, swimming, bike riding, did aerobics)	
I often (3 — 4 times last week) did physical things in my free time	
I quite often (5 — 6 times last week) did physical things in my free time	
I very often (7 or more times last week) did physical things in my free time	

9. Mark how often you do physical activity (like playing sports, games, doing dance, or any other physical activity) **in a normal week**

	None	Little bit	Medium	Often	Very often
Monday					
Tuesday					
Wednesday					
Thursday					
Friday					
Saturday					
Sunday					

10. Were you sick last week, or did anything prevent you from doing your normal physical activities? (Check one.)

Yes	
No	

If Yes, what prevented you? ___________________________________

11. Have you had any injuries recently? _____________________________

If yes, what kind and when? ____

12. How would you describe yourself?

White	Brown	Black	Indian/ Asian

APPENDIX J

Author guidelines of Journal, *The Foot*

THE FOOT

Now indexed in Medline!

AUTHOR INFORMATION PACK

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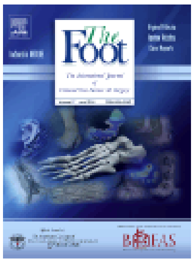

ISSN: 0958-2592

DESCRIPTION

The Foot is an international peer-reviewed journal covering all aspects of scientific approaches and **medical** and **surgical treatment** of the **foot and ankle**.

The Foot aims to provide a multidisciplinary platform for all specialties involved in treating disorders of the foot and ankle. At present it is the only journal which provides this inter-disciplinary opportunity.

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All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, stock ownership, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. If there are no conflicts of interest then please state this: 'Conflicts of interest: none'. More information.

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Contributors

Each author is required to declare his or her individual contribution to the article: all authors must have materially participated in the research and/or article preparation, so roles for all authors should be described. The statement that all authors have approved the final article should be true and included in the disclosure.

Authorship

All authors should have made substantial contributions to all of the following: (1) the conception and design of the study, or acquisition of data, or analysis and interpretation of data, (2) drafting the article or revising it critically for important intellectual content, (3) final approval of the version to be submitted.

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DESCRIPTION

Gait & Posture is a vehicle for the publication of up-to-date basic and clinical research on all aspects of **locomotion** and **balance**.

The topics covered include: Techniques for the measurement of **gait** and **posture**, and the standardization of results presentation; Studies of normal and **pathological gait**; Treatment of gait and **postural abnormalities**; Biomechanical and theoretical approaches to gait and posture; Mathematical models of **joint** and **muscle mechanics**; **Neurological** and **musculoskeletal** function in gait and posture; The evolution of **upright posture** and **bipedal locomotion**; Adaptations of carrying loads, walking on uneven surfaces, climbing stairs etc; spinal biomechanics only if they are directly related to gait and/or posture and are of general interest to our readers; The effect of aging and development on gait and posture; Psychological and cultural aspects of gait; Patient education.

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APPENDIX L

Differences in footwear habits between Caucasian and African South-African children

Table L.1: Footwear habit distributions of South-African children

	Caucasian	non-Caucasian
Shod	24.4%	24.5%
Barefoot	75.6%	75.5%

No difference was found in the distribution of footwear habits in the South-African sample.

APPENDIX M

Influence of physical activity levels on foot posture and plantar pressure parameters

Table M.1: Foot posture parameters of children with different habitual levels of physical activity

	Not Active	Moderately active	Very active
Arch height index	0.253 (0.021)	0.260 (0.021)	0.259 (0.021)
Dynamic arch index	0.195 (0.065)	0.181 (0.067)	0.178 (0.073)
Pliability	1.043 (0.029)	1.041 (0.027)	1.045 (0.028)

No significant differences were found between any variable and any level of activity ($p > 0.05$)

APPENDIX N

Table N.1: Comparison of pressure-time integral between German and South African children

		Pressure-time integral	p ; Effect size
Total Object	SA	163.638 (55.256)	0.00 ; 0.77^L
	GER	208.124 (62.052) *	
Big Toe	SA	71.786 (42.725)	0.00 ; 0.52^M
	GER	96.905 (57.518) *	
Toes 2 to 5	SA	32.989 (16.648)	0.00 ; 0.55^M
	GER	43.402 (22.747) *	
Lateral Hindfoot	SA	62.852 (19.018)	0.00 ; 0.53^M
	GER	74.299 (25.716) *	
Medial Hindfoot	SA	68.211 (21.864)	0.00 ; 0.51^M
	GER	80.518 (28.019) *	
Lateral Midfoot	SA	25.742 (11.952)	0.08 ; 0.24^S
	GER	28.955 (15.384)	
Medial Midfoot	SA	15.398 (8.334)	0.75 ; 0.04^N
	GER	15.789 (9.918)	
Lateral Forefoot	SA	76.984 (34.849)	0.00 ; 0.74^M
	GER	105.477 (45.200) *	
Central Forefoot	SA	75.205 (32.841)	0.00 ; 0.69^M
	GER	99.889 (41.147) *	
Medial Forefoot	SA	62.000 (30.000)	0.00 ; 0.39^S
	GER	73.999 (32.406) *	

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large

Pressure-time integral: In all areas of the foot (except for the lateral and medial midfoot), the German children presented with significantly greater pressure-time integral values as seen in table N.1 ($p < 0.05$).

Table N.2: Comparison of force-time integral relative to body weight between

German and South African children

		Force-time Integral	p ; Effect size
Total Object	SA	50.556 (9.045)	0.00 ; 1.19^{VL}
	GER	59.029 (5.911) *	
Big Toe	SA	4.142 (1.816)	0.00 ; 0.49^{M}
	GER	5.202 (2.759) *	
Toes 2 to 5	SA	1.441 (.854)	0.00 ; 0.51^{M}
	GER	1.978 (1.393) *	
Lateral Hindfoot	SA	7.531 (1.630)	0.01 ; 0.35^{S}
	GER	8.182 (2.313) *	
Medial Hindfoot	SA	8.957 (1.915)	0.00 ; 0.39^{s}
	GER	9.827 (2.796) *	
Lateral Midfoot	SA	2.913 (2.206)	0.65 ; 0.09^{N}
	GER	3.116 (2.385)	
Medial Midfoot	SA	0.366 (0.458)	0.29 ; 0.12^{N}
	GER	0.316 (0.349)	
Lateral Forefoot	SA	11.178 (3.384)	0.00 ; 0.81^{L}
	GER	14.166 (4.286) *	
Central Forefoot	SA	7.305 (1.820)	0.00 ; 0.82^{L}
	GER	9.017 (2.570) *	
Medial Forefoot	SA	6.717 (2.395)	0.31 ; 0.17^{S}
	GER	7.155 (2.806)	

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large, ^{VL}Very Large

Force-time integral relative to body weight: In all regions of the foot, the German children had significantly greater force-time integral values compared to the South African children ($p < 0.05$), except for the lateral and medial midfoot, as well as medial forefoot (table N.2).

Table N.3: A comparison of absolute contact time between German and South African children

		Absolute contact time	p ; Effect size
Total Object	SA	679.040 (84.781)	0.00 ; 1.43^{VL}
	GER	814.573 (111.658) *	
Big Toe	SA	406.035 (112.532)	0.00 ; 1.19^{VL}
	GER	546.731 (128.954) *	
Toes 2 to 5	SA	373.069 (108.176)	0.00 ; 1.2^{VL}
	GER	517.535 (142.672) *	
Lateral Hindfoot	SA	380.278 (69.474)	0.00 ; 0.75^{L}
	GER	441.545 (101.024) *	
Medial Hindfoot	SA	385.829 (70.098)	0.00 ; 0.73^{M}
	GER	445.642 (101.775) *	
Lateral Midfoot	SA	398.373 (89.051)	0.00 ; 0.54^{M}
	GER	452.595 (122.538) *	
Medial Midfoot	SA	273.920 (90.508)	0.22 ; 0.16^{S}
	GER	290.733 (122.870)	
Lateral Forefoot	SA	562.007 (80.489)	0.00 ; 1.34^{VL}
	GER	675.455 (91.911) *	
Central Forefoot	SA	542.077 (81.360)	0.00 ; 1.35^{VL}
	GER	659.697 (98.036) *	
Medial Forefoot	SA	512.750 (85.940)	0.00 ; 1.17^{VL}
	GER	619.3418 (100.1844)*	

* Represents significant difference of $p < 0.05$
Effect sizes: ^{N}Negligible, ^{S}Small, ^{M}Medium, ^{L}Large, ^{VL}Very Large

Absolute contact time: Table N.3 shows that in all regions of the foot, except the medial midfoot, the German children had significantly greater contact time ($p < 0.05$).

APPENDIX O

Comparison of Coefficient of spreading and DAI between German and South African children was done by means of a student T-test.

Table N.1: DAI and coefficient of spreading of German and South-African children

	SA Mean (SD)	GER Mean (SD)
Coefficient of spreading	0.375 (0.021) *	0.371 (0.022)
DAI	0.177 (0.068)	0.179 (0.66)