Plantar foot loading patterns of healthy weight and overweight school children from South Africa and Germany

by

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DECLARATION

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

March 2017

SUMMARY

Background: Excessive plantar loading (peak pressures) can possibly cause deterioration of the soft tissue such as the fat pads in the foot during locomotion (Mickle, Steele & Munro, 2006). This can increase the risk for developing foot pathologies in adults and children (Yan et al., 2013). It is speculated that foot pain experienced by overweight individuals results from the higher mechanical loading of their feet because of the additional body weight they carry (Butterworth et al., 2015).

Objective: The current study investigated the plantar loading differences between the healthy weight and overweight children aged 10 to 13 years from South Africa. An additional investigation was carried out to determine the plantar loading differences between children aged 10 to 13 years from Germany and South Africa of the same weight category.

Methods: The current study followed a descriptive cross sectional study design. A random stratified sample of four schools were randomly selected from five regions within the Western Cape. Plantar loading measurements were obtained from 178 children (mean age 12.3 ± 1.2 years; body weight 49.2 ± 12.2kg; height 1.56 ± 0.01m; n = 178 of which 87 were girls and 91 boys) from South Africa and 139 children (mean age 12.3 ± 0.1 years; body weight 47.3 ± 1.0kg; height 1.55 ± 0.01m; n = 139 of which 61 were girls and 78 boys) from Germany with the Emed n50 pressure platform using the two-step method at a self-selected walking speed. Peak pressure, pressure-time integral, force-time integral and contact area variables were investigated for nine regions of the foot. In addition, the children were categorised into a heathy weight category or overweight category according to their body mass index (BMI) (Cole & Lobstein, 2012). A mixed model linear regression was used to analyse the data. The level of significance was adjusted from p = 0.05 by using a Šidák correction to: p = 0.0057.

Results: The overweight category of children from South Africa had statistically significantly higher peak pressure, pressure-time integral, force-time integral and contact area for most of the foot regions than the healthy weight children from South Africa. The German children had significantly higher peak pressure, pressure-time integral and force-time integral values than the South African children of the same weight category. Interestingly, the healthy weight South African children had significantly greater contact area for most regions of the foot compared to the healthy weight German children.

Conclusion: Body weight is a primary factor influencing plantar loading values (of overweight children). It is possible that the significant differences found in the midfoot region

of the overweight children compared to healthy weight children could have been influenced by structural foot differences such as additional fat mass of the medial longitudinal arch or structurally lowered medial longitudinal arch of the foot. It is possible that the plantar loading differences between the German and South African children are a result of structural foot differences.

OPSOMMING

Agtergrond: Oormatige plantaarlading (piekdruk) kan moontlik lei tot agteruitgang van die sagteweefsels soos die vetsak in die voet gedurende voortbeweging (Mickle, Steele & Munro, 2006). Dit kan die risiko vir die ontwikkeling van voetpatologieë in volwassenes en kinders verhoog (Yan et al., 2013). Daar word gespekuleer dat voetpyn wat deur oorgewig individue ondervind word, die gevolg kan wees van hoër meganiese lading van die voete as gevolg van die addisionele liggaamsgewig (Butterworth et al., 2015).

Doel: Die huidige studie het die verskille in plantaarlading tussen gesonde-gewig en oorgewig kinders tussen die ouderdomme van 10 en 13 in Suid-Afrika bestudeer. ‘n Addisionele ondersoek is gedoen om te bepaal of daar verskille is in die plantaarladings by kinders tussen die ouderdomme van 10 en 13, in die dieselfde gewigskategorieë, van Suid-Afrika en Duitsland.

Metodes: Die huidige studie het ‘n beskrywende deursnee studie ontwerp gevolg. Vier skole is op ‘n lukrake gestratifiseerde manier uit die vyf streke van die Wes-Kaap gekies. Plantaarladingsmetings is verkry van 178 kinders (gem ouderdom12.3 ± 1.2 jaar; liggaamsgewig 49.2 ± 12.2kg; lengte 1.56 ± 0.01m; n = 178; 87 meisies en 91 seuns) uit Suid-Afrika en 139 kinders (gem ouderdom 12.3 ± 0.1 jaar; liggaamsgewig 47.3 ± 1.0kg; lengte 1.55 ± 0.01m; n = 139 met 61 meisies en 78 seuns) van Duitsland. Die Emed n50 drukplatform en ‘n twee-tree stapmetode teen ‘n selfgeselekteerde stapspoed is gebruik. Piekdruk, druk-tyd intervalle, krag-tyd intervalle en kontakarea veranderlikes is vir nege areas van die voet ondersoek. Kinders is ingedeel in gesonde enoorgewigkategorieë op grond van hulle liggaamsmassa indeks (LMI) (Cole & Lobstein, 2012). . ‘n Gemengde model lineêre regressie is gebruik om die data te analiseer. Die vlak van beduidenheid is aangepas van p = 0.05 tot p = 0.0057 deur middel van ‘n Šidák regstelling.

Resultate: Oorgewig kinders van Suid-Afrika het statisties beduidende hoër piekdruk, druk-tyd intervalle, krag-tyd intervalle en kontakarea vir die meeste dele van die voet gehad in vergelyking met die gesonde-gewig kinders van Suid-Afrika. Vir dieselfde gewigskategorieë het die Duitse kinders statisties beduidende hoër piekdruk, druk-tyd intervalle, krag-tyd intervalle as die Suid-Afrikaanse kinders gehad. Die gesonde-gewig kinders van Suid-Afrika het beduidend groter kontakareas vir die meeste dele van die voet gehad in vergelyking met hul Duitse ewekenieë

Gevolgtrekking: Liggaamsgewig is ‘n primêre faktor wat die plantaarladings waardes van oorgewigkinders beïnvloed. Daar word vermoed dat die beduidende verskille wat tussen die middelvoet-area van oorgewig kinders teenoor gesonde-gewig kinders gevind is, moontlik deur strukturele voetverskille kan wees, soos bykomende vetmassa van die mediale langboog of ‘n strukturele laer mediale boog van die voet. Dit is moontlik dat die plantaarladingsverskille tussen Duitse en Suid-Afrikaanse kinders die gevolg kan wees van strukturele voetverskille.

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"For I can do everything through Christ, who gives me strength" ~ Philippians 4:13

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ABBREVIATIONS

BMI	Body Mass Index
CA	Contact Area
CT	Contact Time
FTI	Force Time Integral
IOTF	International Obesity Task Force
LHF	Lateral Hindfoot
MF	Midfoot
MHF	Medial Hindfoot
MH1	Metatarsal head one
MH2	Metatarsal head two
MH3	Metatarsal head three
MH4	Metatarsal head four
MH5	Metatarsal head five
PP	Peak Pressure
PTI	Pressure Time Integral

KEY TERMINOLOGY

Foot structure:

Refers to the alignment of the bony and ligament structures the foot.

Foot posture:

Refers to the positioning of the feet such as pronation or supination.

Force-time integral:

The cumulative force produced within a period of time. It is often expressed as a force area under the force versus time curve.

Healthy weight category:

The children classified being healthy weight according to their age, gender and body mass index (BMI) by the International Obesity Task Force (IOTF) BMI cut-off values for children.

Overweight category:

The children classified being overweight, obese and morbid obese according to their age, gender and BMI by the IOTF BMI cut-off values for children.

Plantar loading:

Refers to the vertical ground reaction forces exerted on the plantar surface of the foot during stance or walking. The variables used to discuss plantar loading in this study are peak pressure, pressure-time integral and force-time integral.

Peak Pressure:

The product of the maximum force that is produced over a particular contact area.

Pressure-time integral:

The cumulative pressure produced within a period of time. It is often expressed as the area under pressure versus time curve for a particular area.

OVERVIEW

The present thesis is an article based thesis which contains two main investigations. The Introduction provides basic information as background to the study, as well as the aims and objectives which guided the research. An in-depth explanation of research pertaining to the current study will be discussed in Chapter Two. Chapter Three contains Article One: Plantar loading differences between healthy weight and overweight children aged 10 to 13 years from the Western Cape, South Africa. This article focuses specifically on the plantar loading differences between healthy weight and overweight South African children which is compiled under the guidelines of the Gait & Posture Journal. The referencing style is compiled through Mendeley. Chapter Four contains Article Two: Plantar loading differences between overweight children aged 10 to 13 years from Germany and South Africa. This article focusses specifically on the plantar loading differences between overweight children from Germany and South Africa which is compiled under the guidelines of the Gait & Posture Journal. The referencing style is compiled through Mendeley. Refer to Appendix A for the Gait and Posture Journal author guidelines. In Chapter Five, a general discussion and conclusion of the objectives of this investigation will be discussed, as well as study limitations and recommendations for future research will be presented. Thereafter, the Appendices will follow. Refer to Appendices B, C for ethical clearance, Appendices D, E, F, G for consent and assent forms, Appendix H for additional data of the study.

The referencing format for this thesis follows the University of Cape Town's Harvard referencing style available by Mendeley.

CHAPTER ONE

INTRODUCTION

OVERVIEW OF LITERATURE

Excessive plantar loading (peak pressures) can possibly cause deterioration of the soft tissue such as the fat pads in the foot during locomotion (Mickle, Steele & Munro, 2006). This can increase the risk for developing foot pathologies in adults and children (Yan et al., 2013). It is speculated that foot pain experienced by overweight individuals results from the higher mechanical loading of their feet because of the additional body weight they carry (Butterworth et al., 2015).

Overweight and obesity can be defined by the additional fat mass an individual has and the most common method used to define overweight or obesity of children is by calculating the individual's body mass index (BMI) (Teh et al., 2006; Rossouw, Grant & Viljoen, 2012). One of the major leading causes for becoming overweight or obese is by consuming an energy rich diet (Rossouw, Grant & Viljoen, 2012). Other factors that can potentially pay a role in individuals becoming overweight or obese is physical inactivity, cultural background, genetics, stress levels and level of education (Rossouw, Grant & Viljoen, 2012). The parents, family members and health professionals need to increase their knowledge on how to increase physical activity levels and decrease the caloric intake of overweight or obese children (Wildermuth, Mesman & Ward, 2011). The prevalence of overweight and obese children have been on the rise in Africa and the prevalence differs according to the children's age, gender and population group (Rossouw, Grant & Viljoen, 2012). South Africa is known for some of the highest numbers of childhood obesity across Africa (Pienaar, 2015). Recent evidence suggests that there are greater numbers of girls that are overweight and obese in South Africa compared to boys (Kruger, Kruger & Macintyre, 2006; Rossouw, Grant & Viljoen, 2012). It is believed in certain African cultures that being overweight and obese may symbolise wealth in their families, happiness or the absence of HIV or AIDS (Rossouw, Grant & Viljoen, 2012). It is estimated that the ground reaction forces experienced by the lower limbs of a healthy weight individual can be as large as three to six times their own body weight (Hills et al., 2001). The magnitude of these ground reaction forces could be quite high for overweight or obese individuals.

During locomotion the feet of an individual plays a vital role in the body's kinetic chain as it serves as a base of support (Mickle, Steele & Munro, 2006; Yan et al., 2013). The longitudinal arch of the foot plays a key role in absorbing and distributing the high ground reaction forces (Dowling, Steele & Baur, 2001). For instance, the foot has to withstand great ground reaction forces or known as plantar loading from day-to-day during locomotion (Yan et al., 2013). The ligaments and muscles within the longitudinal arch of the foot provide support for maintaining the arch as it mimics the mechanism of an elastic band by storing the energy as it is stretched and releases the energy as it returns to its original state. Therefore, assisting with propulsion of the body during locomotion. Overloading the ligaments and soft tissue within the arch may cause the arch to lose its elastic properties causing damage to the ligaments and soft tissue, ultimately leading to possible foot pathologies (Dowling, Steele & Baur, 2001).

Fat pads are found in various regions of the foot and absorbs the high plantar loading during locomotion to provide protection to the bony structures of the foot (Mickle, Steele & Munro, 2006). Damage to the soft tissues such as fat pads can occur from excessive loading of the foot (Mickle, Steele & Munro, 2006). It is speculated that foot pain experienced by overweight individuals results from the higher mechanical loading of their feet because of the additional body weight they carry (Butterworth et al., 2015). The assessment of plantar loading through pressure platforms can provide valuable clinical information about the management of individuals that are at risk of developing flat foot, foot ulcerations or Charcot foot by providing information about ones' foot print (Riddiford-Harland, Steele & Baur, 2011; Periyasamy et al., 2012). The pressure platforms provide indirect information about whether an individuals' foot appears flatter by means of their foot print and it is assumed that this flatter foot appearance is caused by a either a lower medial longitudinal arch or additional fat mass within this arch (Riddiford-Harland, Steele & Baur, 2011).

Most studies investigating the differences in plantar loading between healthy weight and overweight individuals were done on adults and only a few studies have investigated the differences of plantar loading between healthy weight and overweight children. Assessing children's plantar loading may be a challenging task which requires the assessor to consider a few factors prior to testing. Factors such as the type of equipment, participants and the protocol utilised should be considered prior to any plantar loading assessment (Cousins, Morrison & Drechsler, 2012). It is believed that the additional body weight particularly of obese individuals are responsible for increasing the plantar loading of individuals. Recent evidence suggests that additional body weight is a key factor that influences the plantar loading (Butterworth et al., 2015).

Hills et al. (2001) discovered that obese adults produce greater plantar loading than non-obese adults particularly in the heel, mid-foot and forefoot regions. In addition, the obese adults had greater contact area of the midfoot region compared to the non-obese adults (Hills et al., 2001). Significant differences in plantar loading between healthy weight and overweight children were found more than a decade ago in a study done by Dowling, Steele and Baur (2004). A recent study found that the most common foot type present in overweight children were flat feet and robust feet (Mauch et al., 2008). In summary, overweight children may have greater plantar loading because of their additional body mass and higher prevalence of flatter feet than healthy weight children.

However, there is a lack of consistency in the way researchers investigate plantar loading differences between various weight categories of children and adults. To the knowledge of the researcher, no studies to date have investigated the plantar loading differences between healthy weight and overweight children in South Africa. In addition, no studies have investigated the plantar loading differences between two countries for the same weight category with the use of the same plantar loading protocol and pressure system.

PRIMARY AND SECONDARY AIMS

The primary aim of the study was to investigate the plantar loading differences between heathy weight and overweight children from South Africa aged 10 to 13 years old. The secondary aim was to investigate plantar loading differences between German and South African children aged 10 to 13 years old of the same weight category.

The following objectives guided the research:

1. To determine the plantar loading differences of various plantar foot regions between the healthy weight and overweight category of children from South Africa.
2. To determine the plantar loading differences of various plantar foot regions between the healthy weight children from Germany and South Africa.
3. To determine the plantar loading differences of various plantar foot regions between the overweight category of children from Germany and South Africa.

HYPOTHESIS

Two main hypotheses were established in this current study. Firstly, it was hypothesised that the overweight category of children will generate greater plantar loading than the healthy weight children from South Africa (hypothesis one). Secondly, it was hypothesised that there will be no significant plantar loading differences between the German and South African children of the same weight category (healthy weight and overweight category) – (hypothesis two).

OUTLINE OF THESIS

The thesis consists of five chapters. Chapter Two presents the theoretical context for this study. This chapter reviews current literature and related studies on plantar loading. In Chapter Three, the first article of this article-format thesis is presented. The focus of the article is to determine the plantar loading differences between the healthy weight and overweight category of children from South Africa aged 10 to 13 years old. Chapter Four contains the second article, which reports on the plantar loading differences between the overweight categories of children from Germany and South Africa aged 10 to 13 years old. Chapter Five contains a discussion of the results, as well as a conclusion to this study, limitations of this study, and recommendations for future research.

CHAPTER TWO

THEORETICAL BACKGROUND

INTRODUCTION

Plantar loading assessments are widely used in a clinical set-up and in research to investigate the effects of plantar loading on individual's feet (Riddiford-Harland, Steele & Baur, 2011; Periyasamy et al., 2012). In the clinical set-up plantar loading is utilised to determine the areas of the foot which are prone to diabetic ulcerations (Mickle, Steele & Munro, 2006). In research the plantar loading is utilised to determine how body weight can influence the plantar loading and the actual foot structure of children and adult's feet (Dowling, Steele & Baur, 2004; Mauch et al., 2008; Jiménez-Ormeño et al., 2013; Butterworth et al., 2015; Mueller et al., 2016). Plantar loading assessments are easy to carry out but it can be complex because of the variations in protocols utilised by researchers for plantar loading assessments. Various studies have been carried out on children and adults to determine the factors influencing plantar loading between weight categories (Burnfield et al., 2004; Phethean & Nester, 2012; Riddiford-Harland, Steele, Cliff, Okely, Morgan & Baur, 2014; Riddiford-Harland, Steele, Cliff, Okely, Morgan, Jones, et al., 2014; Mueller et al., 2016). A few studies found that body weight is the main the factor contributing to the plantar loading differences between weight categories of adults and children (Dowling, Steele & Baur, 2004; Butterworth et al., 2015). However, there are several variations within the plantar loading assessments researchers use and needs to be considered while comparing results of various studies. In addition, a number of factors besides body weight can influence the plantar loading of an individual (Cousins, Morrison & Drechsler, 2012). Firstly, background information pertaining to plantar loading of the foot and assessments will be addressed within this study. Secondly, various factors and variations of plantar loading assessments will be discussed to highlight the complexity of plantar loading assessments. Thirdly, background information pertaining previous studies that investigated plantar loading of adults and children will be discussed. In addition, the contradictions of previous studies will be highlighted.

PLANTAR LOADING OF THE FOOT

Plantar loading is a term used to refer to the vertical ground reaction forces exerted on the plantar surface of the foot during stance or walking. The variables used to describe plantar loading in this study are peak pressure, pressure-time integral and force-time integral. Peak pressure is the product of the maximum force that is produced over a particular contact area (commonly known as foot region or mapping area) of the foot. Pressure-time integral is often expressed as the area under the pressure versus time curve. In other words, it is the cumulative pressure produced within a period of time for a particular contact area of the foot. Force-time integral is often expressed as the area under the force versus time curve. In other words, it is the cumulative force produced within a period of time for a particular contact area of the foot. Plantar loading can be measured through pressure platforms. The pressure platforms can also provide information about individuals' foot print as it provides indirect information about whether an individuals' foot appears flatter (Riddiford-Harland, Steele & Baur, 2011). For example, the foot appears flatter when a greater area is occupied in the midfoot region and it is assumed that this flatter foot appearance is caused by a lower medial longitudinal arch (Riddiford-Harland, Steele & Baur, 2011). However, it is also suggested that this flatter foot appearance may be as a result of additional fat tissue within the midfoot region (Riddiford-Harland, Steele & Baur, 2011). In this section, the assessment of plantar loading will be discussed along with the variations that exist between plantar loading assessments and additional information on the factors possibly influencing plantar loading.

ASSESSMENT OF PLANTAR LOADING

Plantar loading of the foot can be assessed by analysing the plantar pressure produced on the plantar surface of the foot during static and dynamic movement. For instance, the plantar pressure provides information about the various foot regions that are loaded during dynamic movement such as walking (Cousins, Morrison & Drechsler, 2012). It is believed that the force during dynamic movement provides more information about the loading of the actual foot structure whereas the pressure provides more information on the loading of the soft tissues. For instance, in a clinical set-up diabetic ulcerations have been associated with higher plantar pressures developed during locomotion (Mickle, Steele & Munro, 2006). It is suggested that researchers should also report on pressure-time integral and force-time integral variables for plantar loading, because it affects different structures of the foot (Cousins, Morrison & Drechsler, 2012). Pressure-time integral and force-time integral tells more about the magnitude of the pressure or force of the foot over a period time. For example, it is assumed that pressure-time integral and force-time integral may play a vital role in the development of skin lesions (Putti et al., 2008). The greater the force-time integral, the higher the risk for bony fatigue of a particular region of the foot. The greater the pressure-time integral, the greater the risk for soft tissue damage (Dowling, Steele & Baur, 2004; Mickle, Steele & Munro, 2006). Furthermore, plantar loading assessments are easy to perform but are complex because of the number of variations within protocols used by researchers to assess plantar loading. These variations and possible factors influencing the plantar loading assessment as well as plantar loading will be discussed within the following section.

Factors that should be considered prior to plantar loading assessment

Assessing children's plantar loading can be a challenging task which requires the assessor to consider a few factors prior to testing. Factors such as the type of equipment, participants and the protocol utilised should be considered prior to any plantar loading assessment (Cousins, Morrison & Drechsler, 2012). These factors will be discussed in detail within this section.

Firstly, one needs to consider the type of equipment used for plantar loading assessments. Several systems are available to determine plantar loading of individuals such as in-shoe sensors and force platforms. The in-shoe systems are mostly used to determine the effect of a particular shoe has on the plantar loading of diabetic individuals either in a clinical or research set-up (Waaijman & Bus, 2012). Pressure platforms are mostly used to determine the factors that influence the plantar loading directly or indirectly while the individual is barefoot. The most popular products used by researchers are produced by Novel and Tekscan. There are, however, concerns among researchers about the comparability of results between studies because of different systems and protocols used to measure plantar loading (Taylor, Menz & Keenan, 2004). This raises a concern amongst researchers as various studies state that one cannot compare their results to other studies unless the same equipment is utilised because of a lack of research on the reliability between various systems (Putti et al., 2008; Cousins, Morrison & Drechsler, 2012). However, it was recently found that the data collected from a Novel Emed platform and a Tekscan MatScan produced the same results in adults (Hafer et al., 2013). The Novel Emed system is one of the most common and frequently used systems in clinical set-ups to determine the plantar loading of patients (Putti et al., 2008; Maetzler, Bochdansky & Abboud, 2010). All researchers should take caution when comparing results of various types of equipment as the reliability to use various systems interchangeably are not yet determined for all the available equipment.

Secondly, in a research set-up one needs to consider possible challenges with the target population such as children, adults or diabetic patients. Young children have difficulty to control their own walking speed without purposefully targeting the pressure platform as they are still developing their gait (Tong & Kong, 2013). A longitudinal study done on young children (average starting age ±1.2 years and average final age ±10.2 years) had to guide the children across the pressure platform with toys or by holding their hand (Bosch, Gerß & Rosenbaum, 2010). A number of studies did not allow the children to walk at a self-selected speed because they controlled the walking speed of the children (Dowling, Steele & Baur, 2001, 2004; Mickle, Steele & Munro, 2006; Bosch, Gerß & Rosenbaum, 2010). Tong and Kong (2013) concluded that the two-step method was easier for the children to implement than the midgait protocol. Various studies have adopted the two-step method in their protocols specifically for children (Dowling, Steele & Baur, 2004; Tong & Kong, 2013; Riddiford-Harland, Steele, Cliff, Okely, Morgan, Jones, et al., 2014; Mueller et al., 2016).

Thirdly, one needs to consider the various protocols that are used amongst researchers to assess the plantar loading of participants. The midgait protocol is known as the "gold standard" for assessing plantar pressure. The pressure measurements are taken midway of a lengthy walkway during steady-state. The steady-state of an individual during walking is reached amongst the second and third step taken after the individual starts to walk. The midgait protocol requires a large area of space and it requires a large amount of time to perform the protocol as more steps are required to capture one trial. The 1-step and 2-step protocols are popular protocols used amongst diabetic patients to assess their plantar pressures (Bus & Lange, 2005). The 2-step protocol is commonly used to assess the plantar loading of children (Dowling, Steele & Baur, 2001, 2004; Taylor, Menz & Keenan, 2004; Müller et al., 2012; Tong & Kong, 2013; Riddiford-Harland, Steele, Cliff, Okely, Morgan, Jones, et al., 2014). An additional factor to consider within a protocol is the number of trials required and the various foot regions or commonly known as mapping regions that can be utilised. The 2-step protocol requires fewer trials to provide acceptable reliability of plantar peak pressure compared to the 1-step and 3-step protocols. It is recommended that three to five trials are required to capture reliable data from non-diabetic patients and diabetic patients (Bus & Lange, 2005). Various foot regions or mapping regions can be produced by software provided by the various in-shoe or pressure platform systems. The number and areas of foot regions vary among researchers from four to ten regions (Burnfield et al., 2004; Bosch, Gerß & Rosenbaum, 2010; Maetzler, Bochdansky & Abboud, 2010; Müller et al., 2012; Wearing et al., 2012; Cousins, Morrison & Drechsler, 2013). The plantar foot print is mostly divided into ten foot regions amongst researchers that investigate plantar loading of children and adults (Dowling, Steele & Baur, 2004; Taylor, Menz & Keenan, 2004; Teh et al., 2006; Putti et al., 2008; Putti, Arnold & Abboud, 2010; Yan et al., 2013; Riddiford-Harland, Steele, Cliff, Okely, Morgan & Baur, 2014; Riddiford-Harland, Steele, Cliff, Okely, Morgan, Jones, et al., 2014). However, the selection of the ten regions may differ between researchers and these various regions are displayed in Figure 1. The foot print is firstly divided into four main regions namely the toes, forefoot, midfoot and hindfoot and these regions are further sub-divided into smaller regions as indicated in Figure1.

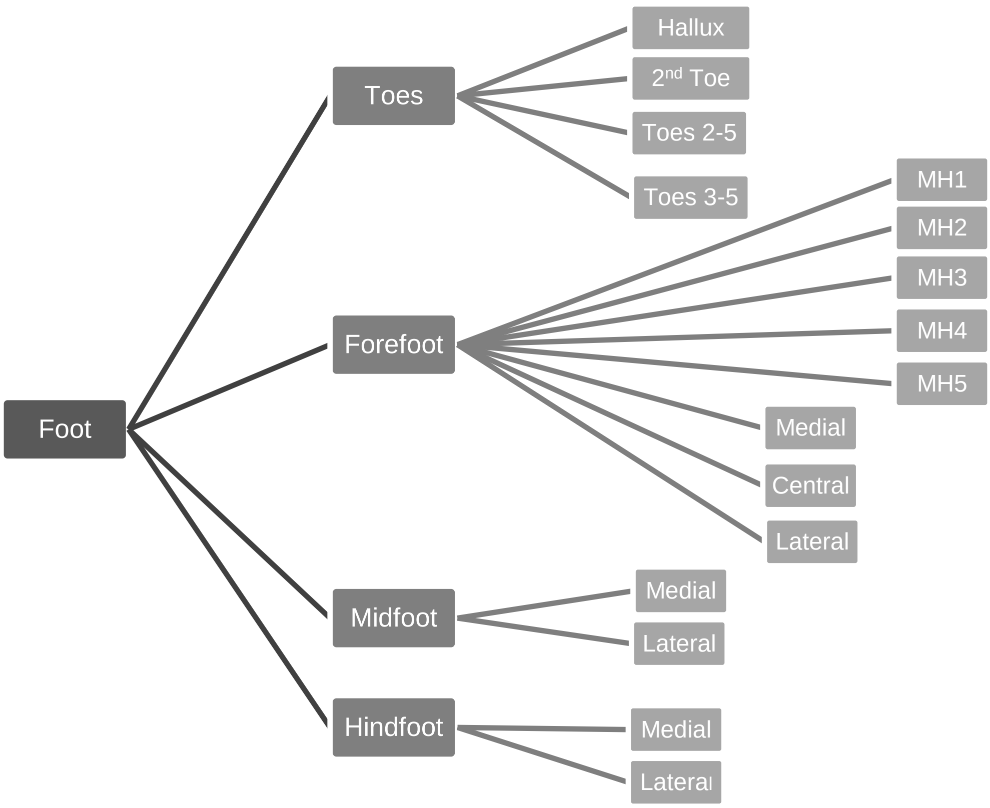

Figure 1: Representation of various foot regions

It was found that the high loading regions of the foot, such as the central forefoot, medial and lateral hindfoot, have greater reliability of plantar loading than the less loaded areas. The medial midfoot has a large variability amongst the various foot regions as it is one of the regions that's loaded the least (Gurney, Kersting & Rosenbaum, 2008). In addition, Cousins, Morrison and Drechsler (2012) reported that the foot region toes 2-5 and the midfoot region showed the greatest variability amongst the various foot regions in their investigation (Cousins, Morrison & Drechsler, 2012). It was suggested that the auto-masking of the midfoot may not represent the medial midfoot to its best ability therefore researchers should choose appropriate mapping regions (Gurney, Kersting & Rosenbaum, 2008).

In summary, it was decided that the best protocol to use for this investigation was the two-step method. The two-step method requires the children to strike the pressure platform with their second foot step as they walk over the walkway. This two-step method is an easy method that can be performed by children since they strike the pressure platform with a greater consistency and without performing many additional trials (Dowling, Steele & Baur, 2004; Bus & Lange, 2005). In addition, the 2-5 toes region was excluded in this study and it was decided that the midfoot region should not be split into medial and lateral regions because the medial midfoot is known for its great variability. A total of nine regions were selected for this study namely the hallux, metatarsal head one (MH1), metatarsal head two (MH2), metatarsal head three (MH3), metatarsal head four (MH4), metatarsal head five (MH5), midfoot (MF), medial hindfoot (MHF) and lateral hindfoot (LHF). These nine regions are demonstrated in Figure 2.

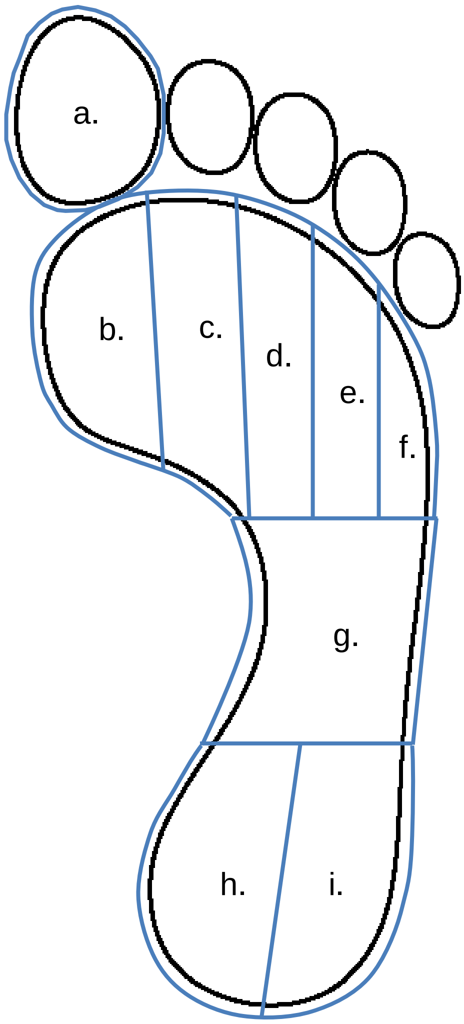

Figure 2: Demonstration of foot regions: a = hallux; b = MH1; c = MH2; d = MH3; e = MH4; f = MH5; g = MF; h = MHF and i = LHF.

FACTORS INFLUENCING PLANTAR LOADING

Plantar pressure loading is influenced through a number of factors such as the individual's foot posture, anatomical structure of the foot, walking speed, joint range of motion and body weight (Periyasamy et al., 2012; Butterworth et al., 2015). Some of the major factors influencing plantar loading will be discussed within this section.

Body weight

An indirect and common method used to determine additional body weight as a result of additional fat mass is by calculating the individual's BMI, which can classify them as being overweight or obese (Teh et al., 2006; Rossouw, Grant & Viljoen, 2012).

Children between the ages of 10 to 13 years old were selected for this study to minimise the misclassification of children being obese by their BMI status, particularly in athletic boys who are going through puberty because boys have a tendency to gain fat free mass during puberty (Lundeen et al., 2016). Rugby is a common competitive sport played by boys in South Africa during secondary education. The boys that play rugby in secondary schools are athletic built. However, it is known that BMI is not the best tool to assess relative fat mass of individuals that are athletic built, particularly rugby players (King, Hills & Blundell, 2005). Rugby players have high body weight but lean fat free mass and according to the BMI cut-off values, they will be incorrectly classified as overweight or obese (King, Hills & Blundell, 2005). The use of BMI is limited on athletes as their muscle mass can be mistaken for fat mass, therefore placing them in an overweight category (Teh et al., 2006). The greatest occurrence of obesity in girls are found between the ages of 11-12 years during puberty which falls within this study's age range of 10 to 13 years (Lundeen et al., 2016). Therefore, one can be assured that girls that are classified as obese within this age range by BMI cut-off values will most likely carry additional body weight because of increased fat-mass and the probability of misclassifying them as obese will be low.

Recent evidence suggests that additional body weight is a key factor that influences the plantar loading of the foot (Butterworth et al., 2015). It is believed that the additional body weight particularly of obese individuals are responsible for increasing the plantar loading of individuals' feet. A recent study done on adults revealed that a weight loss intervention caused a reduction of plantar loading within certain regions of the foot and that weight loss did not cause structural changes to the foot (Song et al., 2015). However, they found a linear correlation with the reduction of peak pressure and reduction of body weight in the MH2, MH3 and medial MF regions.

Walking speed

Changes in walking velocity has been associated with obese individuals (Butterworth et al., 2015). A recent study found that healthy weight children walked significantly faster than obese children between the ages of 8 and 12 years (Shultz et al., 2014). Children's walking speed increases with age and it is believed that this increased walking speed may be a contributing factor for increasing the plantar loading of children during growth (Phethean & Nester, 2012). No studies to date have investigated the influence of various walking speeds on the plantar loading of children. A few studies investigating the influence of walking speed on plantar loading of adults discovered that greater walking speeds resulted greater plantar loading (Burnfield et al., 2004; Taylor, Menz & Keenan, 2004). Taylor, Menz and Keenan (2004) investigated how varying walking speeds of adults influenced their plantar loading. Their results revealed that greater walking speeds resulted in higher maximum force, PP values and decreased PTI and FTI values for most regions of the foot (Taylor, Menz & Keenan, 2004). Therefore, it is important to adjust the plantar loading by the total contact time (as a measure of walking speed) in this study to account for various changes in walking speed between the children.

Foot structure

Literature supports the fact that children may have developed their major foot structures by the age of six to seven years which depicts the foot of an adult and continue to develop their gait until they are 13 years old (Cousins, Morrison & Drechsler, 2012). It was concluded in recent research that foot structure indirectly influences the plantar loading of feet (Butterworth et al., 2015). In a study done by Jiménez-Ormeño et al. (2013) concluded that the body weight of children influenced their foot structure as they found significant differences in foot structure between healthy weight, overweight and obese children but could not confirm whether additional fat mass or changes to the bony structures caused the differences in foot structure between the weight categories.

Gender

Differences in plantar loading have been noticed between genders of various ages in previous research. A longitudinal study done by Bosch, Gerß and Rosenbaum (2010), on children from the approximate age of 14 months till the approximate age of 9 years old found that there were gender differences between boys and girls. However, they found that boys tend to have a wider MF region throughout the study and a lower longitudinal arch than girls. Contrary to these results, Phethean and Nester (2012) investigated children aged 4 to 7 years old for gender differences and found that there was no significant difference between genders for plantar pressure data that was recorded. It was suggested that significant gender differences may only exist in children during the initial development phase (more or less before the age of 4 years old) of their walking gait (Phethean & Nester, 2012).

Plantar loading differences were also noted between genders amongst adults. It was noted that men tend to generate greater plantar forces with their feet possibly because they have stiffer arches than women and disperse the plantar forces less than in women (Griffiths et al., 2013). For instance, males tend to have significantly greater contact area in all regions of the foot and greater force-time integral in MH1, MH3 and MH4 regions but no significant difference for peak pressure or pressure-time integral were found between adult male and females (Putti, Arnold & Abboud, 2010). Although greater contact areas and force-time integral values were found in men, one can speculate whether the larger contact areas were sufficient enough to disperse the peak pressure and pressure-time integral values (pressure variables) during plantar loading so that no significant difference was found in the pressure variables between male and females.

In summary, researchers are faced with the challenge of selecting the appropriate plantar loading protocol and pressure system as well as being faced with numerous factors that can influence the plantar loading of individuals. However, factors such as body weight, walking speed and foot structure may influence the plantar loading of the children selected for this study to some degree but body weight may be the greatest factor influencing the plantar loading. As Butterworth et al. (2015) discovered that body weight is one of the primary factors influencing plantar loading of individuals that are overweight or obese and that foot structure serves as a secondary factor for influencing the plantar loading.

WEIGHT CATEGORIES AND PLANTAR LOADING

Plantar loading assessments through various pressure systems are extensively used in clinical and research backgrounds to evaluate foot structure and plantar loading of individuals (Tong & Kong, 2013). Through research, various studies have been done on young children and adults (Mickle, Steele & Munro, 2006; Bosch, Gerß & Rosenbaum, 2010; Phethean & Nester, 2012; Wearing et al., 2012; Butterworth et al., 2015). A few studies investigating the plantar loading of healthy weight and overweight children used various methods to determine the weight categories of children (Yan et al., 2013; da Rocha et al., 2014; Riddiford-Harland, Steele, Cliff, Okely, Morgan & Baur, 2014; Mueller et al., 2016). This raises various challenges within the research setting as the determination of weight categories of children are inconsistent. Furthermore, this raises the question of whether one can compare plantar loading results of studies that implemented different methods to determine the weight categories. One of the major challenges of this study was to determine the best method to utilise to determine the weight categories of the children. The determination of weight categories will be discussed within the following section followed by the overview of literature investigating the plantar loading differences between healthy weight and overweight adults and children.

DETERMINATION OF WEIGHT CATEGORIES

Many studies reporting on plantar loading of overweight or obese individuals use various methods to determine their weight category. The most common method used is the BMI cut-off values, as it is cost-effective and an easy method to use (de Onis & Lobstein, 2010). The downfall of using BMI cut-off values is that it does not discern the amount of fat mass or fat free mass an individual has (King, Hills & Blundell, 2005). Other methods that are seldom used are skin-folds and bioimpedence readings. The greatest challenge is selecting the most appropriate BMI cut-off values particularly for children. Some countries have established their own BMI cut-off values specific for their population (Yan et al., 2013; da Rocha et al., 2014; Mueller et al., 2016). However, to the knowledge of the researcher South Africa has no reliable children specific BMI cut-off values to date.

Adults are usually classified as overweight when their BMI is greater than 25kg/m^2 but smaller than 30kg/m^2 and classified as obese when their BMI score is greater than 30kg/m^2. During childhood BMI changes as they become older and it is important to have age related cut-off points to determine whether children fall within certain weight category such as overweight or obese. Children can be classified into a weight category by their z scores that are developed by converting BMI scores of a dataset (population) into a z score from centile curves (Cole et al., 2000) or by BMI age related cut-off values. One of the challenges of this investigation was facing the lack of well-established BMI cut-off values for the South African children.

There are two well know sources for international BMI weight category standards. Firstly, the standards produced by the World Health Organisation (WHO) and secondly from the International Obesity Task Force (IOTF). To the knowledge of the researcher the IOTF BMI standards includes a larger variation of the world's population compared to the WHO. Therefore, in order to comply to the objectives of this study it was decided that the best BMI cut-off values to utilise for the current study were the International Obesity Task Force (IOTF) cut-off values produced by Cole and Lobstein (2012) since South Africa has no reliable BMI cut-off values for children. Refer to Table 1 for the BMI cut-off values. In addition, the IOTF international standards would be the best for this study as the plantar loading of South African children were compared to the plantar loading of German children.

Table 1: BMI cut-off values for healthy weight, overweight, obese and morbid obese children adapted from Cole and Lobstein (2012).

Age (years)	Female BMI (kg/m^2) cut-off values				Male BMI (kg/m^2) cut-off values			
	Healthy	Overweight	Obese	Morbid Obese	Healthy	Overweight	Obese	Morbid Obese
10	14.58	19.78	23.97	28.36	14.63	19.80	23.96	28.35
10 ½	14.78	20.21	24.62	29.28	14.79	20.15	24.54	29.22
11	15.03	20.66	25.25	30.14	14.96	20.51	25.07	29.97
11 ½	15.30	21.12	25.87	30.93	15.15	20.85	25.56	30.63
12	15.59	21.59	26.47	31.66	15.36	21.20	26.02	31.21
12 ½	15.91	22.05	27.04	32.33	15.59	21.54	26.45	31.73
13	16.23	22.49	27.57	32.91	15.84	21.89	26.87	32.19
13 ½	16.55	22.90	28.03	33.39	16.11	22.25	27.26	32.61

PLANTAR LOADING IN ADULTS

Most studies investigating the differences in plantar loading between healthy weight and overweight individuals were performed on adults and only a few studies have investigated the differences of plantar loading between healthy and overweight children.

More than a decade ago Hills et al. (2001) discovered that obese adults produce greater plantar loading than non-obese adults particularly in the heel, mid-foot and forefoot regions. In addition, the obese adults had greater contact area of the midfoot region compared to the non-obese adults.

Recent research has found that obese adults have a significantly larger contact area of the midfoot region and total foot region than the healthy weight adults with the adjustment for contact time. The obese adults produced greater maximum force and peak pressure values for entire foot, hindfoot, midfoot, forefoot and hallux regions than the healthy weight adults (Butterworth et al., 2015).

It was recently found that body weight is an independent factor predicting the PP loading in the hallux, toes 2-5, forefoot, midfoot and hindfoot regions with adults (Butterworth et al., 2015). Butterworth et al. (2015) concluded that the primary factor influencing the plantar loading was body weight and the secondary factor was most likely the of foot structure differences. Therefore, body weight influences the plantar loading directly and foot structure differences influence the plantar loading indirectly (Butterworth et al., 2015).

An intervention study performed on adults over a six-month period investigated the influence of weight loss on the foot structure and plantar loading of adults. The intervention consisted of a treatment group which received a weight loss program for the full duration of the intervention and delayed weight loss group received a weight loss program for the last three months of the intervention program. Although significant reduction of body weight was found, no structural foot changes were present after three and six months of the intervention. Therefore, it was suggested that the weight loss was not sufficient to cause structural foot changes. After 3 months, the treatment group had significantly reduced PP of MH4 and lateral MF region. After 6 months, the weight loss categories revealed significant reduction of PP particularly in MH2, MH3, medial MF, lateral MF and MHF. Further analysis of the results revealed that the reduction of PP correlated linearly with the reduction of body weight particularly in MH2, MH3 and medial MF regions (Song et al., 2015). In other words, weight loss had the greatest effect on peak pressure within these regions of the foot.

Wearing et al. (2012) found that the appearance of a "flatter foot" was a result of a greater contact area occupied by the midfoot region of a foot print and this "flatter foot" appearance was most likely caused by additional fat tissue within the midfoot region of obese adults. In addition, they concluded that the additional body weight of obese adults does not affect the foot structure of the medial longitudinal arch. Therefore, the medial longitudinal arch height of obese individuals can be misrepresented by their plantar foot print (Wearing et al., 2012).

PLANTAR LOADING IN CHILDREN

Most plantar loading studies carried out on children investigated the plantar loading differences of various age groups in order to provide more information about the child's gait (Bosch, Gerß & Rosenbaum, 2010; Müller et al., 2012; Jiménez-Ormeño et al., 2013) or investigate the plantar loading differences between weight categories to determine whether body weight and foot structure influence plantar loading (Dowling, Steele & Baur, 2004; Cousins, Morrison & Drechsler, 2013; Yan et al., 2013; Mueller et al., 2016).

Significant differences in plantar loading between healthy weight and overweight children were found more than a decade ago in a study by Dowling, Steele and Baur (2004). The children were matched per gender, age, and height (6 to 12 years old healthy and obese children). All the children walked at the same speed and were not given the option to walk at their natural self-selected speed. The results revealed that the obese children had greater contact area for all the regions of the foot except the hallux region; greater peak pressure for medial MF, lateral MF, MH2, MH3, MH4 and MH5 regions; greater force-time integral for MHF, LHF, central forefoot and lateral forefoot regions; greater pressure-time integral for LHF, MF and lateral forefoot regions during walking. Therefore, obese children generated greater plantar loading in the forefoot, midfoot and heel region as a result of their additional body weight they carry and this additional body weight does not affect the planar loading of the toe regions. They proposed that obese children are at greater risk for bony fatigue because of the higher FTI found in the heel, MF and metatarsal heads region (particularly the lateral forefoot region) of the foot and the obese children are at risk for soft tissue damage because of the greater PTI found particularly in the lateral forefoot and MHF region.

The greater area of the midfoot region may result from the greater fat pad (fat tissue) available in the midfoot region compared to the healthy children. They mentioned that this additional fat pad in obese children can be an adaptation to help aid with decreasing the higher plantar loading of the foot in obese children or simply that the additional fat pad size has no significant function in obese children. It was also suggested that the increased contact area of the MF region of obese children may also represent a change in the actual foot structure such as a decreased medial longitudinal arch of the foot (Dowling, Steele & Baur, 2004). Therefore, it is important to include more direct ways to determine whether the increased midfoot contact area is a result of changes to the actual foot structure (collapsed arch) or the additional fat tissue in the MF region of overweight children.

A recent study by Cousins, Morrison and Drechsler (2013), found similar plantar loading results between healthy weight and obese children of similar age as Dowling, Steele and Baur (2004). Their results revealed that the overweight children had significantly higher peak pressure in the MF and metatarsal heads 2-5 (MH2-5) region and the obese children had significantly higher peak pressure in the MHF, MF and MH2-5 regions than the healthy weight children (Cousins, Morrison & Drechsler, 2013). The overweight children had higher pressure-time integral and force-time integral values in MF and MH2-5 regions and the obese children had higher pressure-time integral and force-time integral values in LHF, MHF, MF and MH2-5 regions than the healthy weight children. Interestingly, there were no significant differences of PTI and FTI within the hindfoot region between the overweight children and healthy weight children. However, the two studies utilised different pressure systems, protocols and weight categories.

A study done children (Yan et al., 2013), between the ages of 7 to 12 years old, in Beijing discovered that obese children had greater peak pressures of the MH2-5 region, MF and LHF in agreement with the results found by Dowling, Steele and Baur (2004) and Cousins, Morrison and Drechsler (2013).

In a study by Mauch et al. (2008), they investigated how body weight, by means of BMI, could possibly influence the prevalence of children's different foot types by analysing their feet with a 3D foot-scanner. Mauch et al. (2008), classified the children into three weight categories, further subdividing the group according to their BMI value, foot type and age. The children were divided into five different foot type classifications namely: flat, robust, slender, short and long feet. The foot type that was presented the most within each weight category was determined. Significant differences in the number of foot classifications according to the children's weight category were found. The results revealed that the number of each foot type was more or less equally distributed amongst the healthy weight category. Within the overweight category the most common foot type found was flat foot and robust feet and the underweight category had slender and long feet. Although higher numbers of flatter and robust feet were found in the overweight category of their study, there was a lack of knowledge of what causes the higher numbers of flat feet type amongst the overweight category of children. Whether the flatter feet are a result of the excess body weight that influences the medial longitudinal arch or is it a result of additional fat tissue within the medial longitudinal arch that results in the flat foot appearance.

However, a study was done on children to determine whether overweight children had flat feet as a result of additional fat mass within the medial longitudinal arch or whether it was a result of structural changes of the foot's medial longitudinal arch. This study by Riddiford-Harland, Steele and Baur (2011), used ultrasonography which provided more direct measures of whether there was additional fat tissue within the medial longitudinal arch or the structure of the medial longitudinal arch was lower. The results revealed that overweight children had significantly more fat mass within the medial longitudinal arch and the medial longitudinal arch was structurally lower than the healthy weight children (Riddiford-Harland, Steele & Baur, 2011). Therefore they concluded that overweight children's flatter feet in their study was a result of a combination of additional fat mass in the medial longitudinal arch and a structurally lowered medial longitudinal arch.

A recent study investigated the plantar loading differences of German children between the ages of 1 to 12 years old of varying weight categories (Mueller et al., 2016). The overweight and obese children had significantly higher PP and FTI loading than the heathy weight children for most regions of the foot (when one refers to the children between the ages of 10 to 12 years old in their study). In addition, the overweight and obese children had greater CA of the foot compared to the heathy weight children.

Contradictions between studies exist which create additional challenges for interpreting results of various studies. A study done on young children between the ages of 2.9 to 5 years old, investigated how overweight or obesity can possibly influence the plantar loading of these children (Mickle, Steele & Munro, 2006). Their results revealed that overweight children had statistical significantly higher CA for all regions of the foot except the toes 2-5 region and PP, PTI and FTI for the MF region. They came to the conclusion that overweight children are at greater risk for soft tissue damage and bony fatigue within the MF region (Mickle, Steele & Munro, 2006). Interestingly, the midfoot region was one of least loaded regions relative to the other foot regions of the overweight children's' feet. This raises the question of whether the regions that are loaded the most are at a greater risk for soft tissue damage and bony fatigue or only where significant plantar loading differences are found. These assumptions are contradictory to the results found by Dowling, Steele and Baur (2004) as they mention that the regions with the highest PTI and FTI values are at the greatest risk for soft tissue damage and bony fatigue particularly with overweight individuals. Their results reveal that the overweight children are at greater risk for soft tissue damage of the lateral heel and lateral forefoot region (high PTI values) and are at greater risk for bony fatigue within the lateral forefoot region (high FTI values) (Dowling, Steele & Baur, 2004).

Research reveals similar plantar loading differences amongst children and adults of various weight categories but there are slight variations within the results found between these studies. It is unknown whether these variations in the results of these studies are from the variations found within the protocols used, the target population or the numerous factors influencing the plantar loading directly or indirectly. To date, no studies have investigated the plantar loading differences between weight categories in South African children or investigated the plantar loading differences between two countries by utilising the same pressure system and plantar loading protocol. Therefore, this will be the first study investigating the plantar loading differences between healthy weight and overweight children from South Africa and the first study to compare the plantar loading of German children to South African children of the same weight category.

CHAPTER THREE

ARTICLE ONE

Plantar foot loading patterns between healthy weight and overweight children aged 10 to 13 years from the Western Cape

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Key words:

Body Mass Index, Children, Pressure, Emed, Foot Loading

Abstract

This study investigated the plantar loading differences between healthy weight and overweight category of children from South Africa. Plantar loading measurements were obtained from 178 children (mean age 12.3 ± 1.2 years; body weight 49.2 ± 12.2kg; height 1.56 ± 0.01m; n = 178 of which 87 were girls and 91 boys) with the Emed n50 pressure platform using the two-step method at a self-selected walking speed. Peak pressure, pressure-time integral, force-time integral and contact area variables were investigated for nine regions of the foot. The overweight category of children had statistically significantly higher peak pressure, pressure-time integral, force-time integral and contact area for most of the foot regions in the basic model and basic model adjusted for total contact time. However, statistical significantly higher peak pressure, pressure-time integral, force-time integral and contact area were only found in the midfoot region in the basic model adjusted for total contact time and body weight. Body weight is a primary factor influencing plantar loading values of overweight children. It is possible that the significant differences found in the midfoot region of the overweight children is not influenced by body weight but possibly by structural foot differences such as additional fat mass of the medial longitudinal arch or structurally lowered medial longitudinal arch of the foot.

Introduction

Excessive plantar loading (peak pressures) can possibly cause deterioration of the soft tissue such as the fat pads in the foot during locomotion [1]. This can increase the risk for developing foot pathologies in adults and children [2]. It is possible that foot pain experienced by overweight individuals results from the higher mechanical loading of their feet because of the additional body weight they carry [3].

During locomotion, the feet of an individual plays a vital role in the body's kinetic chain as it serves as a base of support [1,2]. The longitudinal arch of the foot plays a key role in absorbing and distributing the high ground reaction forces [4]. It is estimated that the ground reaction forces experienced by the lower limbs of a healthy weight individual can be as large as three to six times their own body weight [5]. The ligaments and muscles within this arch provide support for maintaining the arch as it mimics an elastic band that stores energy as it is stretched and releases the energy as it returns to its original state, therefore assisting with propulsion of the body during locomotion [4]. Overloading the ligaments and soft tissue within the arch may cause the arch to lose its elastic properties causing damage to the ligaments and soft tissue, ultimately leading to possible foot pathologies [4]. Therefore, the assessment of plantar loading can provide valuable clinical information about the management of individuals that are at risk of developing foot pathologies [6]. Plantar loading is a term used to refer to the vertical ground reaction forces exerted on the plantar surface of the foot during stance or walking. Plantar loading can be measured through pressure platforms. The pressure platforms can also provide information about individuals' foot print and it is assumed that a flat foot appearance is caused by a lower medial longitudinal arch or by additional fat tissue within the midfoot region [7].

It is believed that the force during dynamic movement provides more information about the loading of the actual foot structure whereas the pressure provides more information on the loading of the soft tissues [1]. Pressure-time integral and force-time integral tells one more about the magnitude of the pressure or force of the foot over a period time [8]. The greater the force-time integral, the higher the risk for bony fatigue on a particular region of the foot and the greater the pressure-time integral, the greater the risk for soft tissue damage [1,9]. Assessing children's plantar loading may be a challenging task which requires the assessor to consider a few factors prior to testing [10]. Plantar pressure loading is influenced by several factors such as the individuals' foot posture, anatomical structure of the foot, walking speed, joint range of motion and body weight [3,6]. Recent evidence suggests that additional body weight is a key factor that influences the plantar loading [3]. It is believed that the additional body weight particularly of obese individuals are responsible for increasing the plantar loading of individuals.

The majority of studies investigating the plantar loading differences between healthy weight and overweight individuals were performed done on adults and only a few studies have investigated the differences of plantar loading between healthy and overweight children. Dowling, Steele and Baur [9] revealed that the obese children had greater contact area, peak pressure, force-time integral and pressure-time integral than healthy weight children during walking. Similar plantar loading results were found by Cousins, Morrison and Drechsler [11] and Yan et al. [2]. Butterworth et al. [3] concluded that the primary factor influencing the plantar loading of adults were body weight and the secondary factor was most likely from foot structure differences. Increased contact area of the midfoot region in obese children may represent a change in the actual foot structure such a decreased medial longitudinal arch of the foot [9]. Riddiford-Harland, Steele and Baur [7] revealed that overweight children had a combination of structurally lower medial longitudinal arch and additional fat mass within the medial longitudinal arch than the healthy weight children. Therefore, the body weight influences the plantar loading directly and the changes of the foot structure influences the plantar loading indirectly [3].

The primary aim of this study was to evaluate the plantar loading patterns of the foot between the healthy weight and the overweight category of children from South Africa. In doing so, the primary objective was to determine if there were significant differences in the plantar loading between the various plantar foot regions of the healthy weight and the overweight category of children. This will be one of the first studies to investigate the plantar loading differences between heathy and overweight children from South African children. It was hypothesised that the overweight category of children will generate greater plantar loading than the healthy weight children.

Methods

Participants

One hundred and seventy-eight children aged 10 to 13 years (mean age 12.3 ± 1.2 years; body weight 49.2 ± 12.2kg; height 1.56 ± 0.01m; n = 178 of which 87 were girls and 91 boys) from four schools that were randomly stratified from five regions of the Western Cape volunteered to participate in this study. This study formed part of the Barefoot LIFE project [12]. The participants were divided into two categories namely the healthy weight category (body weight 44.7 ± 8.3kg; height 1.55 ± 0.10m; n = 128 of which 66 were girls and 62 boys) and the overweight category (body weight 60.8 ± 13.1kg; height 1.55 ± 0.09m; n = 50 of which 21 were girls and 29 boys) based on their body mass index (BMI). Throughout this paper, the term overweight category will be used to refer to all the children that either fall within the overweight, obese or morbid obese according to their BMI [13].

Ethical clearance was granted by the Western Cape Education Department (South Africa) under the study: Moving feet – a comparative study of children between habitually barefoot and shod school-aged children. Ethical clearance was granted at Stellenbosch University through the Research Ethics Committee (proposal number: HS1153/2014): Human Research Ethics Committee (HUMANIORA).

Participants were included in the study if they were between the ages of 10 to 13 years old, provided assent, signed consent forms from their parents or guardians and verbal consent. All personal information obtained from the voluntary participants and their parents or guardians were kept confidential by providing each participant with a participant number. Participants were excluded from this study if they were classified as being underweight, had foot abnormalities (e.g. missing toes), abnormal walking gait, pain or injury of the lower limbs. Participants were also excluded if incomplete data was captured in the database.

Height and Weight

Height was obtained with a portable stadiometer (Charder HM200P Portstad portable stadiometer, Stuttgart, Germany) to the nearest 0.1 centimetre (cm). The weight of the participants were measured with an electronic scale (A & D personal precision UC-321 scale, A & D Medical, Tokyo, Japan) to the nearest 0.05 kilogram (kg). The BMI was calculated using the $\frac{\text{weight}}{\text{height}^2}$ formula (weight in kilograms and height in meters) for each participant to determine their weight category according to the International Obesity Task Force (IOTF) cut-off values [13,14].

Dynamic measurements

The plantar loading of the foot was obtained with the Emed n50 pressure platform (NovelGmbH, Munich, Germany) during a self-selected walking speed and the data was processed using Novel Database Pro M software (Version 24.3.20, NovelGmbH, Munich, Germany). The pressure platform was built into a portable chip-board wooden walkway (61cm wide and 480cm in length) which has 6080 sensors within a 47,5 x 32 cm area (4 sensors/cm^2). The pressure platform was positioned in the middle and flush within the walkway. It was decided that the best protocol to use for this investigation was the two-step method. The two-step method required the participants to strike the pressure platform with their second foot step as they continued walking over the walkway. This two-step method is an easy method that can be performed by children since they strike the pressure platform with a greater consistency and without performing many additional trials [9,15]. The participants continued to walk over the pressure platform while looking straight ahead of them until three valid trials were captured bilaterally. The average of the three trials were calculated for each foot. Trials were excluded if the second foot step did not strike the pressure platform, abnormal gait was visually seen and if the participant did not look straight ahead of them.

The plantar surface of the foot was divided into 9 regions namely (demonstrated in Figure 1): hallux, metatarsal head 1 (MH1), metatarsal head 2 (MH2), metatarsal head 3 (MH3), metatarsal head 4 (MH4), metatarsal head 5 (MH5), midfoot (MF), medial hindfoot (MHF) and the lateral hindfoot (LHF) using Novel-ortho automask software (NovelGmbH, Munich, Germany). It was decided that it would be the best to exclude the region toes 2-5 in this study as it was proven that this region was unreliable amongst children between the ages of seven to eleven years old [10]. The medial midfoot has a large variability amongst the various foot regions as it is one of the regions that is loaded the least [16]. It was suggested that the auto-masking of the midfoot may not represent the medial midfoot to its best ability, therefore researchers should choose an appropriate mask [16]. For this current study, it was decided that the midfoot region should not be split into medial and lateral regions with the acknowledgement of the medial midfoot region having the greatest variability. Contact area (CA; cm^2), peak pressure (PP; kPa) and force-time integral (FTI; N•s) measures were captured for each foot region and the total contact time (CT; ms) as a substitute measure for walking speed.

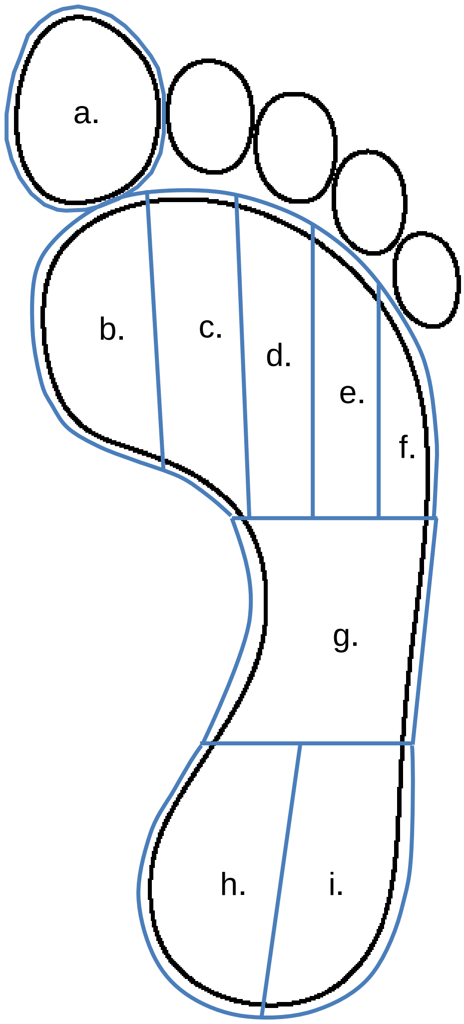

Figure 1. Demonstration of foot regions: a = hallux; b = MH1; c = MH2; d = MH3; e = MH4; f = MH5; g = MF; h = MHF and i = LHF.

Statistical analysis

The data captured through Novel Database Pro M software (Version 24.3.20, NovelGmbH, Munich, Germany) were exported into Microsoft Excel (2016, Washington, USA) where descriptive statistics, calculations for weight categories and pressure-time integral were processed using Microsoft Excel (2016, Washington, USA).

The pressure-time integral (PTI; N•s/cm^2) was calculated using the following formula:

$$\text{Pressure-time integral} = \frac{\text{Force-time integral}}{\text{Contact area}}$$

All variables were analysed for normality by using the skewness coefficient, where skewness greater than -1 and smaller than 1 was accepted as normally distributed (SPSS version 23.0, IBM Corporation, New York, USA). The variables that were not normally distributed were logarithmic transformed and re-assessed for normality.

Statistical analyses were performed using SPSS (Version 23.0, IBM Corporation, New York, USA). A mixed model linear regression was used to evaluate if the dynamic measurements differ between healthy weight category and overweight category of children. Both the left and right foot measures were used; therefore, the participant was added as a random effect to adjust for within participant correlations. Three models were developed namely: basic model, basic model adjusted for total CT and basic model adjusted for total CT and body weight. The ranking of maximum to minimum values of each variable for each foot region was processed using Microsoft Excel (2016, Washington, USA). Due to the evaluation of nine regions for every outcome, the level of significance was adjusted from $p = 0.05$ by using a Šidák correction to: $p = 0.0057$. The results of the logarithmic transformed variables were inversely log transformed to provide the final results.

Results

The results of this study found the following variables were normally distributed: PP for region LHF; PTI for regions MH1; MH2, MH3, MHF and LHF; CA for all regions and total CT. All logarithmic transformed variables were normally distributed. Mean total CT for South African children for the left foot = 689,12 ± 84,73ms and the right foot = 684,12 ± 84,73ms. Furthermore, this section will highlight the significant plantar loading differences between the healthy weight and overweight category of children.

Peak pressure

In the basic model the overweight category had statistical significantly higher PP values for the MH1, MH2, MH3, MH4, MH5 and MF regions. In the basic model adjusted for CT the overweight category had statistical significantly higher PP values for all the regions of the foot except the hallux and LHF region (refer to Table 1).

Pressure time integral and force time integral

In the basic model and basic model adjusted for total CT the overweight category had statistical significantly higher PTI and FTI values for all the regions of the foot except for the hallux region (refer to Table 2 and 3). In the basic model the greatest PTI values were found in MH2 region followed by MH3 region for both weight categories. The greatest PTI values were found in the MHF region in the basic model adjusted for total CT and the MH4 region in the basic model adjusted for total CT and body weight for both weight categories. Within all three models the FTI values were the greatest in the MHF region followed by the LHF region for both weight categories.

Contact area

The overweight category had statistical significantly higher CA values for all the regions of the foot in the basic model and the basic model adjusted for total CT. The greatest CA was found in the midfoot region for heathy weight and overweight category of children with the basic model (refer to Table 4).

Once the adjustment for total CT and body weight was carried out on the basic model, the overweight category had statistical significantly higher PP, PTI, FTI and CA within the MF region.

Table 1: Peak pressure differences between healthy weight and overweight category of children aged 10 to 13 years from South Africa.

Peak Pressure		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (kPA)	(95% CI)	p	mean (kPA)	(95% CI)	p	mean (kPA)	(95% CI)	p
Hallux	healthy	288,82	(258,98 - 322,10)		294,90	(264,25 - 329,10)		234,87	(205,63 - 268,26)	
	overweight	288,02	(262,58 - 315,92)	0,960	294,24	(194,69 - 444,70)	0,968	194,75	(125,57 - 302,04)	0,006
MH1	healthy	175,29	(160,70 - 191,21)		287,03	(263,31 - 312,89)		218,95	(198,04 - 242,07)	
	overweight	199,80	(185,60 - 215,08)	0,003*	331,59	(239,67 - 458,77)	0,001*	202,96	(145,71 - 282,70)	0,138
MH2	healthy	217,13	(203,26 - 231,95)		334,66	(313,53 - 357,21)		242,25	(226,57 - 259,03)	
	overweight	278,22	(263,07 - 294,24)	0,000*	433,91	(339,47 - 554,62)	0,000*	241,52	(193,63 - 301,25)	0,929
MH3	healthy	213,76	(200,73 - 227,64)		299,92	(281,74 - 319,27)		222,79	(208,69 - 237,84)	
	overweight	274,71	(260,44 - 289,77)	0,000*	389,02	(307,46 - 492,21)	0,000*	226,91	(182,87 - 281,56)	0,582
MH4	healthy	157,10	(146,92 - 167,99)		163,76	(153,09 - 175,18)		128,74	(119,23 - 139,00)	
	overweight	208,68	(197,16 - 220,88)	0,000*	217,77	(168,98 - 280,66)	0,000*	140,77	(109,28 - 181,33)	0,023
MH5	healthy	124,88	(111,20 - 140,25)		72,26	(64,36 - 81,11)		55,49	(48,28 - 63,78)	
	overweight	155,31	(140,75 - 171,37)	0,000*	88,53	(57,29 - 136,81)	0,001*	54,86	(34,64 - 86,86)	0,871
MF	healthy	74,35	(69,15 - 79,93)		74,73	(69,48 - 80,37)		62,72	(57,47 - 68,44)	
	overweight	110,12	(103,56 - 117,09)	0,000*	110,70	(84,16 - 145,62)	0,000*	80,57	(60,39 - 107,49)	0,000*
MHF	healthy	265,88	(247,44 - 285,69)		519,92	(484,97 - 557,39)		459,62	(422,18 - 500,40)	
	overweight	288,08	(271,05 - 306,19)	0,029	573,76	(441,56 - 745,54)	0,006*	458,84	(346,59 - 607,44)	0,968
LHF	healthy	252,73	(236,19 - 269,27)		414,22	(398,27 - 430,17)		383,98	(364,56 - 403,40)	
	overweight	269,14	(255,11 - 283,16)	0,052	435,04	(375,00 - 495,07)	0,011	380,21	(316,09 - 444,32)	0,703

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the healthy weight and overweight category ($p < 0.0057$).

Table 2: Pressure-time integral differences between the healthy weight category and overweight category of children aged 10 to 13 years from South Africa.

Pressure-Time Integral		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (N•s/cm²)	(95% CI)	p	mean (N•s/cm²)	(95% CI)	p	mean (N•s/cm²)	(95% CI)	p
Hallux	healthy	2,00	(1,82 - 2,20)		0,46	(0,42 - 0,50)		0,40	(0,36 - 0,44)	
	overweight	2,13	(1,97 - 2,31)	0,193	0,47	(0,34 - 0,64)	0,603	0,36	(0,26 - 0,51)	0,085
MH1	healthy	2,48	(2,28 - 2,67)		0,07	(-0,11 - 0,25)		-0,42	(-0,63 - -0,20)	
	overweight	2,85	(2,68 - 3,01)	0,000*	0,38	(-0,31 - 1,06)	0,001*	-0,51	(-1,23 - 0,20)	0,396
MH2	healthy	3,20	(2,99 - 3,40)		0,48	(0,29 - 0,67)		-0,42	(-0,62 - -0,22)	
	overweight	3,83	(3,66 - 4,00)	0,000*	1,04	(0,32 - 1,76)	0,000*	-0,59	(-1,25 - 0,07)	0,090
MH3	healthy	3,02	(2,82 - 3,22)		0,17	(-0,01 - 0,36)		-0,70	(-0,89 - -0,50)	
	overweight	3,80	(3,62 - 3,97)	0,000*	0,87	(0,17 - 1,57)	0,000*	-0,70	(-1,35 - -0,05)	0,937
MH4	healthy	2,24	(2,07 - 2,42)		0,75	(0,70 - 0,81)		0,59	(0,54 - 0,64)	
	overweight	3,01	(2,82 - 3,21)	0,000*	0,98	(0,76 - 1,28)	0,000*	0,63	(0,49 - 0,82)	0,103
MH5	healthy	1,60	(1,44 - 1,78)		0,41	(0,37 - 0,45)		0,31	(0,27 - 0,34)	
	overweight	2,11	(1,93 - 2,30)	0,000*	0,52	(0,36 - 0,76)	0,000*	0,31	(0,21 - 0,45)	0,982
MF	healthy	0,73	(0,67 - 0,80)		0,23	(0,21 - 0,25)		0,18	(0,17 - 0,20)	
	overweight	1,15	(1,06 - 1,25)	0,000*	0,36	(0,25 - 0,50)	0,000*	0,23	(0,16 - 0,33)	0,000*
MHF	healthy	2,93	(2,75 - 3,11)		1,00	(0,83 - 1,16)		0,51	(0,31 - 0,71)	
	overweight	3,40	(3,25 - 3,55)	0,000*	1,41	(0,78 - 2,05)	0,000*	0,54	(-0,12 - 1,19)	0,803
LHF	healthy	2,43	(2,29 - 2,57)		0,56	(0,43 - 0,69)		0,15	(0,00 - 0,30)	
	overweight	2,83	(2,71 - 2,95)	0,000*	0,90	(0,41 - 1,40)	0,000*	0,16	(-0,35 - 0,67)	0,911

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the healthy weight and overweight category ($p < 0.0057$).

Table 3: Force-time integral differences between the healthy weight category and overweight category of children aged 10 to 13 years from South Africa.

Force-Time Integral		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (N•s)	(95% CI)	p	mean (N•s)	(95% CI)	p	mean (N•s)	(95% CI)	p
Hallux	healthy	16,10	(14,17 - 18,29)		1,33	(1,02 - 1,29)		1,36	(1,29 - 1,70)	
	overweight	18,40	(16,51 - 20,50)	0,040	1,25	(1,86 - 4,49)	0,157	1,26	(1,06 - 2,66)	0,026
MH1	healthy	24,01	(21,74 - 26,51)		7,18	(6,54 - 7,88)		4,94	(4,46 - 5,48)	
	overweight	31,07	(28,56 - 33,80)	0,000*	8,99	(6,32 - 12,77)	0,000*	4,57	(3,25 - 6,43)	0,138
MH2	healthy	24,78	(22,95 - 26,74)		7,69	(7,18 - 8,24)		5,05	(4,75 - 5,37)	
	overweight	34,57	(32,40 - 36,88)	0,000*	10,39	(8,02 - 13,46)	0,000*	4,85	(3,96 - 5,93)	0,186
MH3	healthy	26,52	(24,57 - 28,63)		7,42	(6,93 - 7,93)		4,88	(4,60 - 5,17)	
	overweight	38,55	(36,13 - 41,14)	0,000*	10,41	(8,08 - 13,42)	0,000*	4,87	(4,01 - 5,91)	0,946
MH4	healthy	17,89	(16,37 - 19,54)		4,64	(4,28 - 5,02)		3,18	(2,93 - 3,46)	
	overweight	26,36	(24,46 - 28,41)	0,000*	6,58	(4,88 - 8,89)	0,000*	3,33	(2,53 - 4,39)	0,287
MH5	healthy	7,63	(6,72 - 8,65)		1,44	(1,28 - 1,62)		0,91	(0,80 - 1,04)	
	overweight	11,02	(9,90 - 12,27)	0,000*	1,99	(1,28 - 3,09)	0,000*	0,86	(0,56 - 1,33)	0,441
MF	healthy	8,38	(6,70 - 10,47)		1,19	(0,96 - 1,48)		0,72	(0,55 - 0,93)	
	overweight	22,71	(18,79 - 27,43)	0,000*	3,06	(1,35 - 6,93)	0,000*	1,22	(0,52 - 2,90)	0,000*
MHF	healthy	38,09	(35,63 - 40,72)		15,17	(14,26 - 16,13)		11,03	(10,37 - 11,73)	
	overweight	49,80	(47,06 - 52,70)	0,000*	19,33	(15,34 - 24,37)	0,000*	10,86	(8,85 - 13,31)	0,609
LHF	healthy	32,09	(30,07 - 34,25)		11,32	(10,68 - 12,00)		8,29	(7,83 - 8,77)	
	overweight	41,61	(39,37 - 43,97)	0,000*	14,26	(11,47 - 17,74)	0,000*	8,11	(6,72 - 9,78)	0,444

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the healthy weight and overweight category ($p < 0.0057$).

Table 4: Contact area differences between the healthy weight category and overweight category of children aged 10 to 13 years from South Africa.

Contact Area		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (cm²)	(95% CI)	p	mean (cm²)	(95% CI)	p	mean (cm²)	(95% CI)	p
Hallux	healthy	8,19	(7,82 - 8,56)		5,35	(4,99 - 5,71)		3,97	(3,57 - 4,38)	
	overweight	8,84	(8,52 - 9,15)	0,001*	5,92	(4,56 - 7,28)	0,002*	3,43	(2,09 - 4,77)	0,009
MH1	healthy	10,32	(9,95 - 10,69)		7,08	(6,72 - 7,44)		5,23	(4,86 - 5,60)	
	overweight	11,71	(11,39 - 12,02)	0,000*	8,38	(7,01 - 9,75)	0,000*	5,02	(3,81 - 6,23)	0,268
MH2	healthy	8,12	(7,83 - 8,40)		5,50	(5,22 - 5,77)		4,12	(3,84 - 4,40)	
	overweight	9,42	(9,18 - 9,66)	0,000*	6,73	(5,68 - 7,77)	0,000*	4,23	(3,29 - 5,17)	0,442
MH3	healthy	9,20	(8,86 - 9,53)		5,61	(5,29 - 5,93)		3,98	(3,65 - 4,30)	
	overweight	10,64	(10,36 - 10,93)	0,000*	6,95	(5,75 - 8,15)	0,000*	4,00	(2,93 - 5,07)	0,903
MH4	healthy	8,07	(7,81 - 8,32)		5,96	(5,71 - 6,20)		4,89	(4,63 - 5,16)	
	overweight	8,84	(8,62 - 9,05)	0,000*	6,67	(5,75 - 7,60)	0,000*	4,74	(3,86 - 5,62)	0,260
MH5	healthy	4,83	(4,65 - 5,02)		3,40	(3,22 - 3,58)		2,60	(2,41 - 2,80)	
	overweight	5,30	(5,14 - 5,46)	0,000*	3,83	(3,15 - 4,51)	0,000*	2,38	(1,73 - 3,03)	0,026
MF	healthy	13,93	(12,21 - 15,64)		3,46	(1,76 - 5,16)		-0,70	(-2,73 - 1,34)	
	overweight	21,40	(19,95 - 22,86)	0,000*	10,65	(4,25 - 17,05)	0,000*	3,11	(-3,61 - 9,83)	0,000*
MHF	healthy	13,50	(13,07 - 13,92)		9,46	(9,05 - 9,87)		7,08	(6,70 - 7,46)	
	overweight	15,26	(14,90 - 15,62)	0,000*	11,11	(9,57 - 12,65)	0,000*	6,79	(5,53 - 8,05)	0,142
LHF	healthy	13,67	(13,25 - 14,08)		9,54	(9,14 - 9,94)		7,25	(6,87 - 7,63)	
	overweight	15,31	(14,95 - 15,66)	0,000*	11,07	(9,55 - 12,58)	0,000*	6,92	(5,66 - 8,17)	0,085

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the healthy weight and overweight category ($p < 0.0057$).

Discussion

This article reports on the plantar loading differences found between healthy weight and overweight children from South Africa through three models. The first model known as the basic model provides information about the raw plantar loading values captured during the investigation without considering the various CT or body weight of participants. Secondly, was the basic model adjusted for total CT which considers the various total CT amongst participants during walking. Thirdly, was the basic model adjusted for total CT and body weight which considers the total CT and the body weight. This is one of the first studies to report on plantar loading in the basic model and report on the adjusted plantar loading values.

The greater PP loading of the overweight category were similar to the results found by Dowling, Steele and Baur [9] and Yan et al. [2]. A study done on obese adults supports the finding of greater PP loading of the forefoot, MF and hindfoot regions [5]. However, a recent study done on children found significantly higher PP loading of the forefoot, medial midfoot and lateral midfoot region for overweight and obese children but no significant differences were found within the hindfoot region [17]. Therefore, body weight influences the PP loading of children [3,9,17] but slight variations in the PP results exist between the studies mentioned above.

In the basic model adjusted for total CT, it was noted that the overweight category of children had greater PP for all the regions of the foot except the hallux and LHF region compared to the healthy weight category. These findings were similar to the finding found with obese adults where obese adults had greater PP loading of the entire foot, hindfoot, midfoot, forefoot and hallux regions [3]. However, the overweight children of this study did not have significantly higher PP of the hallux region which agrees with the findings found on overweight and obese children by Dowling, Steele and Baur [9] and Mueller et al. [17].

The results of this study revealed statistical significantly higher PTI and FTI for the overweight category of children in all regions of the foot except the hallux region with the basic model which was similar to the finding found by Dowling, Steele and Baur [9] and Cousins, Morrison and Drechsler [11]. The greatest PTI values were found in the central forefoot (MH2 and MH3) region for both weight categories where FTI values were the highest in the hindfoot (MHF and LHF) region in the basic model. These findings are consistent with the results found by Putti et al. [8]. A possible explanation for these results are that the hindfoot region of the foot has greater CA than the forefoot (MH2 and MH3) regions, therefore decreasing the PTI produced on the hindfoot compared to the forefoot regions [8]. Therefore, the central forefoot region of the foot has a greater risk for soft tissue damage and the hindfoot has the greatest risk for bony fatigue [1]. The same significant differences for PTI and FTI in the basic model was found in the basic model adjusted for total CT. Therefore, total CT did not influence the PTI and FTI values of the children. These results agree with the findings found by Mickle, Steele and Munro [1] with children aged 2,9 to 5,5 years old.

Wearing et al. [18] found that the appearance of a “flatter foot”, as a result of a greater CA of the midfoot region, from a plantar foot print is most likely a result of additional fat tissue within the midfoot region of obese adults and the additional body weight of obese adults do not affect the foot structure of the medial longitudinal arch. The results of this study revealed that the overweight category of children had a greater CA for all the regions of the foot and the greatest CA was found in the midfoot region. Potentially representing a “flat foot” appearance. The medial longitudinal arch height of Obese individuals can be misrepresented by their plantar foot print [18]. In a study done by Riddiford-Harland, Steele and Baur [7] on children (mean age of 8,3 years old), used direct measures to determine the foot structure of healthy weight and obese children. Their results revealed that obese children had flatter feet from a combination of additional fat mass found in the medial longitudinal arch and a structurally lowered medial longitudinal arch [7]. One can speculate that the larger CA of the MF region found within the overweight category of children in this study can potentially be caused by a combination of additional fat mass within the medial longitudinal arch and/or a structurally lowered medial longitudinal arch. However, these results should be viewed with caution as structural foot measurements such as radiographs or ultrasound were not included within this current study.

Although the overweight category of children had greater CA of all the regions of the foot in the basic model and basic model adjusted for CT the overweight category of children still generated greater PP and PTI values over several regions of the foot. This indicates that total CT did not influence the CA of the foot and that the large CA was not sufficient to overcome the great plantar loading of the overweight category of children. Therefore, body weight is a primary factor for increasing the PP and PTI values of the overweight category of children except for the midfoot region [3]. Body weight influenced the CA of all the regions of the foot except the MF region.

As soon as the adjustment for total CT and body weight was made on the basic model, statistical significantly higher PP, PTI, FTI and CA was only found in the MF region of the overweight category of children. This indicates that total CT and body weight did not influence the plantar loading of the MF region of the overweight category of children. Butterworth et al. [3] found that body weight was the primary factor influencing plantar loading directly where changes to the foot structure was a secondary factor influencing the plantar loading indirectly. One can speculate that structural foot differences can possibly be a factor contributing to the significant differences found in the MF region between the heathy weight and overweight category of children in the basic model adjusted for total CT and body weight. However, other possible confounding factors like gender, age, hallux angle, foot posture, biomechanical motion of the foot during locomotion could have contributed to the significant differences found in the MF region.

This study had several strengths as it is the first study to report on the plantar loading differences between healthy weight and overweight children from South Africa, it included a large sample size and provides valuable information on the plantar loading of children between the ages of 10 to 13 years old. However, the results should be interpreted with caution as direct foot structure measurements were not included into this study which serves as a limitation. The use of total CT as a measure for walking speed serves as an additional limitation to the study. In addition, one needs to consider the type of equipment, protocol and age group of this study when comparing it to other research. Future research should develop a standardised plantar loading protocol specific to various age ranges and type of pressure system used. In addition, direct foot structure measurements should be included with any plantar loading assessments to avoid the misinterpretation of whether individuals have “flatter” or “fatter” feet [7].

Conclusion

The hypothesis stated was accepted as significant plantar loading differences were found between healthy weight and overweight children from South Africa. Body weight was the main factor influencing the plantar loading of overweight children for most foot regions. Interestingly, the body weight of overweight children did not influence the plantar loading of the MF region. Therefore, it is possible that the significant differences found in the MF region is a result of structural differences that exist between the feet of healthy weight children and overweight children from South Africa. This raises the question of whether the overweight category of children had “flatter” or “fatter” feet or a combination of the two which potentially leads to the significant findings in the MF region. However, a limitation of this study was that structural foot differences were not accounted for. Although significant plantar loading differences were found between the healthy weight and overweight category, the values of the midfoot region were relatively low compared to the other regions that were loaded the most. Therefore, the midfoot region should not be considered a problematic region for possible foot pathologies. The areas that will most likely be susceptible to foot pathologies in the overweight category of children are the MH2, MH3, MHF and LHF regions. The greatest PTI values were found in the MH2, MH3 and MHF regions in this study which are susceptible to soft tissue damage. The greatest FTI values were found in the MHF and LHF regions in this study and are susceptible to bony fatigue according to Dowling, Steele and Baur [9].

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CHAPTER 4

ARTICLE TWO

Differences in plantar foot loading patterns between overweight South African and German children aged 10 to 13 years

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Key words:

Body Mass Index, Children, Pressure, Emed, Foot Loading

Abstract

This study investigated the plantar loading differences between overweight children from Germany and South Africa. Plantar measurements were obtained for 29 German children (body weight 61.0 ± 13.6kg; height 1.55 ± 0.10m; n = 29 of which 15 were girls and 14 boys) and 50 South African children (body weight 60.8 ± 13.1kg; height 1.55 ± 0.09m; n = 50 of which 21 were girls and 29 boys) with the Emed n50 pressure platform using the two-step method at a self-selected walking speed. The German overweight children had statistically significantly higher plantar loading in the forefoot region of the foot compared to the South African overweight children. Despite the lack of structural foot measurements within this study, it is possible that structural foot differences between German and South African children could have led to the plantar loading differences.

Introduction

Body weight is the primary factor influencing plantar loading patterns of the foot of overweight and obese individuals [1]. Overweight children and adults tend to have greater plantar loading than their healthy weight counterparts [2–5].

It is estimated that the ground reaction forces experienced by the lower limbs of a healthy weight individual can be as large as three to six times their own body weight [6]. One can imagine that overweight and obese individuals must withstand even greater forces because of their additional body weight. Excessive plantar loading (peak pressures) of the foot can possibly cause deterioration of the soft tissue such as the fat pads in the foot during locomotion [7]. This can increase the risk for developing foot pathologies in adults and children [4]. Overloading the ligaments and soft tissue within the foot's medial longitudinal arch may cause the arch to lose its elastic properties causing damage to the ligaments and soft tissue, ultimately leading to possible foot pathologies [8]. It is possible that foot pain experienced by overweight individuals results from the higher mechanical loading of their feet because of the additional body weight they carry [1].

Several studies have investigated the plantar loading differences between healthy weight, overweight and obese children [2–4] but to the knowledge of the researcher, no study has investigated children from two countries by implementing the same plantar loading protocol. Therefore, determining if similar plantar loading results are found for a particular weight category and age group with the use of identical protocols between countries are not yet known. However, to the knowledge of the researcher, no studies to date have investigated plantar loading differences of South African children and one recent study done by Mueller et al. [5] investigated the plantar loading differences of German children aged 1 to 12 years old. Mueller et al. [5] found that increased body weight may lead to greater plantar loading in overweight and obese children.

The primary aim of this study was to evaluate the plantar loading of the foot between overweight children from Germany and South Africa. In doing so, the primary objective was to determine if there were significant differences of the plantar loading between the various plantar foot regions of the overweight children from Germany and South Africa. It was hypothesised that no significant plantar loading differences would be found between the overweight children from Germany and South Africa. This will be one of the first studies to investigate the plantar loading differences of overweight children between two countries by implementing the same plantar loading protocol.

Methods

Participants

Seventy-nine children aged 10 to 13 years volunteered to participate in this research study where twenty-nine children (body weight 61.0 ± 13.6kg; height 1.55 ± 0.10m; n = 29 of which 15 were girls and 14 boys) were recruited from Germany under the research project named: Barefoot LIFE project [9] and fifty children (body weight 60.8 ± 13.1kg; height 1.55 ± 0.09m; n = 50 of which 21 were girls and 29 boys) from South Africa were recruited under the research study named: Moving feet – a comparative study of children between habitually barefoot and shod school-aged children. All the children included in this study were classified as overweight, obese or morbid obese according to their body mass index (BMI) [10]. Throughout this article, the term overweight category will be used to refer to all the children that fell within these three weight categories.

Ethical clearance for the German participants were granted under the research project named: Barefoot LIFE project (proposal number: PV4971) by the Medical Association Hamburg. Ethical clearance for the South African participants were granted under the research study named: Moving feet – a comparative study of children between habitually barefoot and shod school-aged children (proposal number: HS1153/2014) by the Human Research Ethics Committee of Stellenbosch University.

Participants were included in the study if they were between the ages of 10 to 13 years old, provided assent, signed consent forms from their parents or guardians and verbal consent. All personal information obtained from the voluntary participants and their parents or guardians were kept confidential by providing each participant with a participant number. Participants were excluded from this study if their BMI value did not fall within the overweight category, had foot abnormalities (e.g. missing toes), abnormal walking gait, pain or injury of the lower limbs. Participants were also excluded if incomplete data was captured in the database.

Height and Weight

Height was obtained with a portable stadiometer (Charder HM200P Portstad portable stadiometer, Stuttgart, Germany) to the nearest 0.1 centimetre (cm). The weight of the participants was measured with an electronic scale (A & D personal precision UC-321 scale, A & D Medical, Tokyo, Japan) to the nearest 0.05 kilogram (kg). The BMI was calculated using the $\frac{\text{weight}}{\text{height}^2}$ formula (weight in kilograms and height in meters) for each participant to determine their weight category according to the International Obesity Task Force (IOTF) cut-off values [10,11].

Dynamic measurements

The plantar loading of the foot was obtained with the Emed n50 pressure platform (NovelGmbH, Munich, Germany) during a self-selected walking speed and the data was processed using Novel Database Pro M software (Version 24.3.20, NovelGmbH, Munich, Germany). The pressure platform was built into a portable chip-board wooden walkway (61cm wide and 480cm in length) which has 6080 sensors within a 47,5 x 32 cm area (4 sensors/cm^2). The pressure platform was positioned in the middle and flush within the walkway. It was decided that the best protocol to use for this investigation was the two-step method. The two-step method required the participants to strike the pressure platform with their second foot step as they continued walking over the walkway. This two-step method is an easy method that can be performed by children since they strike the pressure platform with a greater consistency and without performing many additional trials [2]. The participants continued to walk over the pressure platform while looking straight ahead of them until three valid trials were captured bilaterally. The average of the three trials were calculated bilaterally. Trials were excluded if the second foot step did not strike the pressure platform, abnormal gait was visually seen and if the participant did not look straight ahead of them.

The plantar surface of the foot was divided into 9 regions namely (demonstrated in Figure 1): hallux, metatarsal head 1 (MH1), metatarsal head 2 (MH2), metatarsal head 3 (MH3), metatarsal head 4 (MH4), metatarsal head 5 (MH5), midfoot (MF), medial hindfoot (MHF) and the lateral hindfoot (LHF) using Novel-ortho automask software (NovelGmbH, Munich, Germany). It was decided that it would be the best to exclude the region toes 2-5 in this study as it was proven that this region is unreliable amongst children between the ages of seven to eleven years old [12]. The medial midfoot has large variability amongst the various foot regions as it is one of the regions that is loaded the least [13]. It was suggested that the auto-masking of the midfoot may not represent the medial midfoot to its best ability, therefore researchers should choose an appropriate mask [13]. For this current study, it was decided that the midfoot region should not be split into medial and lateral regions with the acknowledgement of the variability of the medial midfoot region. Contact area (CA; cm^2), peak pressure (PP; kPa) and force-time integral (FTI; N•s) measures were captured for each foot region and the total contact time (CT; ms) as a substitute measure for walking speed.

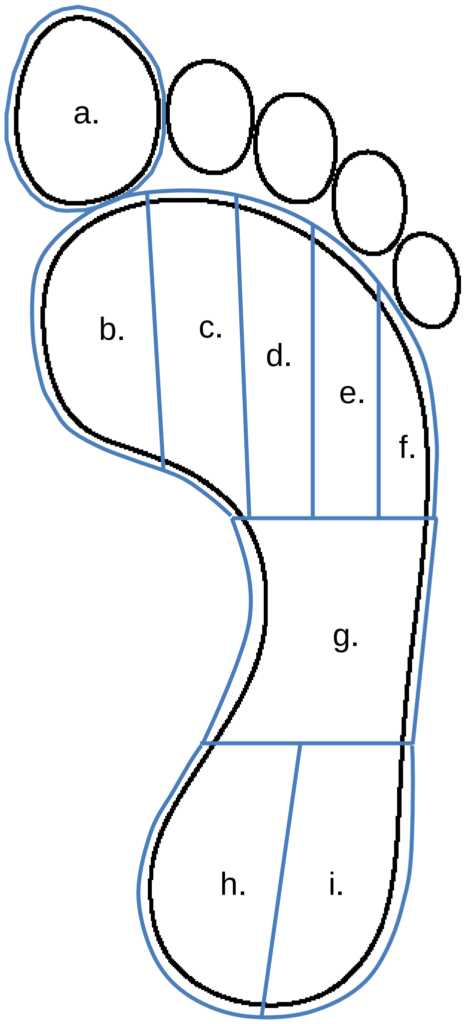

Figure 1. Demonstration of foot regions: a = hallux; b = MH1; c = MH2; d = MH3; e = MH4; f = MH5; g = MF; h = MHF and i = LHF.

Statistical analysis

The data captured through Novel Database Pro M software (Version 24.3.20, NovelGmbH, Munich, Germany) were exported into Microsoft Excel (2016, Washington, USA) where descriptive statistics, calculations for weight categories and pressure-time integral were processed using Microsoft Excel (2016, Washington, USA). The pressure-time integral (PTI; N•s/cm^2) was calculated using the following formula:

$$\text{Pressure-time integral} = \frac{\text{Force-time integral}}{\text{Contact area}}$$

All variables were analysed for normality by using the skewness coefficient, where skewness greater than -1 and smaller than 1 was accepted as normally distributed (SPSS version 23.0, IBM Corporation, New York, USA). The variables that were not normally distributed were logarithmic transformed and re-assessed for normality.

Statistical analyses were performed using SPSS (Version 23.0, IBM Corporation, New York, USA). A mixed model linear regression was used to evaluate if the dynamic measurements differ between healthy weight category and overweight category of children. Both the left and right foot measures were used; therefore, the participant was added as a random effect to adjust for within participant correlations. Three models were developed namely: basic model, basic model adjusted for total contact time and basic model adjusted for total contact time and body weight. The ranking of maximum to minimum values of each variable for each foot region was processed using Microsoft Excel (2016, Washington, USA). Due to the evaluation of nine regions for every outcome, the level of significance was adjusted from $p = 0.05$ by using a Šidák correction to: $p= 0.0057$. The results of the logarithmic transformed variables were inversely log transformed to provide the final results.

Results

The results of this study found the following variables were normally distributed: PTI for regions MH2, MH3, MHF and LHF; CA for all regions and CT. All logarithmic transformed variables were normally distributed. Mean total contact time for South African children for the left foot = 704,03 ± 95,25ms and the right foot = 695,87 ± 87,53ms and the German children for left foot = 777,82 ± 78,01ms and the right foot = 795,86 ± 103,61ms. Furthermore, this section will highlight the significant plantar loading differences between the overweight category of German and South African children.

Peak pressure

No statistical significant differences were found between the German and South African in the basic model and basic model adjusted for total CT. However, the German children had statistical significantly higher PP for MH2, MH3 and LHF regions in the basic model adjusted for total CT and body weight (refer to Table 1).

Pressure-time integral

In the basic model the German children had statistical significantly higher PTI values for MH2, MH3, MH4 and MH5 regions. Within the basic model adjusted for total CT and the basic model adjusted for total CT and body weight the German children had statistical significantly higher PTI for MH2 and MH3 regions (refer to Table 2).

Force-time integral

Within the basic model and basic model adjusted for total CT and body weight the German children had statistical significantly higher FTI values for MH2 and MH3 regions and MH5 was the least loaded region. Within the three models, there was a tendency for the children of both countries to load the MHF relatively more than the LHF (refer to Table 3).

Contact area

No statistical significant differences were found between the German and South African children for CA in the basic model. The greatest CA was found in the midfoot region for both countries in the basic model (refer to Table 4).

Table 1: Peak Pressure differences between South African and German overweight category of children.

Peak pressure		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (kPA)	(95% CI)	p	mean (kPA)	(95% CI)	p	mean (kPA)	(95% CI)	p
Hallux	Germany	287,94	(254,89 - 325,26)		478,08	(249,63 - 915,59)		381,45	(192,52 - 755,79)	
	South Africa	288,02	(247,10 - 335,71)	0,997	452,17	(382,24 - 534,90)	0,513	356,74	(301,90 - 421,55)	0,429
MH1	Germany	175,34	(157,94 - 194,65)		241,64	(138,15 - 422,67)		144,99	(84,15 - 249,84)	
	South Africa	199,80	(175,20 - 227,85)	0,051	265,77	(229,99 - 307,11)	0,195	155,47	(136,13 - 177,55)	0,301
MH2	Germany	293,19	(272,68 - 315,25)		465,28	(317,39 - 682,07)		273,29	(198,46 - 376,34)	
	South Africa	278,22	(253,98 - 304,78)	0,258	419,56	(380,05 - 463,18)	0,041	240,00	(221,97 - 259,50)	0,001*
MH3	Germany	291,61	(272,57 - 311,98)		360,35	(251,12 - 517,07)		217,94	(161,15 - 294,74)	
	South Africa	274,71	(252,36 - 299,04)	0,167	331,62	(302,06 - 364,08)	0,081	195,61	(181,71 - 210,57)	0,004*
MH4	Germany	232,59	(214,06 - 252,71)		192,14	(123,15 - 299,78)		121,50	(79,75 - 185,12)	
	South Africa	208,68	(188,01 - 231,63)	0,042	176,07	(156,94 - 197,53)	0,136	108,83	(98,20 - 120,61)	0,036
MH5	Germany	185,18	(158,35 - 216,56)		59,16	(26,04 - 134,39)		32,91	(14,37 - 75,38)	
	South Africa	155,31	(127,57 - 189,08)	0,079	56,28	(45,52 - 69,58)	0,643	30,41	(24,84 - 37,23)	0,441
MF	Germany	109,35	(100,33 - 119,18)		98,99	(62,35 - 157,17)		59,07	(38,53 - 90,56)	
	South Africa	110,12	(98,83 - 122,71)	0,898	100,79	(89,44 - 113,59)	0,766	58,62	(52,81 - 65,06)	0,885
MHF	Germany	304,15	(281,81 - 328,26)		505,77	(338,49 - 755,72)		395,23	(261,91 - 596,41)	
	South Africa	288,08	(261,74 - 317,08)	0,265	452,89	(408,22 - 502,44)	0,037	349,58	(316,17 - 386,53)	0,017
LHF	Germany	276,35	(259,41 - 294,40)		412,33	(295,33 - 575,67)		315,11	(226,13 - 439,11)	
	South Africa	260,91	(240,96 - 282,50)	0,155	372,45	(341,66 - 406,02)	0,021	280,85	(259,00 - 304,55)	0,006*

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.

* Significant difference between the South African and German overweight category of children ($p < 0.0057$).

Table 2: Pressure-time integral differences between the South African and German overweight weight category of children.

Pressure-Time Integral		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (N•s/cm²)	(95% CI)	p	mean (N•s/cm²)	(95% CI)	p	mean (N•s/cm²)	(95% CI)	p
Hallux	Germany	2,55	(2,30 - 2,83)		0,61	(0,37 - 1,02)		0,51	(0,30 - 0,87)	
	South Africa	2,13	(1,87 - 2,43)	0,007	0,60	(0,52 - 0,68)	0,736	0,50	(0,44 - 0,57)	0,636
MH1	Germany	2,96	(2,71 - 3,24)		1,29	(0,81 - 2,05)		0,90	(0,57 - 1,43)	
	South Africa	2,69	(2,40 - 3,01)	0,091	1,28	(1,14 - 1,45)	0,933	0,88	(0,79 - 0,99)	0,689
MH2	Germany	4,93	(4,64 - 5,21)		1,15	(-0,25 - 2,56)		-0,55	(-1,81 - 0,72)	
	South Africa	3,83	(3,47 - 4,19)	0,000*	0,47	(0,11 - 0,84)	0,000*	-1,31	(-1,62 - -1,00)	0,000*
MH3	Germany	4,86	(4,56 - 5,15)		0,08	(-1,30 - 1,46)		-1,62	(-2,85 - -0,39)	
	South Africa	3,80	(3,43 - 4,17)	0,000*	-0,45	(-0,81 - -0,10)	0,004*	-2,24	(-2,54 - -1,94)	0,000*
MH4	Germany	3,74	(3,41 - 4,12)		0,89	(0,57 - 1,41)		0,57	(0,37 - 0,87)	
	South Africa	3,01	(2,67 - 3,39)	0,000*	0,84	(0,75 - 0,95)	0,303	0,52	(0,47 - 0,58)	0,117
MH5	Germany	2,67	(2,34 - 3,03)		0,43	(0,23 - 0,80)		0,23	(0,13 - 0,43)	
	South Africa	2,11	(1,79 - 2,48)	0,005*	0,41	(0,35 - 0,49)	0,695	0,22	(0,19 - 0,26)	0,409
MF	Germany	1,26	(1,12 - 1,40)		0,37	(0,21 - 0,66)		0,19	(0,12 - 0,32)	
	South Africa	1,15	(1,00 - 1,32)	0,216	0,39	(0,34 - 0,45)	0,538	0,20	(0,17 - 0,22)	0,839
MHF	Germany	3,79	(3,54 - 4,03)		1,40	(0,14 - 2,65)		0,63	(-0,65 - 1,92)	
	South Africa	3,40	(3,09 - 3,71)	0,013	1,27	(0,95 - 1,60)	0,449	0,47	(0,16 - 0,78)	0,307
LHF	Germany	3,11	(2,92 - 3,30)		0,67	(-0,29 - 1,64)		-0,06	(-1,03 - 0,90)	
	South Africa	2,83	(2,58 - 3,07)	0,024	0,66	(0,41 - 0,91)	0,920	-0,11	(-0,35 - 0,12)	0,678

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the South African and German overweight category of children ($p < 0.0057$).

Table 3: Force-time integral differences between the South African and German overweight category of weight children.

Force-Time Integral		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (N•s)	(95% CI)	p	mean (N•s)	(95% CI)	p	mean (N•s)	(95% CI)	p
Hallux	Germany	21,63	(18,82 - 24,85)		4,58	(2,26 - 9,26)		2,93	(1,43 - 6,01)	
	South Africa	18,40	(15,45 - 21,92)	0,070	4,62	(3,85 - 5,55)	0,915	2,89	(2,42 - 3,45)	0,889
MH1	Germany	32,20	(28,62 - 36,23)		13,21	(7,13 - 24,46)		7,02	(3,92 - 12,59)	
	South Africa	31,07	(26,79 - 36,02)	0,633	14,06	(11,99 - 16,49)	0,439	7,24	(6,28 - 8,35)	0,667
MH2	Germany	43,09	(39,67 - 46,81)		15,25	(10,11 - 23,03)		7,88	(5,80 - 10,71)	
	South Africa	34,57	(31,15 - 38,36)	0,000*	13,72	(12,34 - 15,27)	0,052	6,86	(6,36 - 7,39)	0,000*
MH3	Germany	47,89	(44,07 - 52,04)		11,88	(8,08 - 17,49)		6,05	(4,67 - 7,84)	
	South Africa	38,55	(34,72 - 42,80)	0,000*	11,16	(10,10 - 12,33)	0,215	5,49	(5,16 - 5,85)	0,003*
MH4	Germany	31,29	(28,22 - 34,69)		5,74	(3,55 - 9,29)		2,91	(1,95 - 4,33)	
	South Africa	26,36	(23,16 - 30,01)	0,010	5,83	(5,15 - 6,61)	0,801	2,85	(2,59 - 3,15)	0,716
MH5	Germany	13,17	(11,29 - 15,37)		1,57	(0,74 - 3,35)		0,64	(0,32 - 1,27)	
	South Africa	11,02	(9,08 - 13,38)	0,071	1,67	(1,37 - 2,02)	0,571	0,65	(0,55 - 0,77)	0,894
MF	Germany	25,58	(20,90 - 31,30)		5,54	(1,93 - 15,94)		1,60	(0,61 - 4,16)	
	South Africa	22,71	(17,62 - 29,26)	0,355	5,83	(4,44 - 7,66)	0,720	1,58	(1,25 - 1,99)	0,917
MHF	Germany	52,98	(49,02 - 57,26)		22,78	(15,35 - 33,81)		13,85	(9,78 - 19,61)	
	South Africa	49,80	(45,16 - 54,91)	0,213	23,51	(21,23 - 26,03)	0,546	13,94	(12,80 - 15,17)	0,880
LHF	Germany	43,46	(40,23 - 46,95)		16,11	(10,98 - 23,62)		9,54	(6,90 - 13,19)	
	South Africa	41,61	(37,76 - 45,85)	0,377	17,21	(15,58 - 19,00)	0,189	9,93	(9,18 - 10,75)	0,319

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the South African and German overweight category of children ($p < 0.0057$).

Table 4: Contact area differences between the South African and German overweight category of children.

Contact Area		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (cm^2)	(95% CI)	p	mean (cm^2)	(95% CI)	p	mean (cm^2)	(95% CI)	p
Hallux	Germany	8,64	(8,18 - 9,10)		7,38	(4,91 - 9,85)		4,98	(2,61 - 7,36)	
	South Africa	8,84	(8,26 - 9,42)	0,503	7,71	(7,08 - 8,35)	0,300	5,20	(4,62 - 5,78)	0,461
MH1	Germany	11,01	(10,54 - 11,48)		9,95	(7,43 - 12,46)		6,76	(4,54 - 8,98)	
	South Africa	11,71	(11,11 - 12,30)	0,021	10,76	(10,11 - 11,41)	0,015	7,42	(6,88 - 7,96)	0,018
MH2	Germany	9,16	(8,79 - 9,53)		8,17	(6,21 - 10,13)		5,61	(3,91 - 7,30)	
	South Africa	9,42	(8,96 - 9,88)	0,268	8,54	(8,04 - 9,05)	0,154	5,85	(5,43 - 6,26)	0,254
MH3	Germany	10,28	(9,89 - 10,67)		8,01	(5,94 - 10,09)		4,81	(3,21 - 6,42)	
	South Africa	10,64	(10,15 - 11,13)	0,147	8,63	(8,09 - 9,16)	0,025	5,27	(4,88 - 5,66)	0,023
MH4	Germany	8,42	(8,14 - 8,71)		6,15	(4,66 - 7,65)		4,21	(2,92 - 5,50)	
	South Africa	8,84	(8,48 - 9,20)	0,024	6,82	(6,43 - 7,20)	0,001*	4,78	(4,46 - 5,09)	0,001*
MH5	Germany	5,02	(4,79 - 5,25)		3,57	(2,36 - 4,77)		1,98	(0,94 - 3,02)	
	South Africa	5,30	(5,01 - 5,58)	0,056	4,01	(3,69 - 4,32)	0,006	2,34	(2,09 - 2,60)	0,005*
MF	Germany	22,08	(20,06 - 24,09)		17,45	(6,64 - 28,27)		5,98	(-4,17 - 16,13)	
	South Africa	21,40	(18,87 - 23,94)	0,601	17,29	(14,49 - 20,09)	0,909	5,24	(2,77 - 7,72)	0,559
MHF	Germany	14,66	(14,13 - 15,20)		12,15	(9,31 - 14,99)		7,74	(5,56 - 9,92)	
	South Africa	15,26	(14,59 - 15,93)	0,081	13,02	(12,29 - 13,76)	0,020	8,39	(7,86 - 8,92)	0,016
LHF	Germany	14,58	(14,07 - 15,10)		12,02	(9,28 - 14,76)		7,70	(5,62 - 9,78)	
	South Africa	15,31	(14,66 - 15,96)	0,029	13,03	(12,32 - 13,74)	0,006*	8,49	(7,98 - 9,00)	0,002*

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the South African and German overweight category of children ($p < 0.0057$).

Discussion

This article reports on the plantar loading differences found between the overweight category of children from Germany and South Africa through three models. The first model known as the basic model provides information about the raw plantar loading values captured during the investigation without considering the various CT or body weight of participants. Secondly, is the basic model adjusted for total CT which considers the various total CT amongst participants during walking. Thirdly, is the basic model adjusted for total CT and body weight which considers the total CT and the body weight. This is one of the first studies to report on plantar loading in the basic model and report on the adjusted plantar loading values. In addition, it is also one of the first studies to compare the results between two countries.

No PP differences were found between the German and South African children in the basic model and basic model adjusted for total CT. Interestingly, once the adjustment for total CT and body weight was made on the basic model the German children had significantly higher PP of the LHF, MH2 and MH3 regions of the foot. This indicates that confounding factors that weren't accounted for, could have influenced the PP values in the adjusted models.

The German children had statistical significantly higher PTI values for the whole forefoot region except the MH1 region than the South African children in the basic model. It was noted that the total CT of the German children were slower than the South African children. The longer total CT may indicate that the German children could accumulate more peak pressure within the total CT resulting in greater PTI values within the forefoot. However, in the basic model adjusted for total CT and basic model adjusted for total CT and body weight, significant PTI differences were only found in MH2 and MH3 regions. This indicates that the total CT possibly influenced the PTI values of MH4 and MH5 regions but the total CT and body weight differences did not influence the MH2 and MH3 regions of the foot as significant differences were found within these regions in the adjusted models. Therefore, confounding factors such as ethnic background, genetic variations, the level of barefootness and foot dimensions could have led to the significant PTI findings in the MH2 and MH3 regions of the German children compared to the South African children. However, the use of total CT as a measure of walking speed serves as a limitation to the study and the results should be interpreted with caution.

Interestingly, Statistical significantly higher FTI values were found in the MH2 and MH3 regions for the German children in the basic model and the basic model adjusted for total CT and body weight but none in the basic model adjusted for total CT. The total CT possibly influenced the FTI values as no significant FTI findings were found in the basic model adjusted for total CT. As mentioned before, the German children had a longer total CT which could explain that more force was accumulated in the total CT period than the South African children.

No statistical significant CA differences were found in the basic model for overweight children. Although South Africa had greater CA for all regions of the foot except the midfoot region, one can not speculate that Germany had higher plantar loading because of a smaller CA of the foot.

One of the strengths of this study is that it is one of the first studies to report on the plantar loading differences between two countries while implementing the same plantar loading protocol. However, several limitations exist such as structural foot measurements were not accounted for, total CT was used as a measure for walking speed as it was not directly measured and to the knowledge of the researcher, limited information was available on plantar loading differences between overweight children from two different countries.

Conclusion

The hypothesis stated was rejected as significant plantar loading differences were found between overweight children from Germany and South Africa. In summary, the German overweight children generated greater plantar loading of the forefoot region compared to the South African overweight children. Despite the lack of structural foot measurements within this study, it is possible that structural foot differences between German and South African children could have led to the plantar loading differences.

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CHAPTER 5

DISCUSSION

INTRODUCTION

The primary aim of the study was to investigate the plantar loading differences between heathy weight and overweight children from South Africa aged 10 to 13 years old. The secondary aim was to investigate plantar loading differences between German and South African children aged 10 to 13 years old of the same weight category. Three main objectives were developed to support the aims of this study. Furthermore, each objective will be discussed separately within this section.

RESEARCH OBJECTIVE ONE

To determine the plantar loading differences of various plantar foot regions between the healthy weight and overweight category of children from South Africa.

This study reports on the plantar loading differences found between healthy weight and overweight children from South Africa through three models. The first model known as the basic model provides information about the raw plantar loading values captured during the investigation without considering the various contact times (CT) or body weights of participants. Secondly, is the basic model adjusted for total CT. Thirdly, is the basic model adjusted for total CT and body weight. This is one of the first studies to report on plantar loading in the basic model and the adjusted plantar loading values. Refer to Appendix H (Tables 2-5) for additional data.

The greater peak pressure (PP) loading of the overweight category in the basic model were similar to the results found by Dowling, Steele and Baur (2004) and Yan et al. (2013). A study done on obese adults supports the finding of greater PP loading of the forefoot, MF and hindfoot regions (Hills et al., 2001). However, a recent study done on children found significantly higher PP loading of the forefoot, medial midfoot and lateral midfoot region for overweight and obese children but no significant differences were found within the hindfoot region (Mueller et al., 2016). However, body weight influences the PP loading of children (Dowling, Steele & Baur, 2004; Butterworth et al., 2015; Mueller et al., 2016) but slight variations in the PP differences exist between the studies mentioned above. The healthy weight category had the greatest PP loading of the hallux region followed by the MHF where the overweight category had the greatest PP loading of MHF followed by the hallux in the basic model. The least PP was found in the MF region for both categories. The overweight category tended to have a relatively higher PP for the MHF region than the LHF region compared to the healthy weight category of children in the basic model. Possibly indicating that the overweight category of children distributes their weight more medially on the hindfoot during the initial contact of foot during walking. Both weight categories had greater PP loading of the MH2 and MH3 within the forefoot region indicating that they loaded the central region of the forefoot more compared to the other regions of the forefoot. However, one needs to keep in mind that biomechanical motion analysis of the foot was not investigated in this study and could not confirm if there were biomechanical deviations of the foot during the initial contact.

In the basic model adjusted for total CT, it was noted that the overweight category of children had greater PP for all the regions of the foot except the hallux and LHF region compared to the healthy weight category. These findings were similar to the finding found with obese adults, where obese adults had greater PP loading of the entire foot, hindfoot, midfoot, forefoot and hallux regions (Butterworth et al., 2015). However, the overweight children of this study did not have significantly higher PP of the hallux region which agrees with the findings found on overweight and obese children by Dowling, Steele and Baur (2004) and Mueller et al. (2016).

The results of this study revealed statistical significantly higher pressure-time integral (PTI) and force-time integral (FTI) for the overweight category of children in all regions of the foot except the hallux region in the basic model. This was similar to the results found by Dowling, Steele and Baur (2004) and Cousins, Morrison and Drechsler (2013). The greatest PTI values were found in the central forefoot (MH2 and MH3) region for both weight categories where FTI values were the highest in the hindfoot (MHF and LHF) region in the basic model. These findings are consistent with the results found by Putti et al. (2008). A possible explanation for these results are that the hindfoot region of the foot has greater contact area (CA) than the forefoot (MH2 and MH3) regions, therefore decreasing the PTI produced on the hindfoot compared to the forefoot regions (Putti et al., 2008). Therefore, the central forefoot region of the foot has a greater risk for soft tissue damage and the hindfoot has the greatest risk for bony fatigue (Mickle, Steele & Munro, 2006). The same significant differences for PTI and FTI in the basic model was found in the basic model adjusted for total CT. Therefore, total CT did not influence the PTI and FTI values of the children. These results agree with the findings found by Mickle, Steele and Munro (2006) with children aged 2,9 to 5,5 years old.

Wearing et al. (Wearing et al., 2012) found that the appearance of a “flatter foot”, as a result of a greater CA of the midfoot region, from a plantar foot print is most likely a result of additional fat tissue within the midfoot region of obese adults and the additional body weight of obese adults do not affect the foot structure of the medial longitudinal arch. The results of this study revealed that the overweight category of children had a greater CA for all the regions of the foot and the greatest CA was found in the midfoot region. Potentially representing a “flat foot” appearance. Obese individuals can misrepresent the medial longitudinal arch height through a plantar foot print (Wearing et al., 2012). In a study done by Riddiford-Harland, Steele and Baur (2011) on children (mean age of 8,3 years old), used direct measures to determine the foot structure of healthy weight and obese children. Their results revealed that obese children had flatter feet from a combination of additional fat mass found in the medial longitudinal arch and a structurally lowered medial longitudinal arch (Riddiford-Harland, Steele & Baur, 2011). One can speculate that the larger CA of the MF region found within the overweight category of children in this study can potentially be caused by a combination of additional fat mass within the medial longitudinal arch and/or a structurally lowered medial longitudinal arch. However, these results should be viewed with caution as structural foot measurements such as radiographs or ultrasound were not included within this current study.

Although the overweight category of children had greater CA of all the regions of the foot in the basic model and basic model adjusted for CT the overweight category of children still generated greater PP and PTI values over several regions of the foot. This indicates that total CT did not influence the CA of the foot and that the large CA was not sufficient to overcome the great plantar loading of the overweight category of children. Therefore, body weight is a primary factor for increasing the PP and PTI values of the overweight category of children except for the midfoot region (Butterworth et al., 2015). Body weight influenced the CA of all the regions of the foot except the MF region.

As soon as the adjustment for total CT and body weight was made on the basic model, statistical significantly higher PP, PTI, FTI and CA was only found in the MF region of the overweight category of children. This indicates that total CT and body weight did not influence the plantar loading of the MF region of the overweight category of children. Butterworth et al. (Butterworth et al., 2015) found that body weight was the primary factor influencing plantar loading directly where changes to the foot structure was a secondary factor influencing the plantar loading indirectly. One can speculate that structural foot differences can possibly be a factor contributing to the significant differences found in the MF region between the heathy weight and overweight category of children in the basic model adjusted for total CT and body weight. However, other possible confounding factors such as gender, age, hallux angle, foot posture, biomechanical motion of the foot during locomotion could have contributed to the significant differences found in the MF region. In summary, plantar loading differences were found between the healthy weight and overweight children from South Africa.

RESEARCH OBJECTIVE TWO

To determine the plantar loading differences of various plantar foot regions between the healthy weight children from Germany and South Africa.

This study reports on the plantar loading differences found between the healthy weight children from Germany and South Africa through three models as mentioned before. Refer to the additional data in Appendix H (Table 6-13).

The results of this study revealed that the healthy weight German children had greater PP loading of the lateral aspect of the forefoot (MH4 and MH5) region compared to the South African children in the basic model. The South African children had greater CA for majority of the foot regions. Therefore, distributing the PP loading to a greater degree than the German children. However, it is possible that structural foot differences such as bonier foot features of the German children can cause the greater PP loading. One needs to interpret these results with caution as structural foot differences were not account within this study. Once the basic model was adjusted for total CT additional significant differences were revealed between the German and South African children (MH2, MH3, MHF and LHF). This indicates that the total CT as a measure of walking speed possibly influenced the PP results. It is known that the heathy weight German children had slower total CT (left foot = 783,43 ± 106,60ms and right foot = 790,71 ± 109,40ms) and the greatest variation in total CT than the South African children (left foot = 683,14 ± 83,51ms and right foot = 679,54 ± 83,51). Therefore, indicating that the German children possibly walked at a slower and had a greater variation of walking speed because of the large standard deviation compared to the South African children. However, research has revealed that walking speed can influence plantar loading of individuals (Burnfield et al., 2004; Taylor, Menz & Keenan, 2004). Interestingly, although the German children had a longer total CT than the South African children, they still generated significantly higher PP values than the South African children in the basic model adjusted for total CT. The total CT could serve as a limitation for this study as it was not validated with direct measurement of walking speed. According to the results found by Taylor, Menz and Keenan (2004), a faster walking speed results in greater PP loading of the foot but this was not the case with the South African children. Furthermore, the South African children had greater CA for most regions of the foot which possibly indicates that the greater CA was sufficient to dissipate the plantar loading to such an extent that the walking speed did not influence the plantar loading of the South African children. Possible confounding factors such as foot structure differences were not accounted for that could have influenced the results. The same significant differences were found in the basic model adjusted for total CT as the basic model adjusted for total CT and body weight. This indicated that body weight differences did not influence the plantar loading between the healthy weight children from Germany and South Africa.

The German children had higher PTI values for all regions of the foot except the LHF region compared to the South African children in the basic model. Once the adjustment for total CT and body weight was made, the significant differences in the forefoot remained. It was noted previously that the total CT of the German children were slower than the South African children. The longer total CT may indicate that the German children could accumulate more pressure within the total CT resulting in greater PTI values than the South African children. However, the total CT possibly influenced the PTI loading of the hindfoot, MF and hallux regions in the basic model adjusted for total CT and body weight differences did not influence the PTI results between German and South African children. The German children also had smaller CA for most regions of the foot which indicates that they will produce greater pressures within these regions compared to the South African children. Other confounding factors such as foot structure differences could have contributed to the PTI differences found. Furthermore, the German children are at a greater risk for developing soft tissue damage within the forefoot region than the South African children (Dowling, Steele & Baur, 2004).

The results of this study revealed that the German children had greater FTI values within the forefoot region than the South African children in the basic model. This indicates that the German children are at greater risk for bony fatigue within the forefoot region as well the MHF region was loaded relatively high. Interestingly, once the basic model was adjusted for total CT the South African children had greater FTI values for the hindfoot region. As mentioned before that the adjustment for total CT could have influenced the results, thus serving as a limitation for this study. However, confounding factors could have influenced the FTI values such as foot structure differences.

The results of the study revealed that South African children had greater CA for all the regions of the foot except the MF and MHF region. Therefore, it is possible that structural foot differences exist between the German and South African children. However, the results of this study must be viewed with caution because structural foot differences were not accounted for and total CT as a measure of walking speed was utilised. In summary, plantar loading differences were found between the healthy weight children from Germany and South Africa with the use of the same pressure system and plantar loading protocol.

RESEARCH OBJECTIVE THREE

To determine the plantar loading differences of various plantar foot regions between the overweight category of children from Germany and South Africa.

This study reports on the plantar loading differences found between the overweight category of children from Germany and South Africa through three models as mentioned before. Refer to the additional data in Appendix H (Table 14-17).

No significant PP differences were found between the German and South African children in the basic model and basic model adjusted for total CT. Interestingly, once the adjustment for total CT and body weight was made on the basic model the German children had significantly higher PP values of the LHF, MH2 and MH3 regions of the foot. This indicates that total CT had no influence on the PP loading between the overweight category of children from Germany and South Africa in the basic model adjusted for total CT. The significant PP findings in the basic model adjusted for total CT and body weight most likely resulted from confounding factors. In other words, once the differences in the body weight was accounted for, significantly higher PP loading was found with the German children. In addition, no significant differences in the CA were present between the German and South African overweight category of children and indicates that confounding factors that weren't accounted for, could have influenced the PP values in the adjusted models. The MHF region had the greatest PP loading within all three models for both countries except in the basic model adjusted for total CT and body weight where South Africa loaded the hallux region the most. Within the three models, there was a tendency for the children of both countries to load the MHF relatively more than the LHF. Indicating that the overweight children tend to load the medial aspect of their hindfoot more than the lateral aspect of their hindfoot. The MF region together with the MH5 region was one of the least loaded regions throughout the three models.

The German children had statistical significantly higher PTI values for the whole forefoot region except the MH1 region than the South African children in the basic model. This places the German children at greater risk for soft tissue damage within the forefoot region compared to the South African children (Dowling, Steele & Baur, 2004). It was noted that the total CT of the German children were slower than the South African children. The longer total CT may indicate that the German children could accumulate more peak pressure within the total CT resulting in greater PTI values within the forefoot. However, in the basic model adjusted for total CT and basic model adjusted for total CT and body weight, significant PTI differences were only found in MH2 and MH3 regions. This indicates that the total CT possibly influenced the PTI values of MH4 and MH5 regions but the total CT and body weight differences did not influence the MH2 and MH3 regions of the foot as significant differences were found within these regions in the adjusted models. Therefore, confounding factors could have led to the significant PTI findings in the MH2 and MH3 regions of the German children. However, the use of total CT as a measure of walking speed serves as a limitation to the study and the results should be interpreted with caution. Within the three models, there was a tendency for the children of both countries to load the MHF relatively more than the LHF. Indicating that German and South African children tended to distribute most of their PTI loading on the medial aspect of their hindfoot.

Interestingly, statistical significantly higher FTI values were found in the MH2 and MH3 regions for the German children in the basic model and the basic model adjusted for total CT and body weight but none in the basic model adjusted for total CT. The total CT possibly influenced the FTI values as no significant FTI findings were found in the basic model adjusted for total CT. As mentioned before, the German children had a longer total CT which could explain that more force was accumulated in the total CT period than the South African children. However, although the German children had significantly higher FTI of the MH2 and MH3 regions it does not indicate that these regions are at risk for bony fatigue. Both countries had the greatest FTI loading of the hindfoot which indicates that both counties are at risk for body fatigue of their hindfoot. However, a study carried out on heathy adults had the greatest FTI loading of the hindfoot as well (Putti et al., 2008).

No statistical significant CA differences were found in the basic model for overweight children. Although South Africa had greater CA for all regions of the foot except the midfoot region, one can not speculate that the German children had higher plantar loading as a result of a smaller CA of the foot. In summary, plantar loading differences were found between the overweight category of children from Germany and South Africa with the use of the same pressure system and plantar loading protocol.

CONCLUSION

Two hypotheses were developed for the investigation carried out in this study. Hypothesis one: the overweight category of children will generate greater plantar loading than the healthy weight children from South Africa was accepted. The overweight category of children aged 10 to 13 years old had significantly higher plantar loading than the heathy weight children from South Africa. Body weight was the main factor contributing to the plantar loading differences found between the healthy weight and overweight category of children from South Africa (Dowling, Steele & Baur, 2004; Butterworth et al., 2015). Body weight was not the main factor resulting in the plantar loading differences found within the midfoot region as it was speculated that structural differences of the foot could have led to the significant finding within the midfoot region. Therefore, structural differences such as additional fat mass within the medial longitudinal arch representing the "fatter foot" and/or a structurally lowered medial longitudinal arch representing the "flatter foot" may have led to the significant findings within the midfoot region of the foot (Riddiford-Harland, Steele & Baur, 2011). Although significant plantar loading differences were found between the healthy weight and overweight category of children from South Africa, the values of the midfoot region were relatively low compared to the other regions that were loaded the most. Therefore, the midfoot region should not be considered a problematic region for possible foot pathologies but the areas that will be susceptible to foot pathologies in the overweight category of children are the MH2, MH3, MHF and LHF regions. As the greatest PTI values were found in the MH2, MH3 and MHF regions in this study are susceptible to soft tissue damage and greatest FTI values found in the MHF and LHF regions in this study are susceptible to bony fatigue according to Dowling, Steele and Baur (2004). Hypothesis two: no significant plantar loading differences will exist between the German and South African children of the same weight category (healthy weight and overweight category) was rejected. The healthy weight children from Germany had greater plantar loading than the healthy weight South African children aged 10 to 13 years old. The overweight category of children from Germany had greater plantar loading than the overweight category of children from South African children aged 10 to 13 years old. It is possible that foot structure differences resulted in the plantar loading differences between Germany and South African children of the same weight category.

In summary, body weight was the main factor influencing the plantar loading of the overweight category of children aged 10 to 13 years from South Africa but body weight was not the main factor influencing the midfoot region. It is possible that structural foot differences are the main factor influencing the midfoot region of the foot. The German children are at a greater risk for developing foot pathologies within the higher loaded regions compared to the South African children of the same weight category. Despite the lack of structural foot measurements within this study, it is possible that structural foot differences between German and South African children could have led to the numerous plantar loading differences between the healthy weight children from German and South Africa. However, fewer plantar loading differences were found between the overweight children from Germany and South Africa within the basic model. Indicating similar plantar loading patterns were found between the overweight category of children from German and South Africa. Confounding factors could have influenced the plantar loading differences found in the adjusted models between German and South African children. One of the strengths of this study is that it is one of the first studies to investigate the plantar loading differences of healthy weight and overweight children from South Africa and report on the plantar loading differences between two countries while implementing the same plantar loading protocol. In addition, this study included a large sample size and provides valuable information on the plantar loading of children between the ages of 10 to 13 years old.

LIMITATIONS

No direct foot structure measurements were recorded within this study to confirm whether individuals had “fatter” or flatter” feet. Total contact time as a measure of walking speed was not validated against the actual walking speed of the children which could have influence the results of the basic model adjusted for the total contact time and the basic model adjusted for total contact time and body weight. The pressure system selected and protocol used may serve as a limitation for comparing the results of this study to previous or future research as these results should be interpreted with caution if the pressure system and protocol utilised by other researchers differ to the ones selected within this study. Limited information is available to support the findings within this study as it is one of the first studies to compare the plantar loading differences of children between two countries with the same plantar loading protocol and pressure system utilised.

SUGGESTIONS FOR FUTURE RESEARCH

Plantar loading protocols vary amongst researchers and it would be beneficial to establish a standardised plantar loading protocol specific for children. In addition, it will be beneficial to perform reliability studies with all available pressure systems on adults and children to determine if the various pressure systems are reliable and can be used interchangeably. Foot structure measurements should be performed with plantar loading assessments as it will be beneficial in aiding the holistic view of the foot.

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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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TIFF (or JPEG): Bitmapped (pure black & white pixels) line drawings, keep to a minimum of 1000 dpi. TIFF (or JPEG): Combinations bitmapped line/half-tone (color or grayscale), keep to a minimum of

500 dpi.

Please do not:

• Supply files that are optimized for screen use (e.g., GIF, BMP, PICT, WPG); these typically have a low number of pixels and limited set of colors;

• Supply files that are too low in resolution;

• Submit graphics that are disproportionately large for the content.

References

Indicate references to the literature in the text by superior Arabic numerals that run consecutively through the paper in order of their appearance. Where you cite a reference more than once in the text, use the same number each time. References should take the following form:

1. Amis AA, Dawkins GPC. Functional anatomy of the anterior cruciate ligament. J Bone Joint Surg

[Br] 1991; 73B: 260-267

2. Insall JN. Surgery of the Knee. New York: Churchill Livingstone; 1984

3. Shumway-Cook A, Woollacott M. Motor Control: Theory and Practical Applications. Baltimore: Williams and Wilkins; 1995.

Please ensure that references are complete, i.e. that they include, where relevant, author's name, article or book title, volume and issue number, publisher, year and page reference *and* comply with the reference style of *Gait Posture*. Only salient and significant references should be included.

Reference management software

Most Elsevier journals have their reference template available in many of the most popular reference management software products. These include all products that support Citation Style Language styles (http://citationstyles.org), such as Mendeley (http://www.mendeley.com/features/reference-manager) and Zotero (https://www.zotero.org/), as well as EndNote (http://endnote.com/downloads/styles). Using the word processor plug-ins from these products, authors only need to select the appropriate journal template when preparing their article, after which citations and bibliographies will be automatically formatted in the journal's style. If no template is yet available for this journal, please follow the format of the sample references and citations as shown in this Guide.

Users of Mendeley Desktop can easily install the reference style for this journal by clicking the following link:

http://open.mendeley.com/use-citation-style/gait-and-posture

When preparing your manuscript, you will then be able to select this style using the Mendeley plug- ins for Microsoft Word or LibreOffice.

Reference style

Text: Indicate references by number(s) in square brackets in line with the text. The actual authors can be referred to, but the reference number(s) must always be given.

List: Number the references (numbers in square brackets) in the list in the order in which they appear in the text.

Examples:

Reference to a journal publication:

[1] Van der Geer J, Hanraads JAJ, Lupton RA. The art of writing a scientific article. J Sci Commun

2010;163:51–9. Reference to a book:

[2] Strunk Jr W, White EB. The elements of style. 4th ed. New York: Longman; 2000. Reference to a chapter in an edited book:

[3] Mettam GR, Adams LB. How to prepare an electronic version of your article. In: Jones BS, Smith

RZ, editors. Introduction to the electronic age, New York: E-Publishing Inc; 2009, p. 281–304.

Note shortened form for last page number. e.g., 51–9, and that for more than 6 authors the first

6 should be listed followed by 'et al.' For further details you are referred to 'Uniform Requirements for Manuscripts submitted to Biomedical Journals' (J Am Med Assoc 1997;277:927–34) (see also http://www.nlm.nih.gov/bsd/uniform_requirements.html).

Reference to a website:

[4] Cancer Research UK. Cancer statistics reports for the UK, http://www.cancerresearchuk.org/

aboutcancer/statistics/cancerstatsreport/; 2003 [accessed 13.03.03].

AudioSlides

The journal encourages authors to create an AudioSlides presentation with their published article. AudioSlides are brief, webinar-style presentations that are shown next to the online article on ScienceDirect. This gives authors the opportunity to summarize their research in their own words and to help readers understand what the paper is about. More information and examples are available at https://www.elsevier.com/audioslides. Authors of this journal will automatically receive an invitation e-mail to create an AudioSlides presentation after acceptance of their paper.

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The following list will be useful during the final checking of an article prior to sending it to the journal for review. Please consult this Guide for Authors for further details of any item.

Ensure that the following items are present:

One author has been designated as the corresponding author with contact details:

• E-mail address

• Full postal address

All necessary files have been uploaded, and contain:

• Keywords

• All figure captions

• All tables (including title, description, footnotes) Further considerations

• Manuscript has been 'spell-checked' and 'grammar-checked'

• References are in the correct format for this journal

• All references mentioned in the Reference list are cited in the text, and vice versa

• Permission has been obtained for use of copyrighted material from other sources (including the

Internet)

Printed version of figures (if applicable) in color or black-and-white

• Indicate clearly whether or not color or black-and-white in print is required.

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AFTER ACCEPTANCE

Use of the Digital Object Identifier

The Digital Object Identifier (DOI) may be used to cite and link to electronic documents. The DOI consists of a unique alpha-numeric character string which is assigned to a document by the publisher upon the initial electronic publication. The assigned DOI never changes. Therefore, it is an ideal medium for citing a document, particularly 'Articles in press' because they have not yet received their full bibliographic information. Example of a correctly given DOI (in URL format; here an article in the journal *Physics Letters B*):

http://dx.doi.org/10.1016/j.physletb.2010.09.059

When you use a DOI to create links to documents on the web, the DOIs are guaranteed never to change.

Online proof correction

Corresponding authors will receive an e-mail with a link to our online proofing system, allowing annotation and correction of proofs online. The environment is similar to MS Word: in addition to editing text, you can also comment on figures/tables and answer questions from the Copy Editor. Web-based proofing provides a faster and less error-prone process by allowing you to directly type your corrections, eliminating the potential introduction of errors.

If preferred, you can still choose to annotate and upload your edits on the PDF version. All instructions for proofing will be given in the e-mail we send to authors, including alternative methods to the online version and PDF.

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AUTHOR INQUIRIES

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APPENDIX B: ETHICS APPROVAL – WESTERN CAPE 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: 20141023-38716
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 **02 February 2015 till 30 September 2015**
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: 24 October 2014

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: ETHICS APPROVAL – STELLENBOSCH UNIVERSITY

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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 D: ENGLISH CONSENT FORM

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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 length and weight will be measured.

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

Jogging and running for 20 metres: While your child runs, he/she will be recorded on a video camera. The child will be asked to do this three times with and without shoes. The video is just to determine how your child lands with his feet while running.

Balance tests: Your child will be asked to walk backwards on three different sized bars. This will be done twice on each bar with and without shoes.

Jumps: Your child will be asked to jump as far as he/she can with both feet together. The distance will be measured. Your child will do this jump three times with and without shoes.
Next your child will be asked to jump sideways as many times as possible in 15 seconds. They will do it twice with and without shoes.

Foot shape: Your child will be asked to walk over a platform with a pressure plate embedded in it. They will also have to stand on a foot measuring platform, which then will determine the child's foot length and breadth as well as the height of his/her foot bridge while standing and seated.

Grip strength: Your child's grip strength will be determined by using a hand grip calliper.

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 E: AFRIKAANS CONSENT FORM

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UNIVERSITEIT STELLENBOSCH
TOESTEMMING TOT DEELNAME AAN NAVORSING

Bewegende voete – 'n vergelykende studie van skoolkinders wat gewoonlik skoene dra teenoor dié wat gewoonlik kaalvoet loop

Ek is Elbé de Villiers ('n PhD-student in Sportwetenskap) van die Departement Sportwetenskap aan die Universiteit Stellenbosch. Ek nooi u kind om deel te neem aan my navorsingstudie. Die resultate van die studie sal deel uitmaak van die tesis vir my doktorsgraad in Sportwetenskap. U kind is as 'n moontlike studiedeelnemer gekies omdat hy/sy in een van die deelnemerskole is en ook die regte ouderdom is.

10. DOEL VAN DIE STUDIE

Die hoofdoel van hierdie studie is om te bepaal watter effek skoene op die ontwikkelende voet het. Ek sal ook vasstel of skoene kinders se bewegingsvermoë beïnvloed.

11. PROSEDURES

Indien u instem dat u kind aan hierdie studie kan deelneem, sal u kind die volgende toetse en metings ondergaan:

Antropometriese meting: U kind se lengte en gewig sal gemeet word.

Invul van 'n vraelys oor fisiese aktiwiteit: Dít word gedoen om te bepaal hoe aktief u kind is.

Invul van 'n vraelys oor kaalvoetgewoontes: Hiermee wil ons agterkom hoe gereeld u kind kaalvoet is.

Draf en hardloop oor 20 meter: Terwyl u kind draf en hardloop sal hy/sy met 'n videokamera afgeneem word. Die video word geneem om te kyk hoe u kind se voet neergesit word tydens die verskillende situasies. Die tyd wat dit u kind neem om die 20 meter te hardloop sal geneem word en hy/sy sal gevra word om dit twee keer te doen met en sonder skoene.

Balanstoetse: Die kind sal gevra word om agteruit te loop op drie verskillende plankies, elkeen met 'n ander breedte. Dit moet twee keer elk gedoen word met en sonder skoene.

Spronge: U kind sal gevra word om so ver as moontlik met albei voete tegelyk te spring. Die afstand sal gemeet word. U kind sal die sprong drie keer doen, met en sonder skoene.
Na die verspring sal u kind gevra word om so veel keer as moontlik in 15 sekondes sywaarts te spring. Dit sal twee keer herhaal word en die beste een sal gebruik word, met en sonder skoene.
Handgreep: Die krag van albei u kind se hande sal gemeet word met 'n handgreepkaliper.

Voetvorm: U kind sal gevra word om kaalvoet op 'n voetmetingsapparaat te staan waar u kind se voetlengte en -breedte sowel as die hoogte van sy/haar voetbrug bepaal sal word.

12. MOONTLIKE RISIKO'S EN ONGEMAK

Hoewel van die toetse dalk onbekend sal wees vir u kind, is dit eenvoudige toetse. Dit behoort nie u kind buitengewoon moeg te maak of ongemak te veroorsaak nie.

13. MOONTLIKE VOORDELE VIR STUDIEDEELNEMERS EN/OF DIE SAMELEWING

U kind sal geen direkte voordeel uit die studie trek nie.

Die studie hou egter wel voordele in vir kennis op die gebied van sportwetenskap en veral oor die uitwerking van skoene op kinders se voete en bewegingsvermoë. Die resultate kan skoenvervaardigers ook moontlik in die toekoms die nodige kennis gee om skoene te ontwerp wat voordelig is vir die ontwikkeling van kinders se voete.

14. VERGOEDING VIR DEELNAME

U kind sal nie vir deelname aan hierdie studie betaal word nie.

15. VERTROULIKHEID

Enige inligting wat in verband met hierdie studie bekom word en u kind se identiteit verklap, sal vertroulik bly en slegs met u toestemming of ingevolge wetsvereistes bekend gemaak word. Vertroulikheid sal gehandhaaf word deur die data op 'n persoonlike rekenaar met 'n wagwoord te berg. Slegs die navorser en die studieleier sal na die data kan kyk. Die data sal te alle tye anoniem hanteer word.

Indien die navorsing gepubliseer word, sal die data in die algemeen – met ander woorde vir die groep in die geheel – bespreek word.

16. DEELNAME EN ONTTREKKING

U kan kies of u kind aan hierdie studie mag deelneem of nie. Indien u aanbied dat u kind kan deelneem, kan u hom/haar steeds in enige stadium onttrek sonder dat dit enige gevolge vir u kind sal inhou. Die navorser kan ook besluit om u kind aan die studie te onttrek indien omstandighede dit vereis.

17. BESONDERHEDE VAN NAVORSERS

As u enige vrae oor die navorsing het of as enigiets daarvan u pla, kontak ons gerus:

Elbé de Villiers (selfoon 084 515 7642; e-pos edup@sun.ac.za) of dr Ranel Venter (selfoon 083 309 2894; e-pos rev@sun.ac.za)

18. REGTE VAN NAVORSINGSDEELNEMERS

U kan in enige stadium u toestemming terugtrek en u kind se deelname staak, sonder enige nadelige gevolge. U kind doen nie afstand van enige wettige aansprake of regte deur aan hierdie navorsingstudie deel te neem nie. Vir enige vrae oor u kind se regte as studiedeelnemer, skakel met me Maléne Fouché in die Universiteit Stellenbosch se Afdeling Navorsingsontwikkeling [mfouche@sun.ac.za; 021 808 4622].

HANDTEKENING VAN OUER / VOOG

Ek het geleentheid gekry om vrae te vra, en dit is bevredigend beantwoord.

Ek stem in dat ___________________________________ aan hierdie studie kan deelneem. Ek het 'n afskrif van hierdie vorm ontvang.

____

Naam van ouer/voog

_______________________________________ _______________

Handtekening van ouer/voog **Datum**

Woonadres:

Straatnaam en nommer: ____

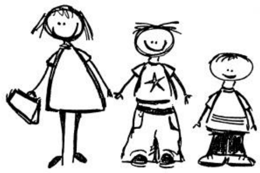
Voorstad / area: ____

Stad / Dorp: ____

APPENDIX F: ENGLISH ASSENT FORM

	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 walk 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

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 over a platform. We will take measurements of your foot while you are standing and sitting
The balance test is next. You will need to 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 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 measure your hand grip strength.

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 G: AFRIKAANS ASSENT FORM

UNIVERSITEIT STELLENBOSCH

INLIGTINGSTUK EN TOESTEMMINGSVORM VIR DEELNEMERS

NAAM VAN DIE NAVORSINGSPROJEK: Bewegende voete – ’n studie waar ons skoolkinders wat gewoonlik skoene dra vergelyk met dié wat gewoonlik kaalvoet loop

NAVORSER(S) SE NAAM: Elbé de Villiers

ADRES: Departement Sportwetenskap, Universiteit Stellenbosch

KONTAKNOMMER: 021 808 4735 **/** 084 515 7642

Wat is NAVORSING?
Navorsing is iets wat ons doen om MEER TE LEER oor hoe dinge (en mense) werk. Ons gebruik navorsingsprojekte of -ondersoeke om meer uit te vind oor kinders en tieners en die dinge wat hulle lewe beïnvloed, soos hulle skool, hulle gesin en hulle gesondheid. Ons doen dit omdat ons die wêreld ’n beter plek probeer maak.

Waaroor gaan hierdie navorsingsprojek?
Met hierdie navorsing wil ons kyk of die skoene wat jy dra, die volgende doen:
Die manier waarop jy loop verander
Die vorm van jou voet verander
Jou balans beter maak
Jou verder laat spring

Hoekom vra julle my om aan hierdie navorsingsprojek deel te neem?
Ons wil graag hê dat jy moet deelneem aan die projek, omdat jy in die skool is wat ons gekies het om deel te wees, jy gesond is, jy nie enige beserings het nie, en jy die regte ouderdom is.

Wie doen die navorsing?
My naam is Elbé de Villiers en ek werk by die Universiteit Stellenbosch. Ek is 'n Biokinetikus. Ek gebruik oefening om mense sterker te maak nadat hulle seergekry het of as hulle baie siek was.

Wat sal ek moet doen as ek aan die studie deelneem?
Ons gaan eers kyk hoe lank en hoe swaar jy is.
Daarna gaan ons jou laat opwarm deur liggies te draf en bietjie strekke te doen om jou reg te kry vir die toetse.
Jy gaan 20 meter moet hardloop terwyl jy met 'n videokamera afgeneem word en jou tyd geneem word.
Dan gaan jy 'n op 'n meetapparaat moet staan vir 'n paar sekondes, sodat ons jou voet kan meet.
Ons gaan ook jou balans toets. Jy sal agteruit moet loop op drie verskillende plankies. Dit gaan jy twee keer moet doen.
Volgende gaan ons kyk hoe ver jy met altwee bene gelyktydig kan spring.
Daarna gaan ons kyk hoeveel keer jy sywaarts kan spring in 15 sekondes. Dit moet ook twee keer gedoen word.
Laastens gaan ons ook kyk hoe sterk jou handgreep is.

Is daar enigiets wat kan verkeerd gaan?
Jy gaan kort ente hardloop en driekeer spring en jou spiere kan dalk vreemd voel, maar niks kan jou seermaak of niks kan verkeerd gaan nie.
Ons sal ook vir jou mooi wys hoe om alles te doen.

Sal ander mense weet ek neem aan die projek deel?
Niemand hoef te weet dat jy aan die studie deelneem nie en niemand anders, behalwe Elbé, sal weet hoe jy met die toetse gevaar het nie.

Met wie kan ek oor die projek gesels?
As jy enige vrae het oor die projek of as jy met iemand wil gesels kan jy vir Elbé de Villiers (selfoon: 084 515 7642; e-pos: edup@sun.ac.za) of Dr Ranel Venter (selfoon: 083 309 2894; e-pos: rev@sun.ac.za) kontak.

Wat gebeur as ek nie wil deelneem nie?
Jy hoef net deel te neem aan die projek as jy wil. Jy gaan nie gedwing word nie en dit maak nie saak as jou ouers gesê het jy mag nie, en as jy nie wil nie, hoef jy nie.

As jy wel gesê het jy wil deelneem en jy sien later jy is nie lus nie, kan jy enige tyd vir my sê en dan kan jy ophou deelneem aan die projek.

Verstaan jy waaroor hierdie navorsing gaan, en sal jy aan die projek deelneem?

JA NEE

Het die navorser ál jou vrae beantwoord?

JA NEE

Verstaan jy dat jy kan OPHOU deelneem net wanneer jy wil?

JA NEE

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Kind se handtekening Datum

APPENDIX H: ADDITIONAL DATA

Table 2: Maximum to minimum ranking of peak pressure of children aged 10 to 13 years from South Africa.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Healthy		Overweight		Healthy		Overweight		Healthy		Overweight	
	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)
1.	Hallux	288,82 (258,98 - 322,10)	MHF	288,08 (271,05 - 306,19)	MHF	519,92 (484,97 - 557,39)	MHF	573,76* (441,56 - 745,54)	MHF	459,62 (422,18 - 500,40)	MHF	458,84 (346,59 - 607,44)
2.	MHF	265,88 (247,44 - 285,69)	Hallux	288,02 (262,58 - 315,92)	LHF	414,22 (398,27 - 430,17)	LHF	435,04 (375,00 - 495,07)	LHF	383,98 (364,56 - 403,40)	LHF	380,21 (316,09 - 444,32)
3.	LHF	252,73 (236,19 - 269,27)	MH2	278,22* (263,07 - 294,24)	MH2	334,66 (313,53 - 357,21)	MH2	433,91* (339,47 - 554,62)	MH2	242,25 (226,57 - 259,03)	MH2	241,52 (193,63 - 301,25)
4.	MH2	217,13 (203,26 - 231,95)	MH3	274,71* (260,44 - 289,77)	MH3	299,92 (281,74 - 319,27)	MH3	389,02* (307,46 - 492,21)	Hallux	234,87 (205,63 - 268,26)	MH3	226,91 (182,87 - 281,56)
5.	MH3	213,76 (200,73 - 227,64)	LHF	269,14 (255,11 - 283,16)	Hallux	294,90 (264,25 - 329,10)	MH1	331,59* (239,67 - 458,77)	MH3	222,79 (208,69 - 237,84)	MH1	202,96 (145,71 - 282,70)
6.	MH1	175,29 (160,70 - 191,21)	MH4	208,68* (197,16 - 220,88)	MH1	287,03 (263,31 - 312,89)	Hallux	294,24 (194,69 - 444,70)	MH1	218,95 (198,04 - 242,07)	Hallux	194,75 (125,57 - 302,04)
7.	MH4	157,10 (146,92 - 167,99)	MH1	199,80* (185,60 - 215,08)	MH4	163,76 (153,09 - 175,18)	MH4	217,77* (168,98 - 280,66)	MH4	128,74 (119,23 - 139,00)	MH4	140,77 (109,28 - 181,33)
8.	MH5	124,88 (111,20 - 140,25)	MH5	155,31* (140,75 - 171,37)	MF	74,73 (69,48 - 80,37)	MF	110,70* (84,16 - 145,62)	MF	62,72 (57,47 - 68,44)	MF	80,57* (60,39 - 107,49)
9.	MF	74,35 (69,15 - 79,93)	MF	110,12* (103,56 - 117,09)	MH5	72,26 (64,36 - 81,11)	MH5	88,53* (57,29 - 136,81)	MH5	55,49 (48,28 - 63,78)	MH5	54,86 (34,64 - 86,86)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the foot region of healthy weight and overweight category of children ($p < 0.0057$).

Table 3: Maximum to minimum ranking of pressure-time integral of children aged 10 to 13 years from South Africa.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Healthy		Overweight		Healthy		Overweight		Healthy		Overweight	
	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)
1.	MH2	3,20 (2,99 - 3,40)	MH2	3,83* (3,66 - 4,00)	MHF	1,00 (0,83 - 1,16)	MHF	1,41* (0,78 - 2,05)	MH4	0,59 (0,54 - 0,64)	MH4	0,63 (0,49 - 0,82)
2.	MH3	3,02 (2,82 - 3,22)	MH3	3,80* (3,62 - 3,97)	MH4	0,75 (0,70 - 0,81)	MH2	1,04* (0,32 - 1,76)	MHF	0,51 (0,31 - 0,71)	MHF	0,54 (-0,12 - 1,19)
3.	MHF	2,93 (2,75 - 3,11)	MHF	3,40* (3,25 - 3,55)	LHF	0,56 (0,43 - 0,69)	MH4	0,98* (0,76 - 1,28)	Hallux	0,40 (0,36 - 0,44)	Hallux	0,36 (0,26 - 0,51)
4.	MH1	2,48 (2,28 - 2,67)	MH4	3,01* (2,82 - 3,21)	MH2	0,48 (0,29 - 0,67)	LHF	0,90* (0,41 - 1,40)	MH5	0,31 (0,27 - 0,34)	MH5	0,31 (0,21 - 0,45)
5.	LHF	2,43 (2,29 - 2,57)	MH1	2,85* (2,68 - 3,01)	Hallux	0,46 (0,42 - 0,50)	MH3	0,87* (0,17 - 1,57)	MF	0,18 (0,17 - 0,20)	MF	0,23* (0,16 - 0,33)
6.	MH4	2,24 (2,07 - 2,42)	LHF	2,83* (2,71 - 2,95)	MH5	0,41 (0,37 - 0,45)	MH5	0,52* (0,36 - 0,76)	LHF	0,15 (0,00 - 0,30)	LHF	0,16 (-0,35 - 0,67)
7.	Hallux	2,00 (1,82 - 2,20)	Hallux	2,13 (1,97 - 2,31)	MF	0,23 (0,21 - 0,25)	Hallux	0,47 (0,34 - 0,64)	MH2	-0,42 (-0,62 - -0,22)	MH1	-0,51 (-1,23 - 0,20)
8.	MH5	1,60 (1,44 - 1,78)	MH5	2,11* (1,93 - 2,30)	MH3	0,17 (-0,01 - 0,36)	MH1	0,38* (-0,31 - 1,06)	MH1	-0,42 (-0,63 - -0,20)	MH2	-0,59 (-1,25 - 0,07)
9.	MF	0,73 (0,67 - 0,80)	MF	1,15* (1,06 - 1,25)	MH1	0,07 (-0,11 - 0,25)	MF	0,36* (0,25 - 0,50)	MH3	-0,70 (-0,89 - -0,50)	MH3	-0,70 (-1,35 - -0,05)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the foot region of healthy weight and overweight category of children ($p < 0.0057$).

Table 4: Maximum to minimum ranking of force-time integral of children aged 10 to 13 years from South Africa.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Healthy		Overweight		Healthy		Overweight		Healthy		Overweight	
	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)
1.	MHF	38,09 (35,63 - 40,72)	MHF	49,80* (47,06 - 52,70)	MHF	15,17 (14,26 - 16,13)	MHF	19,33* (15,34 - 24,37)	MHF	11,03 (10,37 - 11,73)	MHF	10,86 (8,85 - 13,31)
2.	LHF	32,09 (30,07 - 34,25)	LHF	41,61* (39,37 - 43,97)	LHF	11,32 (10,68 - 12,00)	LHF	14,26* (11,47 - 17,74)	LHF	8,29 (7,83 - 8,77)	LHF	8,11 (6,72 - 9,78)
3.	MH3	26,52 (24,57 - 28,63)	MH3	38,55* (36,13 - 41,14)	MH2	7,69 (7,18 - 8,24)	MH3	10,41* (8,08 - 13,42)	MH2	5,05 (4,75 - 5,37)	MH3	4,87 (4,01 - 5,91)
4.	MH2	24,78 (22,95 - 26,74)	MH2	34,57* (32,40 - 36,88)	MH3	7,42 (6,93 - 7,93)	MH2	10,39* (8,02 - 13,46)	MH1	4,94 (4,46 - 5,48)	MH2	4,85 (3,96 - 5,93)
5.	MH1	24,01 (21,74 - 26,51)	MH1	31,07* (28,56 - 33,80)	MH1	7,18 (6,54 - 7,88)	MH1	8,99* (6,32 - 12,77)	MH3	4,88 (4,60 - 5,17)	MH1	4,57 (3,25 - 6,43)
6.	MH4	17,89 (16,37 - 19,54)	MH4	26,36* (24,46 - 28,41)	MH4	4,64 (4,28 - 5,02)	MH4	6,58* (4,88 - 8,89)	MH4	3,18 (2,93 - 3,46)	MH4	3,33 (2,53 - 4,39)
7.	Hallux	16,10 (14,17 - 18,29)	MF	22,71* (18,79 - 27,43)	MH5	1,44 (1,28 - 1,62)	MF	3,06* (1,35 - 6,93)	Hallux	1,36 (1,29 - 1,70)	Hallux	1,26 (1,06 - 2,66)
8.	MF	8,38 (6,70 - 10,47)	Hallux	18,40 (16,51 - 20,50)	Hallux	1,33 (1,02 - 1,29)	MH5	1,99* (1,28 - 3,09)	MH5	0,91 (0,80 - 1,04)	MF	1,22* (0,52 - 2,90)
9.	MH5	7,63 (6,72 - 8,65)	MH5	11,02* (9,90 - 12,27)	MF	1,19 (0,96 - 1,48)	Hallux	1,25 (1,86 - 4,49)	MF	0,72 (0,55 - 0,93)	MH5	0,86 (0,56 - 1,33)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the foot region of healthy weight and overweight category of children ($p < 0.0057$).

Table 5: Maximum to minimum ranking of contact area of children aged 10 to 13 years from South Africa.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Healthy		Overweight		Healthy		Overweight		Healthy		Overweight	
	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)
1.	MF	13,93 (12,21 - 15,64)	MF	21,40* (19,95 - 22,86)	LHF	9,54 (9,14 - 9,94)	MHF	11,11* (9,57 - 12,65)	LHF	7,25 (6,87 - 7,63)	LHF	6,92 (5,66 - 8,17)
2.	LHF	13,67 (13,25 - 14,08)	LHF	15,31* (14,95 - 15,66)	MHF	9,46 (9,05 - 9,87)	LHF	11,07* (9,55 - 12,58)	MHF	7,08 (6,70 - 7,46)	MHF	6,79 (5,53 - 8,05)
3.	MHF	13,50 (13,07 - 13,92)	MHF	15,26* (14,90 - 15,62)	MH1	7,08 (6,72 - 7,44)	MF	10,65* (4,25 - 17,05)	MH1	5,23 (4,86 - 5,60)	MH1	5,02 (3,81 - 6,23)
4.	MH1	10,32 (9,95 - 10,69)	MH1	11,71* (11,39 - 12,02)	MH4	5,96 (5,71 - 6,20)	MH1	8,38* (7,01 - 9,75)	MH4	4,89 (4,63 - 5,16)	MH4	4,74 (3,86 - 5,62)
5.	MH3	9,20 (8,86 - 9,53)	MH3	10,64* (10,36 - 10,93)	MH3	5,61 (5,29 - 5,93)	MH3	6,95* (5,75 - 8,15)	MH2	4,12 (3,84 - 4,40)	MH2	4,23 (3,29 - 5,17)
6.	Hallux	8,19 (7,82 - 8,56)	MH2	9,42* (9,18 - 9,66)	MH2	5,50 (5,22 - 5,77)	MH2	6,73* (5,68 - 7,77)	MH3	3,98 (3,65 - 4,30)	MH3	4,00 (2,93 - 5,07)
7.	MH2	8,12 (7,83 - 8,40)	MH4	8,84* (8,62 - 9,05)	Hallux	5,35 (4,99 - 5,71)	MH4	6,67* (5,75 - 7,60)	Hallux	3,97 (3,57 - 4,38)	Hallux	3,43 (2,09 - 4,77)
8.	MH4	8,07 (7,81 - 8,32)	Hallux	8,84* (8,52 - 9,15)	MF	3,46 (1,76 - 5,16)	Hallux	5,92* (4,56 - 7,28)	MH5	2,60 (2,41 - 2,80)	MF	3,11* (-3,61 - 9,83)
9.	MH5	4,83 (4,65 - 5,02)	MH5	5,30* (5,14 - 5,46)	MH5	3,40 (3,22 - 3,58)	MH5	3,83* (3,15 - 4,51)	MF	-0,70 (-2,73 - 1,34)	MH5	2,38 (1,73 - 3,03)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.

* Significant greater difference between the foot region of healthy weight and overweight category of children ($p < 0.0057$).

Table 6: Peak pressure differences between the South African and German healthy weight children.

Peak Pressure		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (kPA)	(95% CI)	p	mean (kPA)	(95% CI)	p	mean (kPA)	(95% CI)	p
Hallux	Germany	266,74	(249,82 - 284,81)		262,27	(180,36 - 381,38)		171,04	(114,65 - 255,18)	
	South Africa	288,82	(264,13 - 315,83)	0,081	284,63	(256,96 - 315,28)	0,117	179,21	(162,06 - 198,17)	0,363
MH1	Germany	164,15	(156,56 - 172,10)		274,46	(210,32 - 358,16)		196,68	(148,23 - 260,97	
	South Africa	175,29	(164,34 - 186,98)	0,046	273,54	(254,36 - 294,16)	0,927	190,72	(177,64 - 204,77)	0,395
MH2	Germany	229,09	(220,83 - 237,66)		382,31	(311,61 - 469,05)		234,04	(192,25 - 284,90)	
	South Africa	217,13	(206,52 - 228,28)	0,036	338,26	(319,89 - 357,69)	0,000*	198,88	(189,29 - 208,96)	0,000*
MH3	Germany	224,07	(216,36 - 232,05)		357,07	(293,69 - 434,11)		223,89	(185,48 - 270,24)	
	South Africa	213,76	(203,80 - 224,22)	0,053	319,98	(303,35 - 337,52)	0,000*	193,07	(184,15 - 202,42)	0,000*
MH4	Germany	175,77	(168,96 - 182,85)		214,83	(171,57 - 269,01)		141,85	(112,79 - 178,41)	
	South Africa	157,10	(148,86 - 165,80)	0,000*	186,91	(175,77 - 198,75)	0,000*	119,27	(112,59 - 126,35)	0,000*
MH5	Germany	158,22	(147,79 - 169,39)		215,54	(146,14 - 317,90)		131,64	(87,14 - 198,85)	
	South Africa	124,88	(113,79 - 137,05)	0,000*	163,20	(146,76 - 181,47)	0,000*	95,71	(86,28 - 106,16)	0,000*
MF	Germany	75,40	(72,24 - 78,69)		86,95	(68,12 - 110,97)		65,28	(50,32 - 84,69)	
	South Africa	74,35	(70,13 - 78,81)	0,637	84,11	(78,69 - 89,90)	0,328	61,68	(57,78 - 65,85)	0,089
MHF	Germany	285,95	(274,90 - 297,44)		557,71	(449,09 - 692,61)		450,08	(356,52 - 568,21)	
	South Africa	265,88	(251,97 - 280,56)	0,008	474,06	(446,82 - 502,95)	0,000*	375,88	(354,50 - 398,56)	0,000*
LHF	Germany	251,33	(242,66 - 260,31)		454,49	(374,71 - 551,25)		365,80	(297,57 - 449,66)	
	South Africa	243,35	(231,97 - 255,28)	0,186	406,39	(385,52 - 428,39)	0,000*	321,30	(305,05 - 338,40)	0,000*

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the South African and German healthy weight children ($p < 0.0057$).

Table 7: Pressure-time integral differences between the South African and German healthy weight children.

Pressure-Time Integral		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (N•s/cm²)	(95% CI)	p	mean (N•s/cm²)	(95% CI)	p	mean (N•s/cm²)	(95% CI)	p
Hallux	Germany	2,39	(2,25 - 2,54)		0,60	(0,43 - 0,82)		0,45	(0,32 - 0,64)	
	South Africa	2,00	(1,84 - 2,17)	0,000*	0,60	(0,55 - 0,66)	0,843	0,44	(0,41 - 0,49)	0,744
MH1	Germany	2,68	(2,56 - 2,80)		1,17	(0,92 - 1,48)		0,88	(0,68 - 1,13)	
	South Africa	2,35	(2,22 - 2,49)	0,000*	1,15	(1,08 - 1,23)	0,551	0,84	(0,79 - 0,90)	0,183
MH2	Germany	4,01	(3,89 - 4,13)		1,71	(1,07 - 2,35)		0,13	(-0,48 - 0,74)	
	South Africa	3,20	(3,04 - 3,36)	0,000*	1,21	(1,04 - 1,39)	0,000*	-0,50	(-0,66 - -0,35)	0,000*
MH3	Germany	3,94	(3,82 - 4,06)		1,39	(0,76 - 2,01)		-0,11	(-0,71 - 0,49)	
	South Africa	3,02	(2,86 - 3,18)	0,000*	0,81	(0,64 - 0,98)	0,000*	-0,81	(-0,96 - -0,66)	0,000*
MH4	Germany	2,88	(2,76 - 3,01)		1,15	(0,92 - 1,44)		0,72	(0,58 - 0,91)	
	South Africa	2,24	(2,11 - 2,37)	0,000*	1,01	(0,95 - 1,08)	0,000*	0,61	(0,58 - 0,65)	0,000*
MH5	Germany	2,13	(2,01 - 2,26)		0,85	(0,62 - 1,18)		0,51	(0,37 - 0,72)	
	South Africa	1,60	(1,48 - 1,73)	0,000*	0,72	(0,66 - 0,79)	0,000*	0,42	(0,39 - 0,46)	0,000*
MF	Germany	0,82	(0,77 - 0,87)		0,25	(0,19 - 0,34)		0,18	(0,13 - 0,24)	
	South Africa	0,73	(0,68 - 0,79)	0,005*	0,27	(0,24 - 0,29)	0,283	0,18	(0,16 - 0,19)	0,705
MHF	Germany	3,24	(3,13 - 3,35)		0,49	(-0,07 - 1,05)		-0,49	(-1,07 - 0,09)	
	South Africa	2,93	(2,78 - 3,08)	0,000*	0,55	(0,39 - 0,70)	0,472	-0,51	(-0,66 - -0,37)	0,743
LHF	Germany	2,60	(2,51 - 2,69)		0,14	(-0,30 - 0,59)		-0,59	(-1,05 - -0,13)	
	South Africa	2,43	(2,31 - 2,55)	0,006	0,30	(0,18 - 0,43)	0,009	-0,49	(-0,61 - -0,38)	0,082

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the South African and German healthy weight children ($p < 0.0057$).

Table 8: Force-time integral differences between the South African and German healthy weight children.

Force-Time Integral		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (N•s)	(95% CI)	p	mean (N•s)	(95% CI)	p	mean (N•s)	(95% CI)	p
Hallux	Germany	17,77	(16,33 - 19,34)		3,28	(2,07 - 5,18)		1,83	(1,12 - 2,97)	
	South Africa	16,10	(14,34 - 18,06)	0,093	3,73	(3,29 - 4,22)	0,044	1,98	(1,75 - 2,24)	0,197
MH1	Germany	25,16	(23,80 - 26,61)		9,11	(6,72 - 12,36)		4,68	(3,47 - 6,32)	
	South Africa	24,01	(22,25 - 25,90)	0,224	9,96	(9,17 - 10,83)	0,035	4,84	(4,49 - 5,23)	0,369
MH2	Germany	29,82	(28,58 - 31,11)		11,57	(9,23 - 14,50)		5,06	(4,28 - 5,99)	
	South Africa	24,78	(23,38 - 26,25)	0,000*	10,91	(10,26 - 11,61)	0,065	4,46	(4,28 - 4,66)	0,000*
MH3	Germany	33,05	(31,68 - 34,48)		12,17	(9,73 - 15,23)		5,34	(4,53 - 6,30)	
	South Africa	26,52	(25,03 - 28,10)	0,000*	11,17	(10,51 - 11,88)	0,006	4,58	(4,39 - 4,78)	0,000*
MH4	Germany	21,75	(20,68 - 22,88)		7,62	(5,80 - 10,02)		3,49	(2,73 - 4,47)	
	South Africa	17,89	(16,69 - 19,17)	0,000*	7,21	(6,69 - 7,77)	0,151	3,10	(2,92 - 3,30)	0,000*
MH5	Germany	9,56	(8,91 - 10,25)		3,41	(2,31 - 5,04)		1,39	(0,95 - 2,03)	
	South Africa	7,63	(6,93 - 8,39)	0,0008	3,13	(2,81 - 3,48)	0,109	1,18	(1,07 - 1,30)	0,001*
MF	Germany	10,40	(9,12 - 11,87)		1,99	(0,95 - 4,15)		0,72	(0,33 - 1,57)	
	South Africa	8,38	(7,00 - 10,03)	0,018	2,00	(1,64 - 2,45)	0,953	0,67	(0,55 - 0,81)	0,436
MHF	Germany	40,25	(38,63 - 41,95)		14,11	(11,38 - 17,49)		7,00	(5,86 - 8,36)	
	South Africa	38,09	(36,01 - 40,30)	0,055	15,37	(14,50 - 16,30)	0,004*	7,20	(6,88 - 7,53)	0,220
LHF	Germany	32,32	(31,02 - 33,68)		10,26	(8,32 - 12,65)		5,21	(4,37 - 6,20)	
	South Africa	32,09	(30,34 - 33,94)	0,800	11,88	(11,22 - 12,58)	0,000*	5,71	(5,46 - 5,96)	0,000*

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the South African and German healthy weight children ($p < 0.0057$).

Table 9: Contact area differences between the South African and German healthy weight children.

Contact Area		Basic Model[a]			Adjusted for total contact time[b]			Adjusted for total contact time and body weight[c]		
Region		mean (cm^2)	(95% CI)	p	mean (cm^2)	(95% CI)	p	mean (cm^2)	(95% CI)	p
Hallux	Germany	7,68	(7,47 - 7,89)		5,57	(4,38 - 6,77)		3,10	(1,91 - 4,29)	
	South Africa	8,19	(7,90 - 8,48)	0,001*	6,36	(6,03 - 6,69)	0,000*	3,68	(3,38 - 3,98)	0,000*
MH1	Germany	9,55	(9,34 - 9,77)		7,40	(6,18 - 8,61)		3,65	(2,61 - 4,70)	
	South Africa	10,32	(10,02 - 10,61)	0,000*	8,45	(8,12 - 8,78)	0,000*	4,40	(4,14 - 4,67)	0,000*
MH2	Germany	7,74	(7,58 - 7,90)		5,48	(4,59 - 6,38)		2,59	(1,84 - 3,34)	
	South Africa	8,12	(7,90 - 8,34)	0,001*	6,16	(5,92 - 6,41)	0,000*	3,03	(2,84 - 3,22)	0,000*
MH3	Germany	8,76	(8,57 - 8,94)		6,57	(5,53 - 7,61)		3,20	(2,33 - 4,06)	
	South Africa	9,20	(8,95 - 9,45)	0,001*	7,31	(7,02 - 7,59)	0,000*	3,65	(3,44 - 3,87)	0,000*
MH4	Germany	7,63	(7,49 - 7,78)		6,58	(5,75 - 7,40)		4,14	(3,41 - 4,87)	
	South Africa	8,07	(7,87 - 8,26)	0,000*	7,15	(6,93 - 7,38)	0,000*	4,52	(4,33 - 4,70)	0,000*
MH5	Germany	4,56	(4,45 - 4,67)		4,04	(3,43 - 4,66)		2,23	(1,68 - 2,77)	
	South Africa	4,83	(4,68 - 4,98)	0,000*	4,38	(4,21 - 4,55)	0,000*	2,42	(2,28 - 2,56)	0,006
MF	Germany	14,77	(13,82 - 15,71)		5,89	(0,54 - 11,23)		-1,96	(-7,57 - 3,65)	
	South Africa	13,93	(12,63 - 15,22)	0,201	6,24	(4,78 - 7,70)	0,637	-2,26	(-3,67 - -0,85)	0,682
MHF	Germany	13,06	(12,82 - 13,30)		10,45	(9,09 - 11,81)		5,40	(4,41 - 6,40)	
	South Africa	13,50	(13,17 - 13,83)	0,010	11,24	(10,87 - 11,61)	0,000*	5,78	(5,53 - 6,03)	0,004*
LHF	Germany	13,10	(12,86 - 13,34)		10,59	(9,24 - 11,94)		5,53	(4,55 - 6,51)	
	South Africa	13,67	(13,34 - 13,99)	0,001*	11,49	(11,12 - 11,86)	0,000*	6,02	(5,77 - 6,26)	0,000*

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant difference between the South African and German healthy weight children ($p < 0.0057$).

Table 10: Maximum to minimum ranking of peak pressure of the healthy weight children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)
1.	MHF	285,95 (274,90 - 297,44)	Hallux	288,82 (264,13 - 315,83)	MHF	557,71* (449,09 - 692,61)	MHF	474,06 (446,82 - 502,95)	MHF	450,08* (356,52 - 568,21)	MHF	375,88 (354,50 - 398,56)
2.	Hallux	266,74 (249,82 - 284,81)	MHF	265,88 (251,97 - 280,56)	LHF	454,49* (374,71 - 551,25)	LHF	406,39 (385,52 - 428,39)	LHF	365,80* (297,57 - 449,66)	LHF	321,30 (305,05 - 338,40)
3.	LHF	251,33 (242,66 - 260,31)	LHF	243,35 (231,97 - 255,28)	MH2	382,31* (311,61 - 469,05)	MH2	338,26 (319,89 - 357,69)	MH2	234,04* (192,25 - 284,90)	MH2	198,88 (189,29 - 208,96)
4.	MH2	229,09 (220,83 - 237,66)	MH2	217,13 (206,52 - 228,28)	MH3	357,07* (293,69 - 434,11)	MH3	319,98 (303,35 - 337,52)	MH3	223,89* (185,48 - 270,24)	MH3	193,07 (184,15 - 202,42)
5.	MH3	224,07 (216,36 - 232,05)	MH3	213,76 (203,80 - 224,22)	MH1	274,46 (210,32 - 358,16)	Hallux	284,63 (256,96 - 315,28)	MH1	196,68 (148,23 - 260,97)	MH1	190,72 (177,64 - 204,77)
6.	MH4	175,77* (168,96 - 182,85)	MH1	175,29 (164,34 - 186,98)	Hallux	262,27 (180,36 - 381,38)	MH1	273,54 (254,36 - 294,16)	Hallux	171,04 (114,65 - 255,18)	Hallux	179,21 (162,06 - 198,17)
7.	MH1	164,15 (156,56 - 172,10)	MH4	157,10 (148,86 - 165,80)	MH5	215,54* (146,14 - 317,90)	MH4	186,91 (175,77 - 198,75)	MH4	141,85* (112,79 - 178,41)	MH4	119,27 (112,59 - 126,35)
8.	MH5	158,22* (147,79 - 169,39)	MH5	124,88 (113,79 - 137,05)	MH4	214,83* (171,57 - 269,01)	MH5	163,20 (146,76 - 181,47)	MH5	131,64* (87,14 - 198,85)	MH5	95,71 (86,28 - 106,16)
9.	MF	75,40 (72,24 - 78,69)	MF	74,35 (70,13 - 78,81)	MF	86,95 (68,12 - 110,97)	MF	84,11 (78,69 - 89,90)	MF	65,28 (50,32 - 84,69)	MF	61,68 (57,78 - 65,85)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time.
[c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the South African and German foot region ($p < 0.0057$).

Table 11: Maximum to minimum ranking of pressure-time integral of the healthy weight children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (N•s/cm^2) (95% CI)	Region	mean (N•s/cm^2) (95% CI)	Region	mean (N•s/cm^2) (95% CI)	Region	mean (N•s/cm^2) (95% CI)	Region	mean (N•s/cm^2) (95% CI)	Region	mean (N•s/cm^2) (95% CI)
1.	MH2	4,01* (3,89 - 4,13)	MH2	3,20 (3,04 - 3,36)	MH2	1,71* (1,07 - 2,35)	MH2	1,21 (1,04 - 1,39)	MH1	0,88 (0,68 - 1,13)	MH1	0,84 (0,79 - 0,90)
2.	MH3	3,94* (3,82 - 4,06)	MH3	3,02 (2,86 - 3,18)	MH3	1,39* (0,76 - 2,01)	MH1	1,15 (1,08 - 1,23)	MH4	0,72* (0,58 - 0,91)	MH4	0,61 (0,58 - 0,65)
3.	MHF	3,24* (3,13 - 3,35)	MHF	2,93 (2,78 - 3,08)	MH1	1,17 (0,92 - 1,48)	MH4	1,01 (0,95 - 1,08)	MH5	0,51* (0,37 - 0,72)	Hallux	0,44 (0,41 - 0,49)
4.	MH4	2,88* (2,76 - 3,01)	LHF	2,43 (2,31 - 2,55)	MH4	1,15* (0,92 - 1,44)	MH3	0,81 (0,64 - 0,98)	Hallux	0,45 (0,32 - 0,64)	MH5	0,42 (0,39 - 0,46)
5.	MH1	2,68* (2,56 - 2,80)	MH1	2,35 (2,22 - 2,49)	MH5	0,85* (0,62 - 1,18)	MH5	0,72 (0,66 - 0,79)	MF	0,18 (0,13 - 0,24)	MF	0,18 (0,16 - 0,19)
6.	LHF	2,60 (2,51 - 2,69)	MH4	2,24 (2,11 - 2,37)	Hallux	0,60 (0,43 - 0,82)	Hallux	0,60 (0,55 - 0,66)	MH2	0,13* (-0,48 - 0,74)	LHF	-0,49 (-0,61 - -0,38)
7.	Hallux	2,39* (2,25 - 2,54)	Hallux	2,00 (1,84 - 2,17)	MHF	0,49 (-0,07 - 1,05)	MHF	0,55 (0,39 - 0,70)	MH3	-0,11* (-0,71 - 0,49)	MH2	-0,50 (-0,66 - -0,35)
8.	MH5	2,13* (2,01 - 2,26)	MH5	1,60 (1,48 - 1,73)	MF	0,25 (0,19 - 0,34)	LHF	0,30 (0,18 - 0,43)	MHF	-0,49 (-1,07 - 0,09)	MHF	-0,51 (-0,66 - -0,37)
9.	MF	0,82* (0,77 - 0,87)	MF	0,73 (0,68 - 0,79)	LHF	0,14 (-0,30 - 0,59)	MF	0,27 (0,24 - 0,29)	LHF	-0,59 (-1,05 - -0,13)	MH3	-0,81 (-0,96 - -0,66)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the South African and German foot region ($p < 0.0057$).

Table 12: Maximum to minimum ranking of force-time integral of the healthy weight children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)
1.	MHF	40,25 (38,63 - 41,95)	MHF	38,09 (36,01 - 40,30)	MHF	14,11 (11,38 - 17,49)	MHF	15,37* (14,50 - 16,30)	MHF	7,00 (5,86 - 8,36)	MHF	7,20 (6,88 - 7,53)
2.	MH3	33,05* (31,68 - 34,48)	LHF	32,09 (30,34 - 33,94)	MH3	12,17 (9,73 - 15,23)	LHF	11,88* (11,22 - 12,58)	MH3	5,34* (4,53 - 6,30)	LHF	5,71* (5,46 - 5,96)
3.	LHF	32,32 (31,02 - 33,68)	MH3	26,52 (25,03 - 28,10)	MH2	11,57 (9,23 - 14,50)	MH3	11,17 (10,51 - 11,88)	LHF	5,21 (4,37 - 6,20)	MH1	4,84 (4,49 - 5,23)
4.	MH2	29,82* (28,58 - 31,11)	MH2	24,78 (23,38 - 26,25)	LHF	10,26 (8,32 - 12,65)	MH2	10,91 (10,26 - 11,61)	MH2	5,06* (4,28 - 5,99)	MH3	4,58 (4,39 - 4,78)
5.	MH1	25,16 (23,80 - 26,61)	MH1	24,01 (22,25 - 25,90)	MH1	9,11 (6,72 - 12,36)	MH1	9,96 (9,17 - 10,83)	MH1	4,68 (3,47 - 6,32)	MH2	4,46 (4,28 - 4,66)
6.	MH4	21,75* (20,68 - 22,88)	MH4	17,89 (16,69 - 19,17)	MH4	7,62 (5,80 - 10,02)	MH4	7,21 (6,69 - 7,77)	MH4	3,49* (2,73 - 4,47)	MH4	3,10 (2,92 - 3,30)
7.	Hallux	17,77 (16,33 - 19,34)	Hallux	16,10 (14,34 - 18,06)	MH5	3,41 (2,31 - 5,04)	Hallux	3,73 (3,29 - 4,22)	Hallux	1,83 (1,12 - 2,97)	Hallux	1,98 (1,75 - 2,24)
8.	MF	10,40 (9,12 - 11,87)	MF	8,38 (7,00 - 10,03)	Hallux	3,28 (2,07 - 5,18)	MH5	3,13 (2,81 - 3,48)	MH5	1,39* (0,95 - 2,03)	MH5	1,18 (1,07 - 1,30)
9.	MH5	9,56 (8,91 - 10,25)	MH5	7,63 (6,93 - 8,39)	MF	1,99 (0,95 - 4,15)	MF	2,00 (1,64 - 2,45)	MF	0,72 (0,33 - 1,57)	MF	0,67 (0,55 - 0,81)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the South African and German foot region ($p < 0.0057$).

Table 13: Maximum to minimum ranking of contact area of the healthy weight children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (cm^2) (95% CI)	Region	mean (cm^2) (95% CI)	Region	mean (cm^2) (95% CI)	Region	mean (cm^2) (95% CI)	Region	mean (cm^2) (95% CI)	Region	mean (cm^2) (95% CI)
1.	MF	14,77 (13,82 - 15,71)	MF	13,93 (12,63 - 15,22)	LHF	10,59 (9,24 - 11,94)	LHF	11,49* (11,12 - 11,86)	LHF	5,53 (4,55 - 6,51)	LHF	6,02* (5,77 - 6,26)
2.	LHF	13,10 (12,86 - 13,34)	LHF	13,67* (13,34 - 13,99)	MHF	10,45 (9,09 - 11,81)	MHF	11,24* (10,87 - 11,61)	MHF	5,40 (4,41 - 6,40)	MHF	5,78* (5,53 - 6,03)
3.	MHF	13,06 (12,82 - 13,30)	MHF	13,50 (13,17 - 13,83)	MH1	7,40 (6,18 - 8,61)	MH1	8,45* (8,12 - 8,78)	MH4	4,14 (3,41 - 4,87)	MH4	4,52* (4,33 - 4,70)
4.	MH1	9,55 (9,34 - 9,77)	MH1	10,32* (10,02 - 10,61)	MH4	6,58 (5,75 - 7,40)	MH3	7,31* (7,02 - 7,59)	MH1	3,65 (2,61 - 4,70)	MH1	4,40* (4,14 - 4,67)
5.	MH3	8,76 (8,57 - 8,94)	MH3	9,20* (8,95 - 9,45)	MH3	6,57 (5,53 - 7,61)	MH4	7,15* (6,93 - 7,38)	MH3	3,20 (2,33 - 4,06)	Hallux	3,68* (3,38 - 3,98)
6.	MH2	7,74 (7,58 - 7,90)	Hallux	8,19* (7,90 - 8,48)	MF	5,89 (0,54 - 11,23)	Hallux	6,36* (6,03 - 6,69)	Hallux	3,10 (1,91 - 4,29)	MH3	3,65* (3,44 - 3,87)
7.	Hallux	7,68 (7,47 - 7,89)	MH2	8,12* (7,90 - 8,34)	Hallux	5,57 (4,38 - 6,77)	MF	6,24 (4,78 - 7,70)	MH2	2,59 (1,84 - 3,34)	MH2	3,03* (2,84 - 3,22)
8.	MH4	7,63 (7,49 - 7,78)	MH4	8,07* (7,87 - 8,26)	MH2	5,48 (4,59 - 6,38)	MH2	6,16* (5,92 - 6,41)	MH5	2,23 (1,68 - 2,77)	MH5	2,42 (2,28 - 2,56)
9.	MH5	4,56 (4,45 - 4,67)	MH5	4,83* (4,68 - 4,98)	MH5	4,04 (3,43 - 4,66)	MH5	4,38* (4,21 - 4,55)	MF	-1,96 (-7,57 - 3,65)	MF	-2,26 (-3,67 - -0,85)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.

* Significant greater difference between the South African and German foot region ($p < 0.0057$).

Table 14: Maximum to minimum ranking of peak pressure of the overweight category of children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)	Region	mean (kPA) (95% CI)
1.	MHF	304,15 (281,81 - 328,26)	MHF	288,08 (261,74 - 317,08)	MHF	505,77 (338,49 - 755,72)	MHF	452,89 (408,22 - 502,44)	MHF	395,23 (261,91 - 596,41)	Hallux	356,74 (301,90 - 421,55)
2.	MH2	293,19 (272,68 - 315,25)	Hallux	288,02 (247,10 - 335,71)	Hallux	478,08 (249,63 - 915,59)	Hallux	452,17 (382,24 - 534,90)	Hallux	381,45 (192,52 - 755,79)	MHF	349,58 (316,17 - 386,53)
3.	MH3	291,61 (272,57 - 311,98)	MH2	278,22 (253,98 - 304,78)	MH2	465,28 (317,39 - 682,07)	MH2	419,56 (380,05 - 463,18)	LHF	315,11* (226,13 - 439,11)	LHF	280,85 (259,00 - 304,55)
4.	Hallux	287,94 (254,89 - 325,26)	MH3	274,71 (252,36 - 299,04)	LHF	412,33 (295,33 - 575,67)	LHF	372,45 (341,66 - 406,02)	MH2	273,29* (198,46 - 376,34)	MH2	240,00 (221,97 - 259,50)
5.	LHF	276,35 (259,41 - 294,40)	LHF	260,91 (240,96 - 282,50)	MH3	360,35 (251,12 - 517,07)	MH3	331,62 (302,06 - 364,08)	MH3	217,94* (161,15 - 294,74)	MH3	195,61 (181,71 - 210,57)
6.	MH4	232,59 (214,06 - 252,71)	MH4	208,68 (188,01 - 231,63)	MH1	241,64 (138,15 - 422,67)	MH1	265,77 (229,99 - 307,11)	MH1	144,99 (84,15 - 249,84)	MH1	155,47 (136,13 - 177,55)
7.	MH5	185,18 (158,35 - 216,56)	MH1	199,80 (175,20 - 227,85)	MH4	192,14 (123,15 - 299,78)	MH4	176,07 (156,94 - 197,53)	MH4	121,50 (79,75 - 185,12)	MH4	108,83 (98,20 - 120,61)
8.	MH1	175,34 (157,94 - 194,65)	MH5	155,31 (127,57 - 189,08)	MF	98,99 (62,35 - 157,17)	MF	100,79 (89,44 - 113,59)	MF	59,07 (38,53 - 90,56)	MF	58,62 (52,81 - 65,06)
9.	MF	109,35 (100,33 - 119,18)	MF	110,12 (98,83 - 122,71)	MH5	59,16 (26,04 - 134,39)	MH5	56,28 (45,52 - 69,58)	MH5	32,91 (14,37 - 75,38)	MH5	30,41 (24,84 - 37,23)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the South African and German foot region ($p < 0.0057$).

Table 15: Maximum to minimum ranking of pressure-time integral of the overweight category of children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)	Region	mean (N•s/cm²) (95% CI)
1.	MH2	4,93* (4,64 - 5,21)	MH2	3,83 (3,47 - 4,19)	MHF	1,40 (0,14 - 2,65)	MH1	1,28 (1,14 - 1,45)	MH1	0,90 (0,57 - 1,43)	MH1	0,88 (0,79 - 0,99)
2.	MH3	4,86* (4,56 - 5,15)	MH3	3,80 (3,43 - 4,17)	MH1	1,29 (0,81 - 2,05)	MHF	1,27 (0,95 - 1,60)	MHF	0,63 (-0,65 - 1,92)	MH4	0,52 (0,47 - 0,58)
3.	MHF	3,79 (3,54 - 4,03)	MHF	3,40 (3,09 - 3,71)	MH2	1,15* (-0,25 - 2,56)	MH4	0,84 (0,75 - 0,95)	MH4	0,57 (0,37 - 0,87)	Hallux	0,50 (0,44 - 0,57)
4.	MH4	3,74* (3,41 - 4,12)	MH4	3,01 (2,67 - 3,39)	MH4	0,89 (0,57 - 1,41)	LHF	0,66 (0,41 - 0,91)	Hallux	0,51 (0,30 - 0,87)	MHF	0,47 (0,16 - 0,78)
5.	LHF	3,11 (2,92 - 3,30)	LHF	2,83 (2,58 - 3,07)	LHF	0,67 (-0,29 - 1,64)	Hallux	0,60 (0,52 - 0,68)	MH5	0,23 (0,13 - 0,43)	MH5	0,22 (0,19 - 0,26)
6.	MH1	2,96 (2,71 - 3,24)	MH1	2,69 (2,40 - 3,01)	Hallux	0,61 (0,37 - 1,02)	MH2	0,47 (0,11 - 0,84)	MF	0,19 (0,12 - 0,32)	MF	0,20 (0,17 - 0,22)
7.	MH5	2,67* (2,34 - 3,03)	Hallux	2,13 (1,87 - 2,43)	MH5	0,43 (0,23 - 0,80)	MH5	0,41 (0,35 - 0,49)	LHF	-0,06 (-1,03 - 0,90)	LHF	-0,11 (-0,35 - 0,12)
8.	Hallux	2,55 (2,30 - 2,83)	MH5	2,11 (1,79 - 2,48)	MF	0,37 (0,21 - 0,66)	MF	0,39 (0,34 - 0,45)	MH2	-0,55* (-1,81 - 0,72)	MH2	-1,31 (-1,62 - -1,00)
9.	MF	1,26 (1,12 - 1,40)	MF	1,15 (1,00 - 1,32)	MH3	0,08* (-1,30 - 1,46)	MH3	-0,45 (-0,81 - -0,10)	MH3	-1,62* (-2,85 - -0,39)	MH3	-2,24 (-2,54 - -1,94)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the South African and German foot region ($p < 0.0057$).

Table 16: Maximum to minimum ranking of force-time integral of the overweight category of children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)	Region	mean (N•s) (95% CI)
1.	MHF	52,98 (49,02 - 57,26)	MHF	49,80 (45,16 - 54,91)	MHF	22,78 (15,35 - 33,81)	MHF	23,51 (21,23 - 26,03)	MHF	13,85 (9,78 - 19,61)	MHF	13,94 (12,80 - 15,17)
2.	MH3	47,89* (44,07 - 52,04)	LHF	41,61 (37,76 - 45,85)	LHF	16,11 (10,98 - 23,62)	LHF	17,21 (15,58 - 19,00)	LHF	9,54 (6,90 - 13,19)	LHF	9,93 (9,18 - 10,75)
3.	LHF	43,46 (40,23 - 46,95)	MH3	38,55 (34,72 - 42,80)	MH2	15,25 (10,11 - 23,03)	MH1	14,06 (11,99 - 16,49)	MH2	7,88* (5,80 - 10,71)	MH1	7,24 (6,28 - 8,35)
4.	MH2	43,09* (39,67 - 46,81)	MH2	34,57 (31,15 - 38,36)	MH1	13,21 (7,13 - 24,46)	MH2	13,72 (12,34 - 15,27)	MH1	7,02 (3,92 - 12,59)	MH2	6,86 (6,36 - 7,39)
5.	MH1	32,20 (28,62 - 36,23)	MH1	31,07 (26,79 - 36,02)	MH3	11,88 (8,08 - 17,49)	MH3	11,16 (10,10 - 12,33)	MH3	6,05* (4,67 - 7,84)	MH3	5,49 (5,16 - 5,85)
6.	MH4	31,29 (28,22 - 34,69)	MH4	26,36 (23,16 - 30,01)	MH4	5,74 (3,55 - 9,29)	MH4	5,83 (5,15 - 6,61)	Hallux	2,93 (1,43 - 6,01)	Hallux	2,89 (2,42 - 3,45)
7.	MF	25,58 (20,90 - 31,30)	MF	22,71 (17,62 - 29,26)	MF	5,54 (1,93 - 15,94)	MF	5,83 (4,44 - 7,66)	MH4	2,91 (1,95 - 4,33)	MH4	2,85 (2,59 - 3,15)
8.	Hallux	21,63 (18,82 - 24,85)	Hallux	18,40 (15,45 - 21,92)	Hallux	4,58 (2,26 - 9,26)	Hallux	4,62 (3,85 - 5,55)	MF	1,60 (0,61 - 4,16)	MF	1,58 (1,25 - 1,99)
9.	MH5	13,17 (11,29 - 15,37)	MH5	11,02 (9,08 - 13,38)	MH5	1,57 (0,74 - 3,35)	MH5	1,67 (1,37 - 2,02)	MH5	0,64 (0,32 - 1,27)	MH5	0,65 (0,55 - 0,77)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the South African and German foot region ($p < 0.0057$).

Table 17: Maximum to minimum ranking of contact area of the overweight category of children from South Africa and Germany.

Max. to Min.	Basic Model[a]				Adjusted for total contact time[b]				Adjusted for total contact time and body weight[c]			
	Germany		South Africa		Germany		South Africa		Germany		South Africa	
	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)	Region	mean (cm²) (95% CI)
1.	MF	22,08 (20,06 - 24,09)	MF	21,40 (18,87 - 23,94)	MF	17,45 (6,64 - 28,27)	MF	17,29 (14,49 - 20,09)	MHF	7,74 (5,56 - 9,92)	LHF	8,49* (7,98 - 9,00)
2.	MHF	14,66 (14,13 - 15,20)	LHF	15,31 (14,66 - 15,96)	MHF	12,15 (9,31 - 14,99)	LHF	13,03* (12,32 - 13,74)	LHF	7,70 (5,62 - 9,78)	MHF	8,39 (7,86 - 8,92)
3.	LHF	14,58 (14,07 - 15,10)	MHF	15,26 (14,59 - 15,93)	LHF	12,02 (9,28 - 14,76)	MHF	13,02 (12,29 - 13,76)	MH1	6,76 (4,54 - 8,98)	MH1	7,42 (6,88 - 7,96)
4.	MH1	11,01 (10,54 - 11,48)	MH1	11,71 (11,11 - 12,30)	MH1	9,95 (7,43 - 12,46)	MH1	10,76 (10,11 - 11,41)	MF	5,98 (-4,17 - 16,13)	MH2	5,85 (5,43 - 6,26)
5.	MH3	10,28 (9,89 - 10,67)	MH3	10,64 (10,15 - 11,13)	MH2	8,17 (6,21 - 10,13)	MH3	8,63 (8,09 - 9,16)	MH2	5,61 (3,91 - 7,30)	MH3	5,27 (4,88 - 5,66)
6.	MH2	9,16 (8,79 - 9,53)	MH2	9,42 (8,96 - 9,88)	MH3	8,01 (5,94 - 10,09)	MH2	8,54 (8,04 - 9,05)	Hallux	4,98 (2,61 - 7,36)	MF	5,24 (2,77 - 7,72)
7.	Hallux	8,64 (8,18 - 9,10)	MH4	8,84 (8,48 - 9,20)	Hallux	7,38 (4,91 - 9,85)	Hallux	7,71 (7,08 - 8,35)	MH3	4,81 (3,21 - 6,42)	Hallux	5,20 (4,62 - 5,78)
8.	MH4	8,42 (8,14 - 8,71)	Hallux	8,84 (8,26 - 9,42)	MH4	6,15 (4,66 - 7,65)	MH4	6,82* (6,43 - 7,20)	MH4	4,21 (2,92 - 5,50)	MH4	4,78* (4,46 - 5,09)
9.	MH5	5,02 (4,79 - 5,25)	MH5	5,30 (5,01 - 5,58)	MH5	3,57 (2,36 - 4,77)	MH5	4,01 (3,69 - 4,32)	MH5	1,98 (0,94 - 3,02)	MH5	2,34* (2,09 - 2,60)

[a] Basic Model; basic model without adjusting for confounders. [b] Adjusted for total contact time; the same model as basic model but adjusted for total contact time. [c] Adjusted for total contact time and body weight; the same model as basic model but adjusted for total contact time and body weight.
* Significant greater difference between the South African and German foot region ($p < 0.0057$).