

The three-dimensional kinematics and spatiotemporal parameters of gait in 6-10
year old typically developed children in the Cape Metropole

A Pilot Study

by

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DECLARATION PAGE

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ABSTRACT

BACKGROUND: A functional gait forms an integral part of life, allowing individuals to function within their environment and participate in activities of daily living. The evaluation of gait forms an essential part of a physical examination and can help screen for physical impairments. To the researchers' knowledge no 3D gait analysis studies of this nature have been conducted in South Africa. South African gait analysis laboratory protocols and procedures may differ from laboratories in other countries; therefore a South African data base of normative values is required to make a valid assessment of South African children's gait.

OBJECTIVE: The aim of this study is to describe kinematics and spatiotemporal parameters of gait of typically developed children between the ages of 6-10 years in the Cape Metropole of the Western Cape, South Africa.

METHODOLOGY: A descriptive study was conducted. Twenty-eight typically developed children were conveniently sampled from aftercare facilities and schools were performed in the Cape Metropole in the Western Cape, South Africa. The three-dimensional (3D) lower limb kinematics and spatiotemporal parameters of gait were analyzed. For data capture, the lower limb Plug-in-Gait (PIG) marker placement was used. Participants were asked to walk bare footed at self-selected speed. Due to a small sample size, children were also sub-divided into two groups (Group A: 6-8 years and Group B: 9-10 years) for comparison. Means and standard deviations (SD) were calculated for all outcomes, followed by statistical tests to determine significant differences between the two sub-groups for spatiotemporal parameters and kinematics.

RESULTS: There was a significant difference between the sub-groups for all the non-normalized spatiotemporal parameters. A statistical significant difference

between the sub-groups for the mean hip rotation minimum values ($p=0.036$) was found. There was no significant difference between the sub-groups for any other kinematic parameter or when comparing the normalized spatiotemporal parameters.

CONCLUSION: This study provides descriptive gait parameters that can be used for comparison or gait analysis purposes. Our results suggest that normalized spatiotemporal parameters showed no significant difference between the age groups and are consistent with international children's spatiotemporal parameters. Kinematic values showed significant changes with hip rotation. Older children had more external rotation at their hips.

KEYWORDS: 3D gait analysis, walking, children, spatiotemporal parameters, kinematics

OPSOMMING

INLEIDING: 'n Funksionele stap is 'n essensiële deel van die lewe wat mens toelaat om in jou omgewing te funksioneer en om deel te neem aan daaglikse aktiwiteite. Evaluasie van stap is 'n belangrike deel van die fisiese evaluasie en kan help om te sif vir fisiese verswakking of abnormaliteite. So ver hierdie navorsers weet, is hierdie die eerste loop analyse studie van sy soort wat in Suid-Afrika onderneem is. Suid-Afrikaanse stap-evaluasie-labrotorium protokols en procedures mag ook dalk verskil van die in ander lande. Dus is 'n Suid-Afrikaanse databasis vir normale waardes van loop nodig om 'n gegronde evaluasie van Suid-Afrikaanse kinders se loopgang te kan maak.

DOELWIT: Die doel van hierdie studie is om die kinematika en spatiotemporale parameters van loop te omskryf in tipies ontwikkelde kinders tussen die ouderdom van 6-10 jaar in die Kaapse Metropool en om die bevindinge tussen die twee ouderdomsgroepe te vergelyk.

METODE: 'n Beskrywende studie is uitgevoer. Ag-en-twintig tipies ontwikkelde kinders is van skole en nasorgfasiliteite in die Kaapse Metropool in die Wes-Kaap, Suid-Afrika gewerf. Die drie-dimensionele (3D) onderste ledemaat se kinematika en spatiotemporale parameters van loop is geanalyseer. Vir data insameling is die onderste ledemaat Plug-in-Gait (PIG) merker-plasing gebruik. Deelnemers is gevra om kaalvoet teen hulle eie spoed te stap. Die kinders is in die verskeie ouderdomsgroepe verdeel, maar as gevolg van klein toetsgroepgetalle, is hulle sub-verdeel in twee groepe (Groep A: 6-8 jaar en Groep B: 9-10 jaar). Beskrywende statistiese tegnieke is gebruik vir alle uitkoms maatreëls. Gemiddeldes en standaardafwykings (SA) was bereken, om beduidende verskille tussen die ouderdomsgroepe en sub-groepe te bepaal.

RESULTATE: Daar is 'n beduidende verskil tussen die jonger en ouer kinders vir nie-genormaliseerde spatiotemporale parameters, asook 'n beduidende verskil tussen die sub-groepe vir die gemiddelde heuprotasie minimum waardes ($p=0.036$). Daar was geen beduidende verskil tussen die twee groepe met die ander kinematisiese parameters of met genormaliseerde spatiotemporale parameters van die sub-groepe nie.

GEVOLGTREKKING: Hierdie studie verskaf beskrywende statistiese data van stapparameters wat gebruik kan word vir vergelyking met ander kinders van dieselfde ouderdomme of loop-analise doeleinades. Ons bevindinge stel voor dat genormaliseerde spatiotemporale parameters geen beduidende bevindings aandui tussen die verskeie ouderdomsgroepe nie. Dit is ook konsekwent met internasionale kinders se spatiotemporale parameterwaardes. Kinematisie waardes het beduidende verskille in heuprotatsie getoon. Ouer kinders het meer eksterne rotasie in hulle heupe in vergelyking met jonger kinders. Soos die kinders ontwikkel, verminder die heup-anteversie en die heup beweeg vanaf interne rotasie na 'n relatiewe eksterne rotasie.

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TABLE OF CONTENTS

Declaration	1
Abstract	2
Opsomming	4
Acknowledgements	6
List of figures	10
List of tables	10
List of abbreviations	11
List of definitions	12
CHAPTER 1: Introduction and Literature review	
1.1 Introduction	13
1.2 Spatiotemporal Parameters	15
1.3 Kinematics	16
1.4 Other factors influencing gait	17
1.4.1 Obesity and Overweight	17
1.4.2 Shoes	18
1.4.3 Genu Valgum and Genu Varum	19
1.4.4 Backpack Carriage	20
1.4.5 Low Foot Arches / Flat Feet	20

1.4.6 Generalized Joint Hypermobility	21
1.4.7 Different Ethnic Backgrounds	22
1.5 Conclusion	23
CHAPTER 2: The Article	
Title page	24
Article	25
CHAPTER 3: Summary	
3.1 Contribution to Knowledge	58
3.2 Limitations of the Study	58
3.3 Recommendations for Future Research	59
Conclusion	60
REFERENCE LIST	61
ADDENDA	
Addendum A: Bio-Med Central Journal (Paediatrics) Guidelines	73
Addendum B: Ethics Approval	85
Addendum C: Informed Consent	87
Addendum D: Informed Assent	90
Addendum E: Information Letter	93
Addendum F: General Health and Activity Questionnaire	94

Addendum G: Telephonic Screening Questionnaire	95
Addendum H: Indemnity Form	97
Addendum I: Vicon Marker Placement	98
Addendum J: Physical Evaluation Form	103
Addendum K: Walking Instructions	104

LIST OF FIGURES

Figure 1: The pelvis and hip joint kinematics of the two sub-groups during a gait cycle

Figure 2: The knee, ankle and foot joint kinematics of the two sub-groups during a gait cycle

LIST OF TABLES

Table 1: The mean values for weight, height and BMI for boys and girls per age group ($n = 28$)

Table 2: Spatiotemporal Parameters (non-normalized and normalized) for each age group

Table 3: Spatiotemporal Parameters (non-normalized and normalized) for the two age subgroups

Table 4: The maximum values for the gait kinematics of the pelvis and lower limb kinematics for the two age groups

Table 5: The minimum values for the gait kinematics of the pelvis and lower limb kinematics for the two age groups

Table 6: The range values for the gait kinematics of the pelvis and lower limb kinematics for the two age groups

LIST OF ABBRIVIATIONS

3D – Three-dimensional

Abd – Abduction

Add – Adduction

DF – Dorsiflexion

E – Extension

EMG – Electromyography

Ext Rot – External rotation

F – Flexion

GJH – Generalized Joint Hypermobility

Int Rot – Internal rotation

PF - Plantar flexion

PIG – Plug-in-Gait model

ROM – Range of motion

SD – Standard Deviation

ST – Spatiotemporal parameters

LIST OF DEFINITIONS

Cadence is the number of steps taken in a unit time (seconds or minutes) [1].

Kinematics provides variables that help to describe the motion of body segments. These variables include the type of displacement (translatory, rotational or a combination thereof), location of the displacement in space (saggital, frontal or transverse planes), direction of displacement (flexion / extension, abduction / adduction, medial / lateral rotation), magnitude of displacement (the degree of movement occurring) and the rate of displacement (the speed, velocity or acceleration of the segment movement) [1].

Spatiotemporal parameters are distance and temporal variables that are used to describe gait. Temporal variables of gait are stance time, single-leg and double-support time, swing, stride and step time, cadence and speed. Distance variables of gait are step length and width; stride length and degree of toe-out [1].

Step length is a linear distance between two successive points of contact of the opposite extremities [1].

Stride length is a distance travelled during a gait cycle and includes two steps (a right step and a left step). It is described as being the linear distance between two successive events that are accomplished by the same lower extremity during gait [1].

CHAPTER 1

INTRODUCTION & LITERATURE REVIEW

1.1 INTRODUCTION

The aim of the literature review is to provide an overview of the spatiotemporal parameters and joint kinematics during gait in typically developed children between the ages of 6-10 years and to highlight some of the most pronounced factors influencing the gait patterns of children. To our knowledge, there are no published studies to describe the walking patterns of typically developed children between the ages of 6-10 years in South Africa. This review will provide an overview of gait patterns in typically developed countries (America, Australia, United Kingdom and Germany) and developing countries (Mexico, Brazil and Turkey).

The following electronic databases were searched: BioMed Central, Cochrane, ProQuest, PubMed, Science Direct and Scopus. Keywords used in different combinations included: ‘gait’, ‘walking’, ‘children’, ‘spatiotemporal’, ‘temporo-spatial’, ‘3D analysis’, ‘kinematics’ and ‘biomechanics’. The literature search was conducted up to September 2014 and included studies published in English and within 2000-2014. Prior to a study by Ferrari et al. [2], which was one of the first studies that compared five different gait analysis protocols to assess inter-protocol variability, there have been no emphasis on standardization of gait analysis protocols between different laboratories. However, recently there has been an increase in studies measuring the reproducibility of data within and between gait laboratories. Therefore, in order to present the most comparable literature findings, studies prior to the year

2000 were excluded in the literature search. Studies published prior to 2000 were included if deemed comparable and insightful.

Gait of a toddler is usually unstable with a wide base of support, abducted thighs, flexion at the hips and knees and the centre of gravity is influenced by the position of the head [3]. As gait matures, the base of support diminishes, normal arm swing appears and step length and walking speed increase [4]. Walking gait is a complex set of specific movements and interactions that require sensory-motor integration and control by the central nervous system [5].

In the literature, the age at which the gait pattern matures, is controversial. Earlier studies [6] [7] suggested that maturation of gait happens between the ages of three and five. More recent studies showed that at a normalized speed, gait parameters showed little change as the children grew older [8] [9]. The general calculated assumption is that a matured gait pattern is reached by the age of seven [10]. However, sagittal movements of the spine and thorax are gradually dependent on age and can evolve right up and into the teenage years [11]. This could suggest that maturation of gait can still happen within the teenage years if the spine and trunk movements are also considered. Other studies support this notion of gait maturation taking place up until the teenage years due to various reasons, for instance significant changes were also found in the normalized measurements of stance duration and double / single leg support time when comparing children's gait with those of young adults [9] [12] [13].

1.2 SPATIOTEMPORAL PARAMETERS

Spatiotemporal parameters are divided into distance and time (temporal) variables. Distance variables of gait are step length and width; stride length and degree of toe-out. Temporal variables of gait are stance time, single-leg and double-support time, swing, stride and step time, cadence and speed. Numerous studies use the spatiotemporal parameters of gait to describe and evaluate walking patterns. It is simpler to compare and to determine the missing / adapted components of gait when researchers and / or clinicians have a basic understanding of the spatiotemporal parameters [1].

The average speed of walking in children varies between studies ranging from 1.19-1.36 m.s⁻¹ [14] [15] [16]. Studies evaluate the effect of speed on the kinematics and other spatiotemporal parameters of gait, because speed is a greater predicting factor of gait patterns than the age of children [14] [16] [17] [18].

As walking speed increases, the cadence, step length and stride length also increase and consequently the stance time and double-support time decrease [18] [19]. However, other studies have reported that as age increases, walking speed, step- and stride-length and base of support also increase, but that the cadence decreases [7] [9] [15]. Lythgo et al. [16] compared the gait of adults and children at 3 different speeds. Their results showed that cadence, step and stride length increased with speed, whereas the time of step and stride decreased within the same age group. On the other hand, with increased age, walking speed, step and stride length increased, the cadence decreased due to increase in step and stride time. Thus, age and speed both play a major role in the spatiotemporal parameters of gait in children.

1.3 KINEMATICS

Kinematics provides variables that help to describe the motion segments [1]. These variables include the type of displacement (translatory, rotational or a combination thereof), location of the displacement in space (sagittal, frontal or transverse planes), direction of displacement (flexion / extension, abduction / adduction, medial / lateral rotation), magnitude of displacement (the degree of movement occurring) and the rate of displacement (the speed, velocity or acceleration of the segment). The kinematics of the foot / ankle, knee, hip and pelvis are mostly described during gait analysis [1].

Thummerer et al. [11] evaluated trunk, spinal and pelvic movement during gait in typically developed children (sub-groups 4-6, 7-9 and 10-12 years) to determine whether age or speed was the predominant factor describing gait kinematics. Their study reported that sagittal spine and trunk movements are gradually dependent on age. Contrary to that, they found that spinal and pelvic parameters in the frontal plane were more dependent on speed than on age. They supported the notion that maturation of gait can happen up to the teenage years, especially regarding thorax and spine kinematics in the sagittal plane. Schwartz et al. [18] establish that sagittal, transverse and frontal plane kinematics were significantly associated with speed in children aged 4-17 years. They found that hip flexion at foot contact, dorsiflexion at toe off and maximum hip extension all increased with a higher walking speed. Van der Linden et al. [17] included children aged 8-11 years in their study and evaluated the kinematic and kinetic characteristics of gait at five different walking speeds. Their research has shown significant differences in hip sagittal movements when comparing the five speed groups. A greater range of flexion and extension movements were produced in both studies when the children were walking at a

faster speed [17] [18]. Van der Linden et al. [17] also reported that walking speed largely affected kinematic parameters of gait and that speed amplified the curves. Stansfield et al. [14] concluded that as normalized speed increases, so the joint range angles will also increase. At an increased normalized speed, the shape of the curves were more pronounced and showed greater minimum and maximum peak values. Both studies by Stansfield et al. [14] and Van der Linden et al. [17] found an increase in hip flexion and ankle dorsiflexion in the sagittal plane at a greater walking speed, whereas Thummerer et al. [11] reported increases in spinal and trunk movements in the sagittal plane due to the older age of the children.

1.4 OTHER FACTORS INFLUENCING GAIT

Other less prominent factors that influence gait parameters of children are described below.

1.4.1 *Obesity and Overweight:*

Obesity and overweight in children are becoming more prevalent across the world ([20] (United Kingdom); [21] (Germany); [22] (United States)). Normal-weight body-mass index (BMI) is defined as having a BMI between the 15th and 85th percentile of BMI for age, overweight is having a BMI for age that falls between the 85th and 95th percentile and obesity is described as having a BMI at or above the 95th percentile [23].

Besides the detrimental effects obesity and overweight have on musculoskeletal structures such as foot deformities and slipped capital femoral epiphysis [24], varus / valgus deformities at the knee [25], Blount's disease [26] and early osteoarthritis [27] [28] [29], it also affects walking gait kinematics and spatiotemporal parameters of

gait [24] [30] [31]. McMillan et al. [32] compared the lower limb frontal biomechanics of gait in normal-weight and overweight boys between the ages of 10 and 14. They found that overweight boys maintained the rear-foot in inversion and the knee in abduction (valgus) through-out the stance phase. Overweight boys also maintained more hip adduction during the stance phase compared to the normal-weight boys. The authors concluded that the lower limb is unable to support the large weight of the body during single leg stance and it appears that the hip collapses into adduction during the stance phase. Increased hip adduction during the stance phase places the distal femur into a relatively medial position, which places the knee into more valgus. Children with excess body weight walk with a slower, more tentative, rigid walking pattern [31] [33] [34] [35], as well as decreased stability [30].

Spatiotemporal parameters of gait differ between obese children and their normal-weight peers. Obese children walk with a larger step width, displaying a greater base of support as a potential mechanism to compensate for decreased stability [31] [33]. They also walk with a slower speed and cadence, spending more time in double leg support than in the swing phase [34].

1.4.2 Shoes:

Wearing shoes may contribute to changes in the gait pattern of children [36]. In a systematic review by Wegener et al. [36], they summarized the effect of shod versus barefoot gait patterns in children 1 ½ -15 years of age in eleven studies. They found that children who wore shoes walked faster, their cadence decreased and the stride length, double-leg support time and base of support increased. Wegener et al. [36] establish that wearing shoes increased the support phases of walking and reduced foot movement.

1.4.3 *Genu Valgum and Genu Varum:*

The load-bearing line of the knee joint crosses through the distal part of the femur and the middle of the proximal part of the tibia. Knock-knees (genu valgum) are characterized by a joint shifted medially in relation to the joint line, causing a change in the alignment of the femur and tibia in the frontal plane [37]. The joint can also be shifted laterally from the line, causing bow legs (genu varum). These conditions cause asymmetrical loading of the joint surfaces and stretching of ligamentous structures surrounding the joint [37] [38]. These positions hamper the proper transfer of body weight toward the foot. It also interferes with the dynamic equilibrium of the muscles (moving and stabilizing) of the body segments, resulting in higher energy consumption during gait for the knock-knee / bowleg children compared to their peers [37] [39] [40].

Comparing the gait parameters of children with knock-knees and those with normal alignment, researchers found a significant difference in the time (temporal) variables of gait and the knee and ankle joint kinematics [37]. Children with knock-knees were found to have longer double and single leg support phases and a shorter swing phase. In essence they walked slower and with a lower cadence. Frontal plane movement of the knee in children with knock-knees was significantly greater than for children with normally aligned knees, whereas the ankle frontal plane movements were smaller [37]. Another study found significant differences in the transverse plane movements during gait [41]. They observed increased external hip rotation and decreased external knee rotation. They concluded that these differences contribute to compensatory gait mechanisms that children with knock-knees use to decrease joint loading.

Stief et al. [42] evaluated the gait of fourteen children with bow-legs and compared it to those with a normal knee alignment. They found that children with bowlegs showed reduced knee extension in the terminal stance phase. Other major differences included kinetic parameters of the hip and knee, such as significantly higher maximum hip abduction moment in loading response and maximum knee adduction moment in mid-stance and terminal in children with bowlegs. They concluded that the walking patterns of children with bowlegs did not show typical compensatory mechanisms and therefore they do not need to alter the spatiotemporal parameters of walking gait in order to decrease knee joint loading.

1.4.4 Backpack Carriage:

Six to ten year old children are expected to carry backpacks that far out-weigh the norm of 15% of their body weight [43].

Numerous studies evaluated the effect of backpack carriage on gait parameters [44] [45] [46] [47] [48] and reported a significant decrease in cadence and speed and an increase in double support time as the weight of the backpack increased [48] [49].

1.4.5 Low Foot Arches / Flat Feet:

In people with flexible flat feet the medial longitudinal foot arch collapses during weight bearing activities, but can return to normal when the body weight is removed [50]. The foot arch develops mainly between the ages of 2-6 years [51] and is largely structurally matured by the age of 12 or 13 years of age [52].

During normal gait, the subtalar joint starts to pronate after initial contact, until the metatarsal head reaches the floor. At this point the subtalar joint starts to supinate and changes the foot into a rigid structure, ready for push off [53] [54] [55]. The

individuals with flat feet do not have an early enough conversion from pronation to supination [56]. There is a coupling movement of the rear-foot eversion / inversion with tibial rotation [57], therefore a prolonged period of pronation is linked to excessive tibial rotation and a larger valgus position at the knee [58].

When comparing the gait of children with flat-feet with those that have normal arches, the children with flat feet showed no significant differences in the spatiotemporal parameters according to Twomey and McInthos [59]. The kinematics showed some significant differences between hip and knee movements. Children with flat feet presented with greater external rotation of the hip in the stance phase and their knees were in a greater valgus angle at heel strike compared to their peers [59]. In a similar study, Shih et al. [60] found no significant differences between the two groups. They reported that children with flat feet had the tendency towards less hip internal rotation and greater hip adduction and flexion during gait. The authors concluded that the excessive knee joint internal rotation could have led to the altered knee and hip kinematics.

1.4.6 Generalized Joint Hypermobility:

The Beighton scoring system is usually used to diagnose generalized joint hypermobility (GJH) [61]. Some cross-sectional studies looked at the effect of GJH in children and reported motor deficits such as clumsiness, delayed first walk and poor co-ordination [62], reduced proprioception [63], decrease in muscle strength [64] and decrease in stamina [65]. Risks include early degenerative changes [61] [66] and an increased risk of injury during contact sport [67].

The gait patterns in children (9-11 years old) with GJH were compared with a control group [68]. The researchers found significant differences in the kinetics, reporting

lower hip, knee and ankle joint moments for the GJH, but in general the same walking pattern. They found no significant differences in the kinematics of the GJH children compared to the control group.

1.4.7 Different Ethnic Backgrounds:

The possibility exists that varied ethnic backgrounds could show variations in walking gait patterns [69]. To enable therapists to evaluate specific parameters of a pathological gait, it is essential to compare it to typically developed individuals of the same age, clinical health and population [15] [70].

Access to recreational or open space was the most important urban form variable related to walking for 5-8 year olds [70]. Frank et al. [70] found that the more children were exposed to open or recreational spaces, the more likely they were to take part in physical activities. The demographics of South Africa encompasses 51.8 million people of diverse origins, cultures, languages, and religious backgrounds with 79.7 % black, 8.9% coloured, 8.9% white and 2.5% of Indian or Asian descent [72]. There are significant differences in average annual household incomes across the different population groups with black African-headed households having the lowest average household income and white-headed households having the highest [72]. Nearly one-third (31%) of the population is aged younger than 15 years [72]. High crime rates [73] and a lack of safe open spaces in many of South Africa's communities may impact the amount of walking and activity levels in children, and subsequently influence their gait patterns.

1.5 CONCLUSION

Gait is a complex functional activity that has many influencing factors of which speed and age are the most pronounced factors in children's gait patterns. Joint kinematics appear to be mostly affected by these influential factors mentioned above. Furthermore, Pinzone et al. [74] reported a large variability in the hip rotation parameter, when comparing two gait analysis facilities from Australia and America. Both of these facilities used the VICON kinematic measuring system (Oxford, UK) and processed the data using the Plug-in Gait software (Oxford, UK). Their results showed large variation in the kinematic parameters for hip rotation and foot progression. There were also small differences in pelvic rotation. Hip rotation can be influenced by the placement of the thigh [75] and knee markers [76] [77]. Foot progression is dependent on the forefoot and heel marker alignment during the calibration stage [78]. If these makers are incorrectly placed or not well defined, an inaccurate axis system of the thigh is defined, leading to errors in the lower limb kinematic measurements. South African gait analysis laboratory, protocols and procedures may differ from laboratories in other countries; therefore a South African data base of normative values is required to validate the assessment of South African children's gait.

Thus the aim of this study is to describe the joint kinematics and spatiotemporal parameters of gait in typically developed children between the ages of 6-10 years in the Cape Metropole. This thesis will follow a publication format as per the faculty and journal guidelines (ADDENDUM A).

CHAPTER 2

ARTICLE

The three-dimensional kinematics and spatiotemporal parameters of gait in 6-10 year old typically developed children in the Cape Metropole

A Pilot Study

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ABSTRACT

BACKGROUND: A functional gait forms an integral part of life, allowing individuals to function within their environment and participate in activities of daily living. The evaluation of gait forms an essential part of a physical examination and can help screen for physical impairments. To the researchers' knowledge no 3D gait analysis studies of this nature have been conducted in South Africa. South African gait analysis laboratory protocols and procedures may differ from laboratories in other countries; therefore a South African data base of normative values is required to make a valid assessment of South African children's gait.

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METHODOLOGY: A descriptive study was conducted. Twenty-eight typically developed children were conveniently sampled from aftercare facilities and schools were performed in the Cape Metropole in the Western Cape, South Africa. The three-dimensional (3D) lower limb kinematics and spatiotemporal parameters of gait were analyzed. For data capture, the lower limb Plug-in-Gait (PIG) marker placement was used. Participants were asked to walk bare footed at self-selected speed. Due to a small sample size, children were also sub-divided into two groups (Group A: 6-8 years and Group B: 9-10 years) for comparison. Means and standard deviations (SD) were calculated for all outcomes, followed by statistical tests to determine significant differences between the two sub-groups for spatiotemporal parameters and kinematics.

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between the sub-groups for the mean hip rotation minimum values ($p=0.036$) was found. There was no significant difference between the sub-groups for any other kinematic parameter or when comparing the normalized spatiotemporal parameters.

CONCLUSION: This study provides descriptive gait parameters that can be used for comparison or gait analysis purposes. Our results suggest that normalized spatiotemporal parameters showed no significant difference between the age groups and are consistent with international children's spatiotemporal parameters. Kinematic values showed significant changes with hip rotation. Older children had more external rotation at their hips.

KEYWORDS: 3D gait analysis, walking, children, spatiotemporal parameters, kinematics

BACKGROUND

Humans walk an average of 10 000 steps per day [79]. A functional gait forms an integral part of life, allowing individuals to function within their environment and participate in activities of daily living. The importance of locomotion from a psychosocial point is often overlooked. It facilitates normal social interaction and participation in recreational activities [80] [81]. The ability to walk is one of the critical elements in measuring and improving quality of life and reflects the individual's health status [5] [80].

The evaluation of gait forms an essential part of a physical examination and can help screen for a range of physical impairments and abnormalities [82]. Similarly analysis of gait at an early age can help predict motor outcome in cerebral palsy [83]. Evidence shows that a better understanding of normal development may be useful in interpreting abnormal findings [15] [84]. Gait analysis can also be used as an outcome measure to evaluate the effect of an intervention such as the single event multi-level surgery on children (mean age: 8 years) with cerebral palsy [85].

Although gait analysis has been conducted in children since the 1980's, surprisingly little is known about age related gait patterns in children with typical development [4]. The gait data of 85 healthy children (4-16 years) at self-selected walking speed was examined using the VICON Plug-In-Gait model [11]. Gait cycles of thorax, spine and pelvis in the sagittal, frontal and transverse planes were recorded, and stratified by age and normalized speed. The sagittal thorax and spine movement were found to be gradually and significantly associated with age, but less so with speed, so that with increasing age, children tended to lean their trunk forward relative to the pelvis. In contrast, the frontal and transverse parameters of spine and pelvic movements

were found to be mainly dependent on speed, not age [11]. A 3D motion analysis study of fifty children between 7 and 11 years old using the ZEBRIS CMS 70 P 3D motion analysis system was conducted to measure flexion-extension, abduction-adduction angles of the hip joint, the flexion-extension of the knee and ankle joints and foot rotations for each age group [86]. Their findings were consistent with other published literature reporting on joint kinematics and suggested that children 7-11 years old presented with adult-like gait patterns [7] [8] [86].

Speed strongly influences other spatiotemporal parameters, joint kinematics and kinetics of walking gait in children aged 4-17 years [8] [17] [18]. Schwartz et al. [18] and Van der Linden et al. [17] found that kinematics, kinetics and EMG readings correspond strongly with speed. Kinematic changes showed greater ranges of movement in the hip, knee and ankle [18]. The kinetic values of peak propulsive forces were found in most of the joints of the lower limb during higher walking speeds, as well as significant differences in ankle dorsiflexion, knee extension and hip flexion and extention in the sagittal plane [17]. EMG readings showed greater muscle activity at higher speeds for the hamstrings, rectus femoris and tibialis anterior muscles [17] [18].

To the researchers' knowledge, no studies describing the 3D gait analysis of children have been conducted in South Africa. Currently there exists no normative dataset for the gait parameter of typically developed children in South Africa. A normative database of typically developed South African children will provide a baseline measure which can be used to assess and understand how gait is affected in other clinical populations. Furthermore, a South African database of normative values is required to demonstrate that a South African gait analysis laboratory, protocols and procedures are similar to laboratories in other countries [87] since previous research

has shown that gait analysis facilities from different countries have reported large variability in the hip rotation and foot progression parameters, which could be due to the different marker placement protocols of the two facilities [74]. Ferrari et al. [2] is one of the first studies that compared five different gait analysis protocols to assess inter-protocol variability. Prior to their study there had not been an emphasis on the standardization of gait analysis protocols between different laboratories, thus no gold standard for evaluation of gait. However, recently there has been an increase in studies measuring the reproducibility of data within and between gait laboratories.

METHODS

ETHICS

Approval from Stellenbosch University Human Research Ethics Committee (HREC) was obtained (Ethics reference number: S13/10/220) (ADDENDUM B).

Parents / guardians of participants signed an informed consent form prior to data collection (ADDENDUM C). Participants seven years and older signed an informed assent form once the procedure was explained and all their questions answered (ADDENDUM D).

STUDY DESIGN AND SETTING

A descriptive study was conducted at the Physiotherapy and FNB 3D Movement Analysis Laboratory, Stellenbosch University, Cape Town, South Africa.

POPULATION AND ELIGIBILITY

The population included typically developed boys and girls between the ages of 6-10 years residing within the Cape Metropole of the Western Cape in South Africa. This geographical area was chosen due to easy accessibility.

INCLUSION AND EXCLUSION CRITERIA

Boys and girls between the ages of 6-10 years, from varied ethnic and socio-economic backgrounds, who attended mainstream schools or education centers in the Cape Metropole area and had good general health, were included in the study. Girls start puberty around the ages of 10-11 years and boys at the age of 12 years. This stage is characterized by rapid skeletal growth and physical changes [88] Therefore only children ten years and younger were eligible to participate.

Any children diagnosed with Attention Deficit Hyperactivity Disorder (ADHD), Cerebral Palsy (CP), Scoliosis, Fetal Alcohol Syndrome (FAS), Developmental Coordination Disorder (DCD), Duchene's, hip dysplasia or any similar syndrome by a health care practitioner were excluded. Children with a BMI level >30 [89] were deemed unsuitable for the purpose of this study and were also excluded. If children sustained a recent (past six months) traumatic injury to the neuro-musculoskeletal system, complained of recurrent idiopathic musculoskeletal pain, or were unwell on the day of testing, they were also excluded from the study as it could potentially influence their normal gait pattern.

SAMPLING

Convenient sampling of centers was performed. Researchers approached local crèches ($n=2$), after care facilities ($n=4$) and primary schools ($n=3$) and invited all eligible children to participate in the study (ADDENDUM E).

A sample size calculation indicated that at least 30-40 children needed to participate in the study to have 95% confidence that the true SD fell within 2° of the measured SD [87].

MEASUREMENT TOOLS

The Vicon motion analysis (Ltd) (Oxford, UK) system is a 3D system used in a variety of human factor applications. It is capable of capturing 250 frames-per second at full frame resolution (1 megapixel). For this study an eight camera T-10 Vicon (Ltd) (Oxford, UK) system with Nexus 1.4 116 software was used to capture walking trials. Kinematics were calculated according to the Plug-in-Gait (PIG) model (Vicon Motion systems, 2010). In the PIG model the pelvis, hip, knee and foot angles

are defined (Vicon Motion systems, 2010). A manual medium international standard goniometer (8") was used to evaluate the joint ranges of the lower limb. The VICON has demonstrated high accuracy and reliability [90] and also demonstrated to have less than a 1.5-degree error [91]. An electronic scale was used to measure participants' weight in kilograms (kg). Height was measured in millimeters (mm) using a T-bar tape measure. Leg length was measured in millimeters (mm), using a measurement tape from predetermined landmarks (anterior superior iliac spine and medial malleoli). The general health and activity questionnaire (ADDENDUM F) included questions on previous injuries, general health, as well as the type of sport the child participated in and the frequency thereof.

STUDY PROCEDURE

Once potential participants had been identified for the study, parents / guardians received written information about the study. They also received written informed consent forms and a general health and activity questionnaire to complete. The questionnaire enabled the researchers to screen potential participants for eligibility. The parents / guardians were contacted telephonically to clarify certain statements and to elaborate on the study or answer questions that the parents / guardians or the children might have had at that time (ADDENDUM G). Children, who were eligible to participate in the study, were scheduled for gait analysis during April – July 2014.

On the day of testing, children were transported from the aftercare facility to the laboratory (ADDENDUM H). Participants were dressed in shorts and a sport top so that the anatomical landmarks were exposed (ADDENDUM I). The children were asked to walk bare footed during the physical evaluation, calibration and gait analysis. The researchers conducted a standard physical evaluation on each

participant (ADDENUM J). Each child's lower limb joint ranges (hip flexion / extension / abduction / internal rotation / external rotation; knee flexion / extension; ankle plantar flexion / dorsiflexion with knee straight / dorsiflexion with knee bent) were measured using a medium international standard goniometer (8") to screen for major joint range discrepancies. The same points of reference were used to measure the participants' range of joint movement. Two researchers evaluated the joint ranges on random days. An electronic scale was used to measure participants' weight in kilograms (kg). Height was measured in millimeters (mm) using a T-bar tape measure. Leg length was measured in millimeters (mm), using a measurement tape from predetermined landmarks (anterior superior iliac spine and medial malleoli).

For data capture, the lower limb Plug-in-Gait (PIG) marker placement was used. The markers were placed by two trained research assistants (on randomly selected days) for whom intra- and inter-person reliability [92] had been established and deemed satisfactory. Standard system and subject calibration procedures were performed.

The walking procedure was explained to the participants and each had two practice walking trials. Participants were asked to walk the full length of the walkway ($\pm 20\text{m}$) six times at self-selected speeds (ADDENDUM K). A walking trial was deemed successful if the child did not look around or veered from the walkway.

DATA ANALYSIS

Gap filling was performed using the standard Wolt ring filter supplied by Vicon. The events for foot contact and lowest vertical position of the pelvis were calculated automatically using Matlab Version R2012b. Segment and joint kinematics were calculated using the PIG-model and filtered with a 4th-order Butterworth filter at a

10Hz cut-off frequency. Data was exported to Matlab to extract the spatiotemporal parameters and the joint kinematics of the lower limbs.

STATISTICAL ANALYSIS

Descriptive statistics (mean, SD, median) were used to describe the participants' demographics and the outcome measures i.e. joint kinematics and spatiotemporal parameters. The data followed a skewed distribution and thus Mann-Whitney statistical tests were performed to determine significant differences between age groups for spatiotemporal parameters and joint kinematics. Differences were considered significant if the p-value was ≤ 0.05 .

RESULTS

SAMPLE DESCRIPTION

Twenty-eight children (boys and girls) with mean age 8.6 years (± 1.34), weight = 32.8kg (± 12.43), height = 1.35m (± 0.11) participated in the study. The demographics of the children per age group are shown in Table 1. Eighteen Coloured children, seven Black children and three Caucasian children participated in the study.

Table 1: The mean values for weight, height and BMI for boys and girls per age group (n= 28).

BOYS					
	6 years (n=0)	7 years (n=2)	8 years (n=3)	9 years (n=4)	10 years (n=3)
Weight (kg)	-	36.25	30.30	38.65	46.63
Height (m)	-	1.29	1.29	1.40	1.42
BMI	-	21.4	17.7	19.7	21.2
GIRLS					
	6 years (n=3)	7 years (n=1)	8 years (n=2)	9 years (n=4)	10 years (n=6)
Weight (kg)	26.37	20.10	28.95	38.20	44.78
Height (m)	1.23	1.11	1.35	1.36	1.45
BMI	17.6	16.3	15.9	20.3	21.7

GENERAL HEALTH AND ACTIVITY QUESTIONNAIRE:

None of the children participating in the study had any health problems. The children presented with no developmental delays or motor problems. Recent injuries, illnesses or body pain had not reported in the past six months. Although all the children participated in sport or a recreational activity, a range of different activity levels were reported. The outcome ranged from playing two types of sport / activities, 4 times a week, to one type of sport / activity, once a week.

SPATIOTEMPORAL PARAMETERS

The non-normalized spatiotemporal parameters for the whole group were 2.22 (± 0.20), 1.27 (± 0.15), 0.58 (± 0.07) and 1.15 (± 0.13) for cadence (steps per second), walking speed (meter per second), step length (meter) and stride length (meter) respectively. For the group, the mean normalized values for cadence, speed, step length and stride length were: 0.60 (± 0.05), 0.48 (± 0.06), 0.82 (± 0.06) and 1.62 (± 0.12) respectively. The parameters were normalized using leg length [93] [94]. There were no differences between boys and girls for the spatiotemporal parameters therefore the genders were combined in each age group. Due to the small sample size, number of participants per age group and no statistical significant differences in the spatiotemporal parameters between the 6-8 year old and 9-10 year old sub-groups, the five age groups were divided into two groups: Group A (6.0-8.11 year olds) and Group B (9.0-10.11 year olds) [11].

Table 2 presents the non-normalized and normalized mean values for the spatiotemporal parameters of each age group. Table 3 shows the non-normalized and normalized mean values for the spatiotemporal parameters for the two age

subgroups (Group A and Group B) as well as the p-values indicating the statistical significance between the two groups. There was a significant difference between the younger and older children for all the non-normalized parameters. However this significance did not persist when controlling for height as can be seen by the p-values for the normalized mean values.

Table 2: Spatiotemporal Parameters (non-normalized and normalized) for each age group

	Non-normalized									
	6 years (n= 3)		7 years (n=3)		8 years (n=5)		9 years (n=8)		10 years (n=9)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cadence (steps / sec)	2.42	0.18	2.34	0.04	2.21	0.30	2.18	0.16	2.16	0.17
Speed (m/s ⁻¹)	1.26	0.16	1.14	0.15	1.16	0.18	1.34	0.12	1.32	0.10
Step Length (m)	0.53	0.04	0.49	0.07	0.53	0.05	0.62	0.03	0.62	0.05
Stride Length (m)	1.04	0.08	0.97	0.14	1.05	0.09	1.23	0.05	1.23	0.10
	Normalized									
Cadence	0.62	0.04	0.59	0.02	0.58	0.07	0.59	0.04	0.60	0.04
Speed	0.50	0.07	0.46	0.05	0.45	0.08	0.50	0.05	0.48	0.04
Step Length	0.83	0.07	0.79	0.06	0.79	0.06	0.85	0.05	0.82	0.05
Stride Length	1.63	0.14	1.56	0.13	1.55	0.12	1.68	0.10	1.61	0.09

Table 3: Spatiotemporal Parameters (non-normalized and normalized) for the two age subgroups

	Group A			Group B			
	Non-Normalized						
	6 - 8 years (n=11)			9 -10 years (n=17)			P-value
	Mean	SD	Median	Mean	SD	Median	
Cadence (steps per second)	2.30	0.23	2.34	2.17	0.16	2.18	0.020*
Speed (m/s ⁻¹)	1.18	0.17	1.20	1.33	0.11	1.35	0.002*
Step Length (m)	0.52	0.05	0.53	0.62	0.04	0.62	0.000*
Stride Length (m)	1.02	0.10	1.03	1.23	0.08	1.23	0.000*
	Normalized						
Cadence	0.59	0.05	0.60	0.60	0.04	0.61	0.535
Speed	0.47	0.07	0.45	0.49	0.04	0.49	0.129
Step Length	0.80	0.06	0.79	0.83	0.05	0.83	0.056
Stride Length	1.58	0.13	1.54	1.65	0.10	1.64	0.055

KINEMATIC PATTERNS

The kinematic patterns of the pelvis, hip, knee, ankle and foot movements during a gait cycle are presented in Figures 1 and 2. Pelvis tilt, hip flexion / extension, knee flexion / extension and ankle dorsiflexion / plantar flexion occur in the sagittal plane. Pelvis obliquity, hip abduction / adduction and knee abduction / adduction occur in the frontal plane and pelvis rotation, hip rotation, knee rotation and foot progression occur in the transverse plane.

Figure 1 (a) – (e) shows minimum variation between the two age groups and a small standard deviation. On the other hand figure 1 (f) demonstrates a larger variation and statistical significant difference between the age groups.

Figure 2 (a), (b), (d) also showed minimum variations, whereas figure 2 (c) and (e) indicates a larger variation between the groups, however, this difference between the two groups did not reach significance.

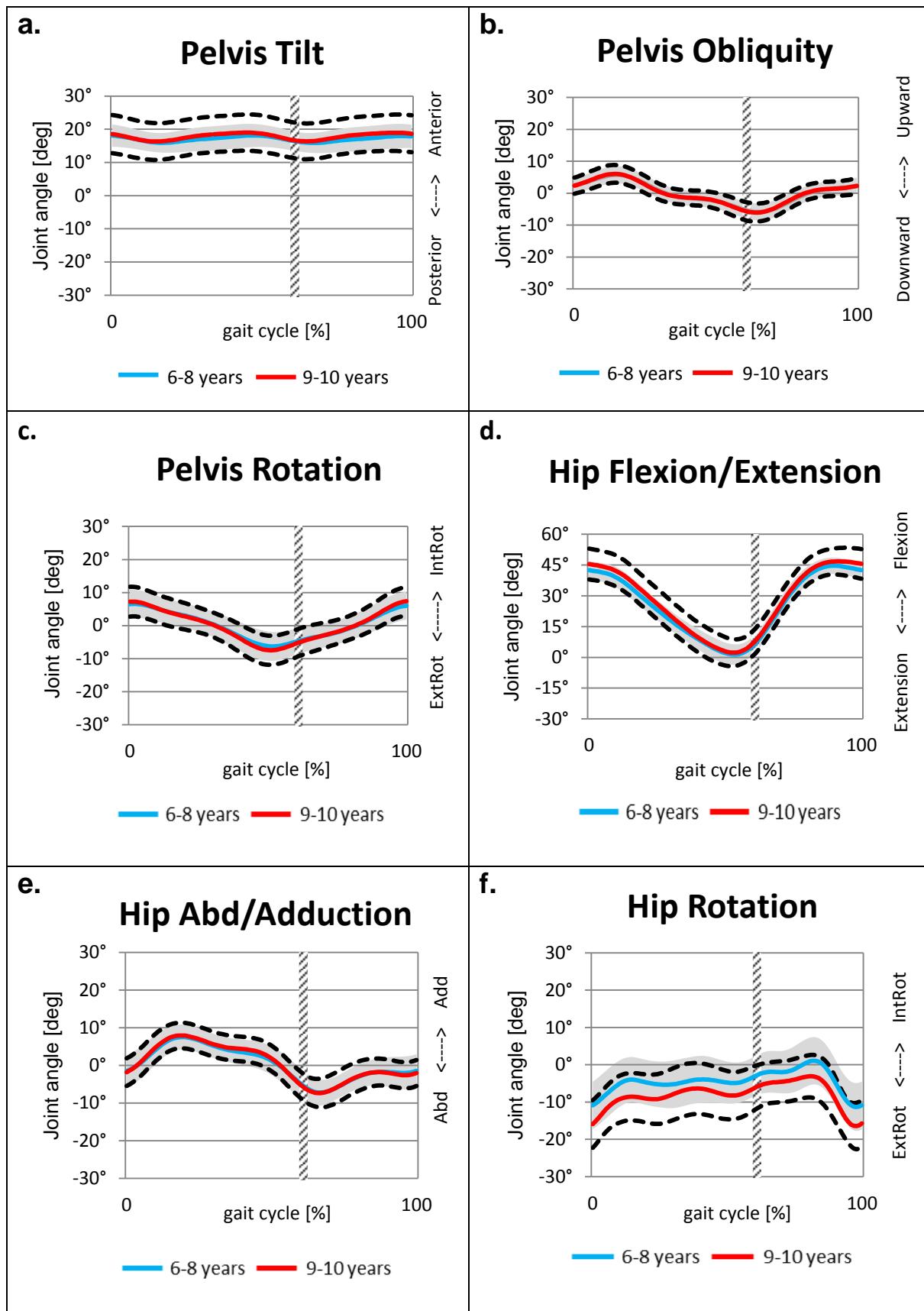


Figure 1: The pelvis and hip joint kinematics of the two sub-groups during a gait cycle

cycle

— Group A (6-8 years) — Group B (9-10 years)	 Standard deviation of Group A	- - - Standard deviation of Group B
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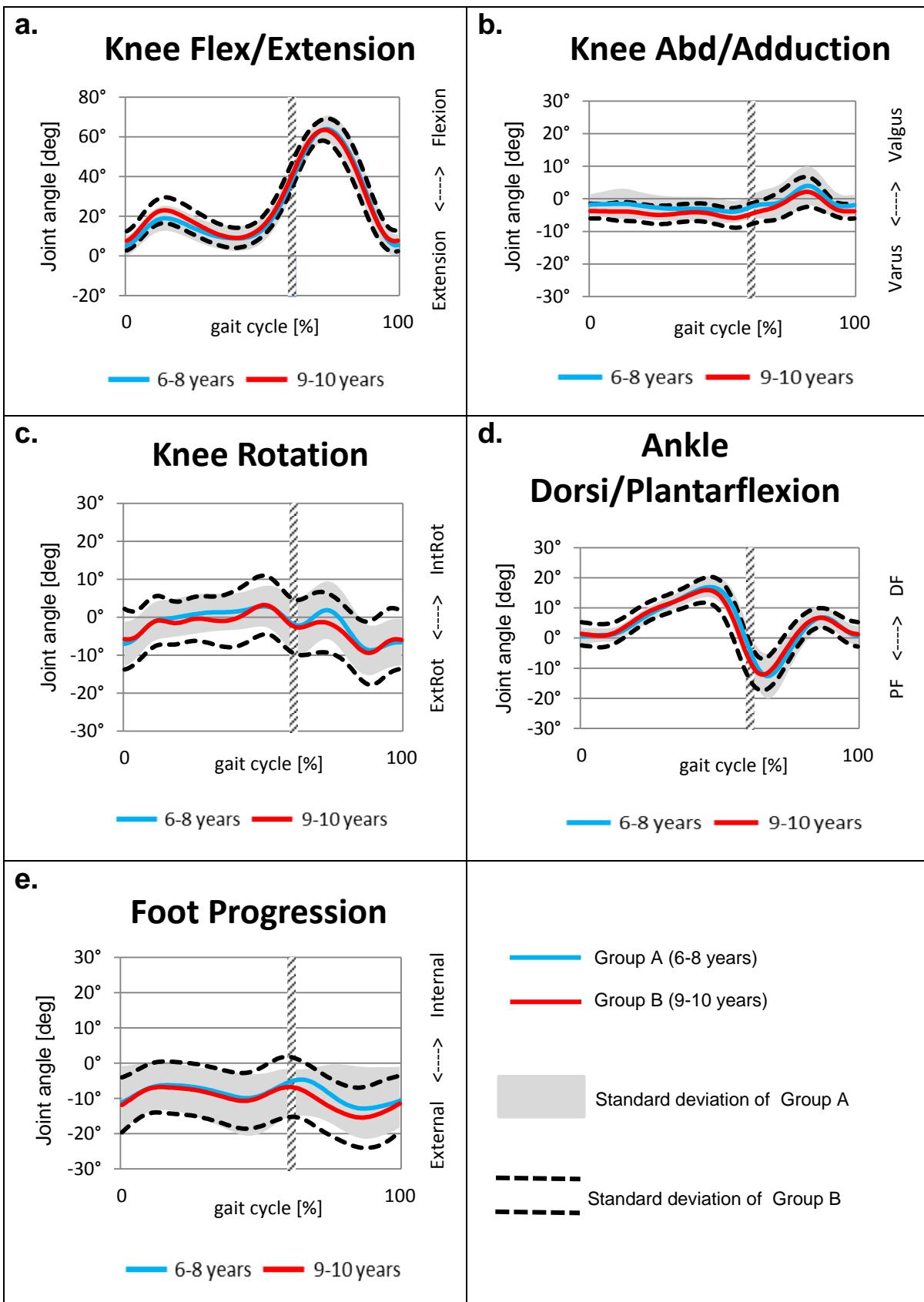


Figure 2: The knee, ankle and foot joint kinematics of the two sub-groups during a gait cycle

JOINT KINEMATICS

Tables 4, 5 and 6 show the mean, SD and median for the maximum, minimum and range values of the lower limb kinematics during the gait cycle respectively. There were no statistical differences between genders or between left and right sides for each of the joint angles. Thus, boys and girls and left and right sides were combined for the two age subgroups (Group A – 6-8 years; Group B – 9-10 years).

Table 4: The maximum values for the gait kinematics of the pelvis and lower limb kinematics for the two age groups

	Group A			Group B			P value	
	6 - 8 years (n=11)			9 -10 years (n=17)				
	Mean	SD	Median	Mean	SD	Median		
Pelvis X	18.72	3.2	18.19	19.76	5.6	19.53	0.495	
Pelvis Y	5.94	1.5	5.97	6.16	1.8	5.72	0.944	
Pelvis Z	7.00	2.7	6.57	7.99	2.5	8.11	0.249	
Hip X	44.77	3.2	43.63	47.41	6.5	46.22	0.196	
Hip Y	7.74	1.9	7.22	8.24	2.1	8.37	0.438	
Hip Z	2.42	5.0	2.48	-0.90	4.1	0.01	0.115	
Knee X	64.39	5.0	65.04	64.05	4.7	64.81	0.906	
Knee Y	4.54	4.9	4.86	2.76	3.3	2.63	0.312	
Knee Z	5.32	4.6	6.75	4.51	7.0	5.40	0.384	
Ankle X	17.24	2.7	16.48	16.17	3.7	16.36	0.557	
Foot Progression Z	-3.20	6.7	-1.84	-4.89	7.1	-4.06	0.525	

(X) Sagittal Plane; (Y) Frontal Plane; (Z) Transverse Plane

Table 5: The minimum values for the gait kinematics of the pelvis and lower limb kinematics for the two age groups

	Group A			Group B			P value	
	6 - 8 years (n=11)			9 -10 years (n=17)				
	Mean	SD	Median	Mean	SD	Median		
Pelvis X	15.11	2.7	15.16	15.95	5.5	16.38	0.495	
Pelvis Y	-6.00	1.6	-5.95	-6.16	1.9	-5.89	0.981	
Pelvis Z	-6.47	2.6	-6.56	-7.60	2.4	-7.58	0.115	
Hip X	1.37	4.6	1.68	2.08	6.4	2.85	0.525	
Hip Y	-7.47	2.5	-7.67	-7.68	2.8	-8.11	0.981	
Hip Z	-12.09	4.9	-11.19	-17.04	5.2	-17.03	0.036*	
Knee X	3.59	4.1	2.60	5.75	4.8	6.48	0.230	
Knee Y	-4.69	3.3	-4.70	-6.77	2.3	-7.10	0.070	
Knee Z	-10.61	3.4	-11.33	-11.11	6.6	-9.86	0.869	
Ankle X	-12.88	4.6	-12.59	-12.73	3.6	-11.83	0.724	
Foot Progression Z	-15.24	4.4	-14.25	-16.63	7.3	-16.02	0.724	

(X) Sagittal Plane; (Y) Frontal Plane; (Z) Transverse Plane

Table 6: The range values for the gait kinematics of the pelvis and lower limb kinematics for the two age groups

	Group A			Group B			P value	
	6 - 8 years (n=11)			9 -10 years (n=17)				
	Mean	SD	Median	Mean	SD	Median		
Pelvis X	3.61	1.1	4.16	3.81	1.0	3.90	0.689	
Pelvis Y	11.94	3.1	11.92	12.33	3.7	11.61	0.981	
Pelvis Z	13.47	5.4	13.19	15.59	4.9	15.95	0.213	
Hip X	43.40	4.8	43.44	45.33	4.2	45.92	0.312	
Hip Y	15.21	2.7	14.76	15.92	4.0	15.71	0.589	
Hip Z	14.51	3.3	14.24	16.14	3.8	15.61	0.312	
Knee X	60.80	4.4	60.66	58.29	4.8	57.67	0.180	
Knee Y	9.23	3.2	9.45	9.53	4.6	7.62	0.796	
Knee Z	15.93	4.0	12.23	15.63	4.1	14.66	0.944	
Ankle X	30.12	6.7	30.91	28.89	4.1	28.03	0.760	
Foot Progression Z	12.04	3.5	11.28	11.74	2.1	11.61	0.869	

(X) Sagittal Plane; (Y) Frontal Plane; (Z) Transverse Plane

There was a statistical significant difference between the two groups for the mean hip rotation minimum values ($p=0.036$), therefore Group B presented with more relative external rotation at the hip joint than Group A. There was no statistical significant difference between the two groups for any other kinematic parameter.

DISCUSSION

This is the first report on normative gait patterns of typically developed South African children. The findings of this study suggest that the kinematic patterns and spatiotemporal parameters of gait in typically developed children 6-10 years old are consistent with the published international literature which reported on the gait patterns of children in developed countries such as Norway, Germany, Australia and China [8] [9] [11] [16] [60]. The results are also in agreement with recent studies indicating that there are no significant differences in spatiotemporal parameters or kinematics between genders [8] [71] [84]. Moreno-Hernández et al. [71] suggests that it is not until the adolescent years when neurological and musculo-skeletal maturity is reached, that gender differences may be notable. Children reach adult-like sensory integration at the age of 12 years and may be gender specific [95]. Other studies have concluded that a child's gait will continue to evolve in terms of spatiotemporal parameters (step and stride length, speed and cadence, balance and percentage of support) until a child is fully grown due to the changes in anthropometric measurements [96] [97] [98].

Moreno-Hernández et al. [71] and Chagas et al. [84] studied children between the ages of 6-13 years and 6-11 years respectively. They reported a non-normalized mean cadence for the whole group of 122.48 ± 13.83 steps/min and 117.9 ± 11.4

steps/min respectively. This compares well with our study. Our study has shown that the non-normalized cadence was significantly lower ($p=0.02$), the speed faster and the step and stride length longer for the older children (9-10 years) compared to the younger children (6-8 years). This concurs with Holm et al. [8] and Dusing and Thorpe [15] who also reported reduced cadence in older children compared to younger children. However, these published studies did not report statistical significant differences. Consistent with the findings of the present study, Moreno-Hernández et al. [71] and Chagas et al. [84] reported no significant differences in normalized cadence when comparing age sub-groups of children between the ages of 6-13 years. This would indicate that as the children grow older, they walk with a faster speed, slower cadence and longer step and stride lengths. Comparison between children and adults also revealed an on-going decrease in cadence as age increased [16] [19]. Cadence was found to decrease with age when the gait of 656 children (aged 5-13 years) was compared with young adults (mean age of 19.7 years) [16]. The cadence for 6-10 year olds ranged between $125.8\pm2.2 - 140.0\pm3.3$ steps/min. Bovi et al. [19] compared twenty children (aged 6-17 years) with 20 adults and found no significant differences in cadence between the two groups (mean of younger group = 124 steps/min and older group = 110 steps/min). This could be due to the fact that the younger group included adolescents, who already showed matured gait patterns [7] and adult-like sensory-motor integration [95].

Step and stride length increased with age, but was not significantly different between the two age sub-groups of our study. Both findings are in agreement with published studies [8] [9] [15] [16] [19]. Non-normalized step length and stride length increased with age, but normalized values remained unchanged [8] [15]. Although speed

affects cadence, step length, stride length and other spatiotemporal parameters, as well as kinematics during gait [11] [14] [17] [18], our study did not show a significant difference in walking speed between younger and older children. The mean group speed for the children in the current study was 1.27 (± 0.15) (Normalized: 0.48 (± 0.06)) and compares well internationally as children, aged 6-13 years, from a Mexican study [71] walked at a mean self-selected speed of 1.13(± 0.19) m/s, in an Australian study [16] children aged 5-13 years walked at a mean self-selected speed of 1.37(± 0.17) m/s and in an American study [68] children aged 9-11, walked at a self-selected speed of 1.22 (± 0.04) m/s. Thus, 6-10 year old South African children's spatiotemporal parameters of gait fall within the international norms when compared with those of other countries.

Since there were no significant differences in the walking speed of the younger and older children, we expect little difference in the lower limb kinematics between the two groups [14]. When comparing the gait kinematics of walking, the lower limb values differed in the amount of degrees of movement (as seen in Figures 1 and 2). Minor variability in the amount of degrees of movement between age groups is similar to the findings of previous studies [7] [11] [60]. This could indicate that the kinematic gait patterns of the pelvis and lower limb of 6-10 year old children are established and mimic more the adult-like patterns observed by Sutherland et al. [7]. They evaluated the gait of 309 children ranging from the onset of walking to seven years of age. They found that between the age of 3.5-4 years, children achieve maturation of gait. In a later study they concluded that growth alone can explain the majority of changes throughout the rest of the growing years [98]. As children mature

and grow, their leg length and body height increase, which directly affect the time-distance parameters of gait [98].

When comparing joint kinematics within the two combined age groups in our study, hip rotation was significantly different between age groups ($p \leq 0.003$). Older children (Group B) presented with a greater degree of external rotation at the hip joint than the younger children (Group A). Femoral anteversion and hip internal rotation are highly correlated and both reduce significantly with advancing age. Thus our study supports the fact that as a child develops, the degree of anteversion of the femoral head decreases and causes the older child to walk with more relative external rotation of the hip than a younger child [99] [100]. The degree of hip internal rotation may indicate surgical intervention in children with pathological gait. Hip rotation kinematic patterns might be age specific and should be considered accordingly when interpreting gait analysis data.

The study was limited by a smaller sample size than was anticipated with limited numbers per age sub-group e.g. no 6 year old boys were included in this study. Activity levels of the children, as captured in the general health questionnaire, differed slightly and could have influenced the findings. Some children only participated in one sporting activity once a week, whereas others participated in 3-4 activities during a week. Kinetics were also not included in this study, but we recommend that future studies include kinetics as it could add valuable information to the understanding and interpretation of the gait patterns in typically developed 6-10 year old children in South Africa.

CONCLUSION

This study evaluated the 3D kinematics and spatiotemporal parameters of gait in 28 typically developed 6-10 year old South African children. It provides normative values for gait parameters that show that this South African gait analysis laboratory compares well with international gait laboratories and values can be used for comparison during gait analysis. Our results suggest that normalized spatiotemporal parameters showed no significant difference between the age groups and are consistent with international children's spatiotemporal parameters. Kinematic values showed significant changes with hip rotation. Older children had more hip external rotation than the younger children. As the child develops, hip anteversion decreases and the hips move into more relative external rotation.

COMPETING INTERESTS

The authors declare that they have no competing interests.

AUTHORS' CONTRIBUTIONS

Miss Y. Smith, Dr Y. Brink and Prof Q.A. Louw took part in the conception and design of the study and the analysis and interpretation of the data.

Miss Y. Smith obtained funding, performed the data collection and writing of the thesis.

Dr Y. Brink and Prof Q.A. Louw supervised the project, provided statistical expertise and ensured critical revision of the manuscript.

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CHAPTER 3

SUMMARY

3.1 CONTRIBUTION TO KNOWLEDGE

To date, there has been no database of gait patterns of typically developed South African children. We found that the kinematic patterns as well as spatiotemporal parameters are similar to international studies conducted in developed countries. This implies that local context or culture have little influence on the development of gait in children.

The findings in this study are valuable to the clinicians and researchers in South Africa that work with children. It provides a sound normative gait dataset that can be used for comparison purposes to identify gait abnormalities in children with pathological gait. The evaluation of gait forms an essential part of a physical examination and can help screen for a range of physical impairments and abnormalities [82]. Early identification of gait problems enables appropriate and timely management. This could be optimising the function of children with gait impairments.

3.2 LIMITATIONS OF THE STUDY

A number of limitations need to be considered:

- A small sample size per age sub-group caused a lower statistical power.

- South Africa is a very diverse country, with many racial groups [72]. The study sample was not representative of the whole South African population, but included a fair representation of the children in the Cape Metropole.
- No 6 year old boys were evaluated in this study, which made the results confined to the limited group that was available.
- Activity levels of the children in the group differed slightly and could have influenced the findings.
- Kinetics were not included as it was not the aim of the study, but could add valuable information to the understanding and interpretation of the gait patterns in typically developed 6-10 year old children in South Africa.
- This study was laboratory-based, and may not accurately reflect the real-life scenario.

3.3 RECOMMENDATIONS FOR FUTURE RESEARCH

We recommend that future studies:

- Describe larger and a more representative sample of South African children when analysing 3D gait kinematics and spatiotemporal parameters in children.
- We also recommend that future studies include kinetics of the lower limb during gait analysis, as it can be beneficial to the understanding and interpretation of gait parameter findings.
- Provided that larger samples are tested, we suggest sub-group analysis per speed group. This is needed since walking speed influences kinematics and spatiotemporal parameters of gait.
- Sub-group analysis and comparison between the different race groups can be performed if a larger, more representative sample is included.

- Random sampling can be performed to obtain a sample free of selection bias.

CONCLUSION

The aim of this study was to describe 3D kinematics and spatiotemporal parameters of gait in typically developed children between the ages of 6-10 years in the Cape Metropole. A statistical significant difference for the mean hip rotation minimum values ($p=0.036$) was found between younger and older children. No other joint kinematics or spatiotemporal parameters differed between genders and age subgroups, therefore the gait pattern in children between six and ten years old mimics an adult-like gait pattern.

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ADDENDA

ADDENDUM A

BIO-MED CENTRAL JOURNAL (PAEDIATRICS) GUIDELINES

Preparing main manuscript text

General guidelines of the journal's style and language are given below.

Overview of manuscript sections for Research articles

Manuscripts for Research articles submitted to BMC Pediatrics should be divided into the following sections (in this order):

- Title page
- Abstract
- Keywords
- Background
- Methods
- Results and discussion
- Conclusions
- List of abbreviations used (if any)
- Competing interests
- Authors' contributions
- Authors' information
- Acknowledgements
- Endnotes
- References
- Illustrations and figures (if any)
- Tables and captions
- Preparing additional files

The Accession Numbers of any nucleic acid sequences, protein sequences or atomic coordinates cited in the manuscript should be provided, in square brackets and include the corresponding database name; for example, [EMBL:AB026295, EMBL:AC137000, DDBJ:AE000812, GenBank:U49845, PDB:1BFM, Swiss-Prot:Q96KQ7, PIR:S66116].

The databases for which we can provide direct links are: EMBL Nucleotide Sequence Database (EMBL), DNA Data Bank of Japan (DDBJ), GenBank at the NCBI (GenBank),

Protein Data Bank (PDB), Protein Information Resource (PIR) and the Swiss-Prot Protein Database (Swiss-Prot).

You can download a template (Mac and Windows compatible; Microsoft Word 98/2000) for your article.

For reporting standards please see the information in the About section.

Title page

The title page should:

- provide the title of the article
- list the full names, institutional addresses and email addresses for all authors
- indicate the corresponding author

Please note:

- the title should include the study design, for example "A versus B in the treatment of C: a randomized controlled trial X is a risk factor for Y: a case control study"
- abbreviations within the title should be avoided

Abstract

The Abstract of the manuscript should not exceed 350 words and must be structured into separate sections: Background, the context and purpose of the study; Methods, how the study was performed and statistical tests used; Results, the main findings; Conclusions, brief summary and potential implications. Please minimize the use of abbreviations and do not cite references in the abstract. Trial registration, if your research article reports the results of a controlled health care intervention, please list your trial registry, along with the unique identifying number (e.g. Trial registration: Current Controlled Trials ISRCTN73824458).

Please note that there should be no space between the letters and numbers of your trial registration number. We recommend manuscripts that report randomized controlled trials follow the CONSORT extension for abstracts.

Keywords

Three to ten keywords representing the main content of the article

Background

The Background section should be written in a way that is accessible to researchers without specialist knowledge in that area and must clearly state - and, if helpful, illustrate - the background to the research and its aims. Reports of clinical research should, where appropriate, include a summary of a search of the literature to indicate why this study was necessary and what it aimed to contribute to the field. The section should end with a brief statement of what is being reported in the article.

Methods

The methods section should include the design of the study, the setting, the type of participants or materials involved, a clear description of all interventions and comparisons,

and the type of analysis used, including a power calculation if appropriate. Generic drug names should generally be used. When proprietary brands are used in research, include the brand names in parentheses in the Methods section.

For studies involving human participants a statement detailing ethical approval and consent should be included in the methods section. For further details of the journal's editorial policies and ethical guidelines see 'About this journal'.

For further details of the journal's data-release policy, see the policy section in 'About this journal'.

Results and discussion

The Results and discussion may be combined into a single section or presented separately. Results of statistical analysis should include, where appropriate, relative and absolute risks or risk reductions, and confidence intervals. The Results and discussion sections may also be broken into subsections with short, informative headings.

Conclusions

This should state clearly the main conclusions of the research and give a clear explanation of their importance and relevance. Summary illustrations may be included.

List of abbreviations

If abbreviations are used in the text they should be defined in the text at first use, and a list of abbreviations can be provided, which should precede the competing interests and authors' contributions.

Competing interests

A competing interest exists when your interpretation of data or presentation of information may be influenced by your personal or financial relationship with other people or organizations. Authors must disclose any financial competing interests; they should also reveal any non-financial competing interests that may cause them embarrassment were they to become public after the publication of the manuscript.

Authors are required to complete a declaration of competing interests. All competing interests that are declared will be listed at the end of published articles. Where an author gives no competing interests, the listing will read 'The author(s) declare that they have no competing interests'.

When completing your declaration, please consider the following questions:

Financial competing interests

- In the past five years have you received reimbursements, fees, funding, or salary from an organization that may in any way gain or lose financially from the publication of this manuscript, either now or in the future? Is such an organization financing this manuscript (including the article-processing charge)? If so, please specify.

- Do you hold any stocks or shares in an organization that may in any way gain or lose financially from the publication of this manuscript, either now or in the future? If so, please specify.
- Do you hold or are you currently applying for any patents relating to the content of the manuscript? Have you received reimbursements, fees, funding, or salary from an organization that holds or has applied for patents relating to the content of the manuscript? If so, please specify.
- Do you have any other financial competing interests? If so, please specify.

Non-financial competing interests

Are there any non-financial competing interests (political, personal, religious, ideological, academic, intellectual, commercial or any other) to declare in relation to this manuscript? If so, please specify.

If you are unsure as to whether you, or one your co-authors, has a competing interest please discuss it with the editorial office.

Authors' contributions

In order to give appropriate credit to each author of a paper, the individual contributions of authors to the manuscript should be specified in this section.

According to ICMJE guidelines, An 'author' is generally considered to be someone who has made substantive intellectual contributions to a published study. To qualify as an author one should 1) have made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data; 2) have been involved in drafting the manuscript or revising it critically for important intellectual content; 3) have given final approval of the version to be published; and 4) agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. Each author should have participated sufficiently in the work to take public responsibility for appropriate portions of the content. Acquisition of funding, collection of data, or general supervision of the research group, alone, does not justify authorship.

We suggest the following kind of format (please use initials to refer to each author's contribution): AB carried out the molecular genetic studies, participated in the sequence alignment and drafted the manuscript. JY carried out the immunoassays. MT participated in the sequence alignment. ES participated in the design of the study and performed the statistical analysis. FG conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors read and approved the final manuscript.

All contributors who do not meet the criteria for authorship should be listed in an acknowledgements section. Examples of those who might be acknowledged include a

person who provided purely technical help, writing assistance, or a department chair who provided only general support.

Authors' information

You may choose to use this section to include any relevant information about the author(s) that may aid the reader's interpretation of the article, and understand the standpoint of the author(s). This may include details about the authors' qualifications, current positions they hold at institutions or societies, or any other relevant background information. Please refer to authors using their initials. Note this section should not be used to describe any competing interests.

Acknowledgements

Please acknowledge anyone who contributed towards the article by making substantial contributions to conception, design, acquisition of data, or analysis and interpretation of data, or who was involved in drafting the manuscript or revising it critically for important intellectual content, but who does not meet the criteria for authorship. Please also include the source(s) of funding for each author, and for the manuscript preparation. Authors must describe the role of the funding body, if any, in design, in the collection, analysis, and interpretation of data; in the writing of the manuscript; and in the decision to submit the manuscript for publication. Please also acknowledge anyone who contributed materials essential for the study. If a language editor has made significant revision of the manuscript, we recommend that you acknowledge the editor by name, where possible.

The role of a scientific (medical) writer must be included in the acknowledgements section, including their source(s) of funding. We suggest wording such as 'We thank Jane Doe who provided medical writing services on behalf of XYZ Pharmaceuticals Ltd.'

Authors should obtain permission to acknowledge from all those mentioned in the Acknowledgements section.

Endnotes

Endnotes should be designated within the text using a superscript lowercase letter and all notes (along with their corresponding letter) should be included in the Endnotes section. Please format this section in a paragraph rather than a list.

References

All references, including URLs, must be numbered consecutively, in square brackets, in the order in which they are cited in the text, followed by any in tables or legends. Each reference must have an individual reference number. Please avoid excessive referencing. If automatic numbering systems are used, the reference numbers must be finalized and the bibliography must be fully formatted before submission.

Only articles, datasets, clinical trial registration records and abstracts that have been published or are in press, or are available through public e-print/preprint servers, may be

cited; unpublished abstracts, unpublished data and personal communications should not be included in the reference list, but may be included in the text and referred to as "unpublished observations" or "personal communications" giving the names of the involved researchers. Obtaining permission to quote personal communications and unpublished data from the cited colleagues is the responsibility of the author. Footnotes are not allowed, but endnotes are permitted. Journal abbreviations follow Index Medicus/MEDLINE. Citations in the reference list should include all named authors, up to the first 30 before adding 'et al.'

Any in press articles cited within the references and necessary for the reviewers' assessment of the manuscript should be made available if requested by the editorial office.

Style files are available for use with popular bibliographic management software:

- BibTeX
- EndNote style file
- Reference Manager
- Zotero

Examples of the BMC Pediatrics reference style are shown below. Please ensure that the reference style is followed precisely; if the references are not in the correct style they may have to be retyped and carefully proofread.

All web links and URLs, including links to the authors' own websites, should be given a reference number and included in the reference list rather than within the text of the manuscript. They should be provided in full, including both the title of the site and the URL, in the following format: The Mouse Tumor Biology Database [<http://tumor.informatics.jax.org/mtbwi/index.do>]. If an author or group of authors can clearly be associated with a web link, such as for weblogs, then they should be included in the reference.

Examples of the BMC Pediatrics reference style

Article within a journal

Koonin EV, Altschul SF, Bork P: BRCA1 protein products: functional motifs. *Nat Genet* 1996,13:266-267.

Article within a journal supplement

Orengo CA, Bray JE, Hubbard T, LoConte L, Sillitoe I: Analysis and assessment of ab initio three-dimensional prediction, secondary structure, and contacts prediction. *Proteins* 1999,43(Suppl 3):149-170.

In press article

Kharitonov SA, Barnes PJ: Clinical aspects of exhaled nitric oxide. *Eur Respir J*, in press.

Published abstract

- Zvaipler NJ, Burger JA, Marinova-Mutafchieva L, Taylor P, Maini RN: Mesenchymal cells, stromal derived factor-1 and rheumatoid arthritis [abstract]. *Arthritis Rheum* 1999, 42:s250.
- Article within conference proceedings
- Jones X: Zeolites and synthetic mechanisms. In Proceedings of the First National Conference on Porous Sieves: 27-30 June 1996; Baltimore. Edited by Smith Y. Stoneham: Butterworth-Heinemann; 1996:16-27.
- Book chapter, or article within a book
- Schnepf E: From prey via endosymbiont to plastids: comparative studies in dinoflagellates. In *Origins of Plastids*. Volume 2. 2nd edition. Edited by Lewin RA. New York: Chapman and Hall; 1993:53-76.
- Whole issue of journal
- Ponder B, Johnston S, Chodosh L (Eds): Innovative oncology. In *Breast Cancer Res* 1998, 10:1-72.
- Whole conference proceedings
- Smith Y (Ed): Proceedings of the First National Conference on Porous Sieves: 27-30 June 1996; Baltimore. Stoneham: Butterworth-Heinemann; 1996.
- Complete book
- Margulis L: *Origin of Eukaryotic Cells*. New Haven: Yale University Press; 1970.
- Monograph or book in a series
- Hunninghake GW, Gadek JE: The alveolar macrophage. In *Cultured Human Cells and Tissues*. Edited by Harris TJR. New York: Academic Press; 1995:54-56. [Stoner G (Series Editor): *Methods and Perspectives in Cell Biology*, vol 1.]
- Book with institutional author
- Advisory Committee on Genetic Modification: Annual Report. London; 1999.
- PhD thesis
- Kohavi R: Wrappers for performance enhancement and oblivious decision graphs. PhD thesis. Stanford University, Computer Science Department; 1995.
- Link / URL
- The Mouse Tumor Biology Database [<http://tumor.informatics.jax.org/mtbwi/index.do>]
- Link / URL with author(s)
- Corpas M: The Crowdfunding Genome Project: a personal genomics community with open source values [<http://blogs.biomedcentral.com/bmcblog/2012/07/16/the-crowdfunding-genome-project-a-personal-genomics-community-with-open-source-values/>]
- Dataset with persistent identifier
- Zheng, L-Y; Guo, X-S; He, B; Sun, L-J; Peng, Y; Dong, S-S; Liu, T-F; Jiang, S; Ramachandran, S; Liu, C-M; Jing, H-C (2011): Genome data from sweet and grain sorghum (*Sorghum bicolor*). *GigaScience Database*. <http://dx.doi.org/10.5524/100012>.

Clinical trial registration record with persistent identifier

Mendelow, AD (2006): Surgical Trial in Lobar Intracerebral Haemorrhage. Current Controlled Trials. <http://dx.doi.org/10.1186/ISRCTN22153967>

Preparing illustrations and figures

Illustrations should be provided as separate files, not embedded in the text file. Each figure should include a single illustration and should fit on a single page in portrait format. If a figure consists of separate parts, it is important that a single composite illustration file be submitted which contains all parts of the figure. There is no charge for the use of color figures.

Please read our figure preparation guidelines for detailed instructions on maximising the quality of your figures.

Formats

The following file formats can be accepted:

- PDF (preferred format for diagrams)
- DOCX/DOC (single page only)
- PPTX/PPT (single slide only)
- EPS
- PNG (preferred format for photos or images)
- TIFF
- JPEG
- BMP

Figure legends

The legends should be included in the main manuscript text file at the end of the document, rather than being a part of the figure file. For each figure, the following information should be provided: Figure number (in sequence, using Arabic numerals - i.e. Figure 1, 2, 3 etc); short title of figure (maximum 15 words); detailed legend, up to 300 words.

Please note that it is the responsibility of the author(s) to obtain permission from the copyright holder to reproduce figures or tables that have previously been published elsewhere.

Preparing tables

Each table should be numbered and cited in sequence using Arabic numerals (i.e. Table 1, 2, 3 etc.). Tables should also have a title (above the table) that summarizes the whole table; it should be no longer than 15 words. Detailed legends may then follow, but they should be concise. Tables should always be cited in text in consecutive numerical order.

Smaller tables considered to be integral to the manuscript can be pasted into the end of the document text file, in A4 portrait or landscape format. These will be typeset and displayed in the final published form of the article. Such tables should be formatted using the 'Table object' in a word processing program to ensure that columns of data are kept aligned when

the file is sent electronically for review; this will not always be the case if columns are generated by simply using tabs to separate text. Columns and rows of data should be made visibly distinct by ensuring that the borders of each cell display as black lines. Commas should not be used to indicate numerical values. Color and shading may not be used; parts of the table can be highlighted using symbols or bold text, the meaning of which should be explained in a table legend. Tables should not be embedded as figures or spreadsheet files. Larger datasets or tables too wide for a portrait page can be uploaded separately as additional files. Additional files will not be displayed in the final, laid-out PDF of the article, but a link will be provided to the files as supplied by the author.

Tabular data provided as additional files can be uploaded as an Excel spreadsheet (.xls) or comma separated values (.csv). As with all files, please use the standard file extensions.

Preparing additional files

Although BMC Pediatrics does not restrict the length and quantity of data included in an article, we encourage authors to provide datasets, tables, movies, or other information as additional files.

Please note: All Additional files will be published along with the article. Do not include files such as patient consent forms, certificates of language editing, or revised versions of the main manuscript document with tracked changes. Such files should be sent by email to editorial@biomedcentral.com, quoting the Manuscript ID number.

Results that would otherwise be indicated as "data not shown" can and should be included as additional files. Since many weblinks and URLs rapidly become broken, BMC Pediatrics requires that supporting data are included as additional files, or deposited in a recognized repository. Please do not link to data on a personal/departmental website. The maximum file size for additional files is 20 MB each, and files will be virus-scanned on submission.

Additional files can be in any format, and will be downloadable from the final published article as supplied by the author. We recommend CSV rather than PDF for tabular data.

Certain supported files formats are recognized and can be displayed to the user in the browser. These include most movie formats (for users with the Quicktime plugin), mini-websites prepared according to our guidelines, chemical structure files (MOL, PDB), geographic data files (KML).

If additional material is provided, please list the following information in a separate section of the manuscript text:

- File name (e.g. Additional file 1)
- File format including the correct file extension for example .pdf, .xls, .txt, .pptx (including name and a URL of an appropriate viewer if format is unusual)
- Title of data
- Description of data

Additional files should be named "Additional file 1" and so on and should be referenced explicitly by file name within the body of the article, e.g. 'An additional movie file shows this in more detail [see Additional file 1]'.

Additional file formats

Ideally, file formats for additional files should not be platform-specific, and should be viewable using free or widely available tools. The following are examples of suitable formats.

- Additional documentation
- PDF (Adobe Acrobat)
- Animations
- SWF (Shockwave Flash)
- Movies
- MP4 (MPEG 4)
- MOV (Quicktime)
- Tabular data
- XLS, XLSX (Excel Spreadsheet)
- CSV (Comma separated values)

As with figure files, files should be given the standard file extensions.

Mini-websites

Small self-contained websites can be submitted as additional files, in such a way that they will be browsable from within the full text HTML version of the article. In order to do this, please follow these instructions:

1. Create a folder containing a starting file called index.html (or index.htm) in the root.
2. Put all files necessary for viewing the mini-website within the folder, or sub-folders.
3. Ensure that all links are relative (ie "images/picture.jpg" rather than "/images/picture.jpg" or "http://yourdomain.net/images/picture.jpg" or "C:\Documents and Settings\username\My Documents\mini-website\images\picture.jpg") and no link is longer than 255 characters.
4. Access the index.html file and browse around the mini-website, to ensure that the most commonly used browsers (Internet Explorer and Firefox) are able to view all parts of the mini-website without problems, it is ideal to check this on a different machine.
5. Compress the folder into a ZIP, check the file size is under 20 MB, ensure that index.html is in the root of the ZIP, and that the file has .zip extension, then submit as an additional file with your article.

Style and language

General

Currently, BMC Pediatrics can only accept manuscripts written in English. Spelling should be US English or British English, but not a mixture.

There is no explicit limit on the length of articles submitted, but authors are encouraged to be concise.

BMC Pediatrics will not edit submitted manuscripts for style or language; reviewers may advise rejection of a manuscript if it is compromised by grammatical errors. Authors are advised to write clearly and simply, and to have their article checked by colleagues before submission. In-house copyediting will be minimal. Non-native speakers of English may choose to make use of a copyediting service.

Language editing

For authors who wish to have the language in their manuscript edited by a native-English speaker with scientific expertise, BioMed Central recommends Edanz. BioMed Central has arranged a 10% discount to the fee charged to BioMed Central authors by Edanz. Use of an editing service is neither a requirement nor a guarantee of acceptance for publication. Please contact Edanz directly to make arrangements for editing, and for pricing and payment details.

Help and advice on scientific writing

The abstract is one of the most important parts of a manuscript. For guidance, please visit our page on Writing titles and abstracts for scientific articles.

Tim Albert has produced for BioMed Central a list of tips for writing a scientific manuscript. American Scientist also provides a list of resources for science writing. For more detailed guidance on preparing a manuscript and writing in English, please visit the BioMed Central author academy.

Abbreviations

Abbreviations should be used as sparingly as possible. They should be defined when first used and a list of abbreviations can be provided following the main manuscript text.

Typography

- Please use double line spacing.
- Type the text unjustified, without hyphenating words at line breaks.
- Use hard returns only to end headings and paragraphs, not to rearrange lines.
- Capitalize only the first word, and proper nouns, in the title.
- All lines and pages should be numbered. Authors are asked to ensure that line numbering is included in the main text file of their manuscript at the time of submission to facilitate peer-review. Once a manuscript has been accepted, line numbering should be removed from the manuscript before publication. For authors submitting their manuscript in Microsoft Word please do not insert page breaks in your manuscript to ensure page numbering is consistent between your text file and the PDF generated from your submission and used in the review process.
- Use the BMC Pediatrics reference format.

- Footnotes are not allowed, but endnotes are permitted.
- Please do not format the text in multiple columns.
- Greek and other special characters may be included. If you are unable to reproduce a particular special character, please type out the name of the symbol in full. Please ensure that all special characters used are embedded in the text, otherwise they will be lost during conversion to PDF.

Units

SI units should be used throughout (liter and molar are permitted, however).

ADDENDUM B

ETHICS APPROVAL



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Approval Notice

Response to Modifications- (New Application)

26-Feb-2014

Smith, Yvonne (Y)

Ethics Reference #: S13/10/220

Title: Determining the normative 3-D kinetic and kinematic parameters of self-selected walking in 6-10 year old children with typical development: A pilot study.

Dear Miss Yvonne Smith

The Response to Modifications - (New Application) received on, was reviewed by members of Health Research Ethics Committee 2 via Minimal

Risk Review procedures on 26-Feb-2014 and was approved.

Please note the following information about your approved research protocol:
Protocol Approval Period: 26-Feb-2014 -26-Feb-2015.

Please remember to use your protocol number (S13/10/220) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

After Ethical Review:

Please note a template of the progress report is obtainable on www.sun.ac.za/rds and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372

Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

Provincial and City of Cape Town Approval

Please note that for research at primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health (healthres@pgwc.gov.za Tel: +27 21 483 9907) and Dr Helene Visser at City Health (Helene.Visser@capetown.gov.za Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and documents please visit: www.sun.ac.za/rds

If you have any questions or need further assistance, please contact the HREC office at.

ADDENDUM C

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

Determining the normative 3-D kinetic and kinematic parameters of self -selected walking in 6 – 10 year old children with typical development: a pilot study

REFERENCE NUMBER: S13/10/220**PRINCIPAL INVESTIGATORS:** Y. Smith & M. Nevin**ADDRESS:**

Faculty of Medicine and Health Sciences - Physiotherapy Department

Tygerberg Campus

Parow

Cape Town

CONTACT NUMBER: 021 938 9300

Your child is being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff or physiotherapists any questions about any part of this project that you or your child do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your child's participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw your child from the study at any point, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee at Stellenbosch University and will be conducted according to the ethical guidelines and principles of the International Declaration of Helsinki 2013, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

- Our research study assesses normal, healthy children's way of walking.
- The study will be conducted in the Gait-Analysis Laboratory of the Faculty of Medicine and Health Sciences on Tygerberg Campus (Stellenbosch University).
- There will be approximately 30 children participating.

- The gait-analysis lab has various instruments that help us look at the different parts of the child's walking pattern.
- The study staff will place specific stickers/markers on the child's legs and feet. The sensor cameras of the gait-analysis lab will pick up the movements during walking. These movement patterns are then converted into data by a computer that enables us to compare the walking patterns of numerous children.

Why has your child been invited to participate?

We are looking for active, healthy children attend a school/crèche in the vicinity of Tygerberg Campus. For the best possible results on the research topic, we need children that walk and run normally – this is to enable us to have an optimum group to compare other children with.

What will your responsibilities be?

You as a parent/legal guardian will have to give informed consent for your child to participate in the research study. You can accompany your child to the laboratory and supervise the child while he/she waits to be evaluated. It may be necessary for you to help explain the process to the child and motivate the child to follow the instructions.

Will you benefit from taking part in this research?

There is no benefit for your child for taking part in this study. Future studies might make use of our data to compare children with disabilities (changes in walking patterns) to the group your child was included in.

Are there in risks involved in your taking part in this research?

There are no risks involved in taking part in this study.

Who will have access to your medical records?

All the personal information we attain from you and your child will remain confidential. Only researchers involved with this study will have access to it. All other persons involved in the research will only have access to data in which the child's name has been replaced by a number. The walking pattern data collected as well as data from the questionnaires will be used for analysis and comparison in a Masters Research thesis which may be published. Your child will remain anonymous.

What will happen in the unlikely event of some form injury occurring as a direct result of your taking part in this research study?

Your child will be covered by Stellenbosch University insurance for medical expenses if injury occurred as a direct result of taking part in this study

Will you be paid to take part in this study and are there any costs involved?

No, you/your child will not be paid to take part in the study. There will be no costs involved for you if your child takes part. Transport will be provided for you and your child from your child's school/crèche/aftercare facility to the Tygerberg Medical Campus.

- **Children included in the study have the option of being transported to and from the laboratory by the researchers, in private vehicles. This will be individually arranged with the parents.**
- **You can contact the Health Research Ethics Committee at 021 938 9207 if you have any concerns or complaints that have not been adequately addressed by your study staff.**
- **You will receive a copy of this information and consent form for your own records.**

DECLARATION:

By signing below, Iparent/ legal guardian of agree to allow him/her to take part in a research study entitled: The 3-D walking gait pattern of typically developed children in the Western Cape.

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and my child has not been pressurized to take part.
- My child may choose to leave the study at any time and will not be penalized or prejudiced in any way.
- My child may be asked to leave the study before it has finished, if the study staff or researcher feels it is in my best interests, or if my child does not follow the study plan, as agreed to.

Signed at (*place*) on (*date*) 20...

Signature of participant

Signature of witness

ADDENDUM D

PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



TITLE OF THE RESEARCH PROJECT:

Determining the normative 3D kinetic and kinematic parameters of self -selected walking in 6 - 10 year old children with typical development: a pilot study

RESEARCHERS NAME(S): M. Nevin & Y. Smith

ADDRESS: Faculty of Health Sciences - Physiotherapy Department

Tygerberg Campus

Parow

Cape Town

CONTACT NUMBER: 021 938 9300

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 disease or illness. Research also helps us to find better ways of helping, or treating children who are sick.

What is this research project all about?

We want to see how your legs move when you walk.

Why have I been invited to take part in this research project?

We are looking for children that walk and run well.

Who is doing the research?

We (Michaela and Yvonne) are two physiotherapists that are doing the study on children.

What will happen to me in this study?

We will put stickers on your legs and feet. You will walk up and down a hall a few times. A computer will look at the stickers and tell us how your legs are moving.

Can anything bad happen to me?

No, it's not sore.

Can anything good happen to me?

You will not get anything for being in the study.

Will anyone know I am in the study?

If you are helping with the study, we will not tell anyone your name or that the video belongs to you.

Who can I talk to about the study?

Yvonne or Michaela (021 938 9300)

You may have some questions; you can ask them at any time.



What if I do not want to do this?

It is okay if you do not want us to do this. If you start and want to stop, that is also okay.

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 pull out of the study at any time?

 YES NO

Signature of Child

Date

ADDENDUM E

INFORMATION LETTER TO SCHOOL

11 April 2014

Tygerberg Medical Campus

Stellenbosch

Dear Parents

Our names are Yvonne Smith and Michaela Nevin. We are physiotherapy Masters Students from the University of Stellenbosch.

Our study evaluates normal children's walking patterns. We are looking for children between the ages of 6-10 years of age, who attend a mainstream school and who are good at following instructions.

The study will be conducted after school hours, so as not to interfere with your child's education. The study will be conducted on Tygerberg Campus (Parow) in the *FNB 3D gait laboratory*. We will provide transport to and from school to the 3D gait-analysis laboratory. They will be transported back to school before 17:00. You are welcome to join your child and observe the procedure.

In the laboratory, reflective markers will be placed on the child's hips, knees and feet. They will walk up and down a walkway and complete a simple balancing task. Specialised camera equipment and motion detectors will capture the movement and a computer programme will create a graph of the various joint movements. This will enable us to create a database of the normal walking pattern in children between the ages of 6-11 years. This is the first study of its kind in South Africa! It will enable future researchers to compare walking patterns of disabled children with those of normally developed children and help us as physiotherapists to treat the patient as effective as we possibly can.

The study has been approved by the University of Stellenbosch Ethics Committee (Ethics reference number: S13/10/220). It is completely voluntary and anonymity is guaranteed.

If your child wants to participate in the study, please fill in the form and return it back to school on Monday.

If you or your child has any questions or queries, please contact us.

Kind regards

Yvonne and Michaela

ADDENDUM F

GENERAL HEALTH AND ACTIVITY QUESTIONNAIRE

Name of child: _____ Grade of child: _____

Date of birth: _____ Weight: _____ Height: _____

Name of parent/guardian: _____ Telephone number: _____

E-mail address of parent/guardian: _____

1. Does your child have any health problems? If YES, please provide details.

2. Has your child been diagnosed with Attention Deficit Hyperactivity Disorder (ADHD), Cerebral Palsy (CP), Scoliosis, Fetal Alcohol Syndrome (FAS), Developmental Coordination Disorder (DCD), Hip dysplasia, Duchenne's or any similar condition? If YES please provide details.

3. Are you aware of any developmental delays or motor problems? If YES, please provide brief detail.

4. Has your child recently (in the past six months) had any injuries or illness (e.g. a broken bone or hospitalization)? If YES please provide details?

5. Has your child recently reported any pain in the body? If YES please provide brief details about where, when and why?

6. Does your child participate in sport? If YES, which sport and how many times a week?

Winter: _____

Summer: _____

ADDENDUM G

TELEPHONIC SCREENING QUESTIONNAIRE

Date of questionnaire: _____

Name of child: _____ Girl / Boy: _____ Age: _____

Name of parent/care giver: _____ Contact details: _____

1. Ask to speak to relevant parent/care giver. Researcher introduces herself and gives short explanation of study:

"We are conducting a study on the walking pattern of normal aged 5 to 10 year old children at the Faculty of Health Sciences, University of Stellenbosch, Tygerberg Campus. Special markers are put onto the skin and video cameras and film and convert the images into computer 3-D models. The information is useful to understand angles and forces around the joints and to look at stride length and step width of children. This information will be used as a normal database which other studies on children with illnesses can be compared. Placement of the markers is painless. The testing procedure requires a few walks up and down the laboratory as well as a short hopping task. Children will at all times be accompanied by parents/care givers. Refreshments will be served before and after testing. Parents/care givers will be asked to read and sign an informed consent form which is sent before testing, and children will give informed assent. They may refuse testing on the day."

2. Would parent/care giver be interested in allowing child to participate?
3. Ask parent/care giver if it would be possible to run through a short screening check list to make sure child may participate in the study.
4. Ensure that parent understands that all information is confidential and will only be used to determine if child may participate.

• Date of birth: _____ Age: _____

• Name of school and grade:

• Is your child coping in his current school and grade?

• Is your child able to walk barefoot? YES / NO

NO: Please explain: _____

• Is your child able to follow basic instructions?

NO: Please explain: _____

Does your child have any health problems? (Has he/she been diagnosed with Attention Deficit Hyperactivity Disorder, Cerebral Palsy, Scoliosis, Fetal Alcohol Syndrome or Developmental Coordination Disorder?)

- Is your child normal weight? **YES / NO**
NO – overweight / underweight? _____
 - Has your child recently had any injuries like a broken bone or bruising? **YES / NO**
YES: where, when?

 - Has your child recently reported any pain in the body? **YES / NO**
YES: where, when, why?

 - Did your child achieve all his developmental milestones like crawling and walking at the correct time? **YES / NO**
 - Are your child's vaccinations up to date? **YES / NO**
 - Has your child been admitted to hospital? **YES / NO**
YES: Why, when, where?

 - Has your child had any operations? **YES / NO**
YES: Why, when, where?

5. Thank parent/caregiver for answering all the questions.
6. Does child qualify for study:
YES: Explain to parent/caregiver, agree on date and time of testing and post/email informed consent. Ask if parent has any questions or concerns?
NO: Explain why child does not qualify, thank the parent/caregiver for time. Ask if any questions/concerns?

ADDENDUM H

CONSENT AND INDEMNITY FORM (3D Children's Walking Gait Study)

1. I..... (Name)
of(Address)
being the parent / guardian of
hereby give consent for my son / daughter to be transported from Excelsior Primary School to the FNB 3D laboratory at Tygerberg Medical Campus and back to school by Ms Yvonne Smith / Ms Michaela Nevin in their private vehicles on the date agreed upon by both parties.

2. I fully understand and accept that this journey is at my son / daughter's own risk.

3. I further hereby declare that the information on this form is correct to the best of my knowledge and understand that failure to disclose relevant information may invalidate inclusion on this journey.

I hereby indemnify, hold harmless and absolve Ms Yvonne Smith/ Ms Michaela Nevin, against any or all claims that may arise in connection with the loss of or damage to the property of or injury to my son/ daughter in the course of this journey, **in the knowledge** that Ms Y Smith and Ms M Nevin **will nevertheless take all responsible precautions for the safety and welfare of my son / daughter.**

Signed at on theday of2014

PARENT / GUARDIAN: WITNESS:

ADDENDUM I

VICON LABORATORY AND MARKER PLACEMENT INFORMATION

Hardware and software

The Vicon Motion Analysis (Oxford, United Kingdom) system consists of eight (either wall or tripod mounted) T-10 MX cameras and a Bertec (model FP6090-15) force plate with Vicon Nexus software was used during this study. The VICON has demonstrated high accuracy and reliability (Ehara, Fujimoto, Miyazaki, Tanaka & Yamamoto, 1997) and also demonstrated to have less than a 1.5-degree error (Richards, 1999).

The T10 is a motion-capturing system with a unique combination of high-speed accuracy and resolution. The system has a resolution of 1-mega pixels and captures 10-bit grey scale images using 1120×896 pixels, with the ability to capture speeds of up to 250 frames per second. Retro-reflective markers (Figure 6.6) with a diameter of 9.5 mm were used.

Anthropometric measurements:

Lower- body Plug-in Gait model: Height, weight, leg length, knee and ankle width

Weight: measured using a three dimensional Bertec (Bertec Corporation Ltd) force plate in the VICON laboratory. The measurements will be in newton (N) and converted to kilograms (kg).

Height: measured in millimeters (mm) using a T-bar tape measure.

Inter-ASIS distance: ASIS-ASIS distance is the distance between the left ASIS and right ASIS. This measurement is only needed when markers cannot be placed directly on the ASIS, for example, in obese patients.

Leg Length: Leg length will be measured in millimeters (mm), using predetermined landmarks (anterior superior iliac spine and medial malleoli). True leg length is measured between the ASIS and the medial malleolus, via the knee joint. If, for example, the subject is standing in crouch, this measurement is NOT the shortest distance between the ASIS and medial malleoli, but rather the measure of the skeletal leg length.

Marker placement:

Lower- body Plug-in Gait model: the anterior and posterior superior iliac spine, the lateral aspect of the knee at the flexion-extension axis, the lateral malleolus of the ankle, the second metatarsal head, the heel of the calcaneus, and the thigh and the tibia laterally.

<p><u>Pelvic Markers</u></p> <p>LASI (Left Anterior Superior Iliac Spine) RASI (Right Anterior Superior Iliac Spine)</p> <p>LPSI Left Posterior Superior Iliac Spine RPSI Right Posterior Superior Iliac Spine</p>	<p>Both markers should be placed directly over the anterior superior iliac spines.</p> <p>These are slight bony prominences which can be felt immediately below the dimples (sacro-iliac joints), at the point where the spine joins the pelvis.</p>
<p><u>Knee Markers</u></p> <p>LKNE (Left Knee Joint) RKNE (Right Knee Joint)</p>	<p>The analysis used in the program assumes that the flexion, abduction, and rotation axes all pass through a single, imaginary point within the knee. This point is midway between the points where the flexion axis passes through the skin. The knee markers should be placed on the lateral of these two points.</p>
<p><u>Thigh Markers</u></p> <p>LTHI (Left mid) RTHI (Right mid)</p>	<p>Ideally, the location and alignment of the knee flexion axis would be tracked in a walking subject.</p>

<u>Ankle Markers</u> LANK (Left Ankle Joint) RANK (Right Ankle Joint)	The analysis used in the PIG model assumes that the flexion, abduction, and rotation axes all pass through a single, imaginary point within the ankle. This point is midway between the points where the ankle flexion axis passes through the skin. The ankle marker should be placed on the lateral of these two points, the lateral malleolus under most circumstances.
<u>Shank Markers</u> LTIB (Left mid-Shank Stick) RTIB (Right mid-Shank Stick)	The marker can either be placed directly on the skin or a base-plate and stick mounted marker is placed over the lower 1/3 of the shank to determine the alignment of the ankle flexion axis. If a KAD is not used, the shank marker should lie in the plane that contains the knee and ankle joint centres and the ankle flexion/ extension axis. Note: In a normal subject the ankle joint axis, between the medial and lateral malleoli, is externally rotated by between 5 and 15 degrees with respect to the knee flexion axis. The placements of the thigh and shank markers should reflect this.
<u>Forefoot Markers</u> LTOE (Left Toe) RTOE (Right Toe) Heel Markers LHEE (Left Heel) RHEE (Right Heel)	The forefoot markers should be placed on the dorsal surface of the foot, most commonly over the second metatarsal head, on the mid-foot side of the equinus break between fore-foot and mid-foot. Note: The toe and heel markers should be placed such that a line between the

	centre of these markers is parallel to the long axis of the foot.
<u>Trunk Markers</u> T10	Spinous Process of the 10th thoracic vertebrae.

System calibration:

A dynamic calibration: a system marker orientation (which tests the ability of the cameras to accurately detect the orientation of the markers to each other and within the capturing volume). Dynamic calibration was performed according to standard laboratory protocol, with the laboratory technician walking through the capturing volume, while moving the T-wand in scooping movements. The ability of the cameras to detect movement within the capturing volume was then calculated by the software. System-marker orientation was undertaken using a standard VICON T-wand. To test the ability of the cameras to detect accurately the orientation of the markers to one another and within the capturing volume, the T-wand was placed on a 3-D Bertec forceplate (Bertec Corporation Ltd), which was synchronised with the VICON motion analysis system.

Static trial:

During the static trial, the participant was asked to assume a standard T-pose (explain T-pose position) within the capturing volume. The trial was reconstructed to produce three-dimensional reconstructions of the markers, which were associated with marker labels from a generic labelling model. This allowed for the markers to be labelled manually, and a graphic simulation of the subject was created. In order for the plug-in gait model to calculate the key parameters, a general marker set model contained in the Vicon Skeleton template was calibrated to the Vicon Skeleton file created for the participant. All trials were reconstructed to view the graphical image of the participant, and the labelling of all trials was checked again for accuracy of the labelling of the anatomical marker positions.

Dynamic trial:

A Dynamic trial consists of the movement that is required for testing (i.e. walking, running, golf swing).

Processing:

The biomechanical data were processed using Nexus Version 1.7, with the full-body Plug-In Gait model being used to calculate the 3D kinematic data. A trained laboratory technician performed the data processing. Sometimes, gaps occurred in the captured data due to markers temporarily being obscured and, thus, not detected by the two minimally-required cameras. The gaps were, by preference, filled by means of the Pattern fill option in the VICON Nexus (1.7) software, which was patterned to a marker on the same rigid body segment (e.g. right wrist A & right wrist B, or ankle & heel). The pattern fill function was that of a spline fill that was corrected at discontinuities therein, in order to follow the pattern of the 2nd marker. After all the data were processed, the data were exported to Microsoft Excel for analysis.

Marker filtering (HIGHLY DEPENDENT ON MOVEMENT-default walking)

The trajectories of the markers (diameter 14mm) were filtered using the standard Woltring filter algorithm provided in the Vicon Nexus software (MSE value of 20).

Biomechanical modelling (CALIBRATIONS ONLY DONE PROPERLY FROM 2013)

Joint angles were calculated using the Vicon Plug-In-Gait model. Standing calibrations were conducted in a standardized manner; subjects were instructed to stand in an upright T-pose position looking down the length of the capture volume with their feet hip-width apart and arms out to the side and parallel to the ground (palms facing down). The joint centres for the hip were calculated with the standard Plug-in-Gait linear regression equations, and the knee and ankle joint centres were calculated medial joint markers (which were removed after calculating tibial torsion as well as thigh and shank offsets during calibration).

Model filtering (HIGHLY DEPENDENT ON MOVEMENT-default walking)

The model outputs were filtered using the standard Butterworth filter algorithm provided in the VICON Nexus software (4th order filter with cut-off frequency of 6Hz).

Events (HIGHLY DEPENDENT ON MOVEMENT-default walking)

Events were automatically inserted for each trial using a customized Matlab algorithm and the Nexus plug-in PECS, and then individually checked in Nexus for visual consistency. The foot contact and foot off events were detected by the Matlab algorithm using the second derivatives of the heel and toe marker trajectories.

ADDENDUM J**FNB MOTION ANALYSIS LABORATORY EVALUATION FORM**

(Children 6-10 years)

Subject code:				
Date:				
Assessment by:				
Movement	Position	Notes	ROM	
			(Degrees)	
Hips			Left	Right
Flexion	Supine			
Extension	Side	Knee in ext		
Abduction	Supine			
Adduction	Supine			
External rotation	Prone			
Internal rotation	Prone			
Knee				
Flexion	Prone			
Extension	Supine			
Ankle				
Dorsiflexion	Supine	Knee Ext		
	Supine	Knee Fl		
Plantar flexion	Supine	Knee Fl		

Leg dominance:

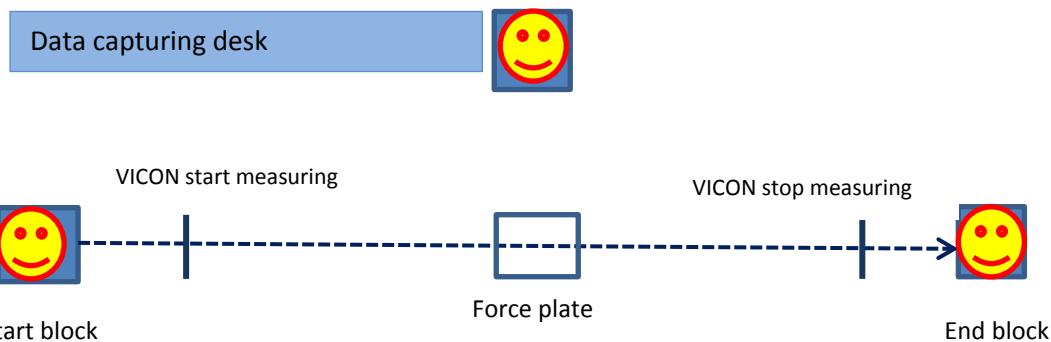
(Place a ball in front of the child and ask him / her to kick it to you.)

ADDENDUM K

INSTRUCTIONS FOR 3-D GAIT ANALYSIS IN CHILDREN 6-10 YEARS

(Physical assessment will be done prior to the VICON trials. Test dominant leg: place the ball in front of the child and ask them to kick it towards you)

- 3x chairs @ start / end block (indicated with blue squares)
- 3x toys on each chair (indicated with smile faces)
- Snacks and juice



Calibration: (place the toy $\pm 5\text{m}$ away from the force plate on a chair)

“Stand up nice and straight. Look at the toy. Lift up your arms (indicate to the child 90° abduction of the shoulders). See how still you can stand for 10 seconds.”

Practice walk: (x2)

Chairs and toys to the start / end blocks.

“Stand in the block, walk towards the toy and don’t stop till you are past it.”

Repeat toward the other side as well.

Walking: (x6)

“Stand in the block, walk towards the toy and don’t stop till you are past it.”