Normative centre of pressure values for single leg standing and tandem stance in children between the ages of six and ten years – a pilot study.

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This thesis presented in partial fulfilment of the requirements for the degree of Master of Science in Physiotherapy (Structured) OMT in the Faculty of Medicine and Health Sciences at Stellenbosch University

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March 2016

Declaration Page

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Abstract

Introduction

Balance in children, both static and dynamic, is a skill required for normal motor development. Postural stability, measured by force plate derived centre of pressure (COP) data is used to infer static balance. A baseline normative reference database for age and gender will allow for more accurate assessment of children's static balance development and ability.

Objective

To describe age and gender differences in postural stability for single leg standing and tandem stance in typically developed children aged six to ten years, and to provide recommendations for future, larger normative database studies.

Methodology

Using a descriptive study design, a convenience sample of 28 children each performed five balance tasks while standing on a dynamic pressure mapping device: left and right single leg standing with eyes open and eyes closed, and tandem stance. Centre of pressure range of movement and COP velocity parameters were used to describe postural stability. Mann-Whitney tests were used to determine significant differences in COP parameters between different age groups and gender. Level of significance was set at $p \leq 0.05$.

Results

For single leg standing with eyes open, significant differences were found between boys and girls for mean COP velocity in the anterior-posterior (AP) direction ($p =< 0.02$) and mean COP velocity combined. Significant differences in mean COP velocity AP were also demonstrated between younger (6-8 yrs) and older (9-10) girls ($p =< 0.03$) No significant differences were found in single leg standing with eyes closed, and tandem stance.

Conclusion

The significant differences in COP velocity AP during single leg standing with eyes open between the older and younger girls illustrates age related improvement in postural stability via slowing of COP velocity with age. This maturation of postural stability was not demonstrated for boys possibly because the boys, as a group, performed better than the girls. The lack of any significant differences between age groups and gender during tandem stance may be attributed to a ceiling effect as the task was not challenging enough. The increased difficulty of performing single leg standing with eyes closed was illustrated by lesser successful trials, larger COP range of movement and faster COP mean velocity across the age groups and genders.

Key words: *Postural stability, centre of pressure, children, single leg standing, tandem stance*

Opsomming

Inleiding

Beide staties en dinamies balans is kinders is ‘n vaardigheid wat benodig word vir normale motoriese ontwikkeling. Posturale stabiliteit, soos gemeet deur drukmiddelpunt (DMP) data afkomstig van kragplaatmetings, word gebruik om afleidings te maak met betrekking tot balans. ‘n Basislyn normatiewe verwysingsdatabasis vir ouderdom en geslag sal ‘n meer akkurate assessering van kinders se statiese balansontwikkeling en –vermoë te weeg bring.

Doelwit

Om ouderdoms- en geslagsverskille in posturale stabiliteit vir een-been staan en tandemstaan in tipies ontwikkelde kinders, ses tot tien jaar oud, te beskryf, en om aanbevelings vir toekomstige, groter normatiewe databasisstudies te voorsien.

Metodologie

Deur gebruik te maak van 'n beskrywende studie-ontwerp het 'n gerieflikheidssteekproef van 28 kinders wat elk vyf balanstake uitgevoer terwyl hulle op 'n dinamiese drukkartering toestel gestaan het; linker en regter een-been staan met oop oë en geslote oë, en tandemstaan. Drukmiddelpunt omvang van beweging en DMP snelheid parameters is gebruik om posturale stabiliteit te beskryf. Mann-Whitney toetse was gebruik om betekenisvolle verskille in DMP parameters tussen verskillende ouderdomsgroepe en geslagte te bepaal. Die vlak van betekenisvolheid was vasgestel op $p \leq 0.05$.

Resultate

Vir een-been staan met oop oë is beduidende verskille gevind tussen die seuns en meisies vir gemiddelde DMP snelheid in die anterior-posterior (AP) rigting ($p = <0,02$) en vir die gemiddelde DMP snelheid gekombineer. Beduidende verskille in die gemiddelde DMP snelheid AP tussen jonger (6-8 jaar) en ouer (9-10) meisies ($p = <0,03$) is ook gevind. Geen beduidende verskille is in een-been staan met geslote oë, en tandemstaan gevind nie.

Gevolgtrekking

Die beduidende verskille in DMP snelheid AP tydens een-been staan met oop oë tussen die ouer en jonger meisies illustreer ‘n ouderdomsverwante verbetering in posturale stabiliteit deur vertraging van DMP snelheid met ouderdom. Hierdie rypwording van posturale stabiliteit is nie in seuns gevind nie moontlik omdat die seuns, as 'n groep, beter presteer het as die meisies. Die gebrek aan enige beduidende verskille tussen ouderdomsgroepe en geslag in tandemstaan, kan toegeskryf word aan 'n plafon-effek siende dat die taak nie uitdagend genoeg was nie. Die verhoogde moeilikheidsgraad om een-been staan met geslote oë uit te voer, is geïllustreer deur minder suksesvolle proewe, groter DMP omvang van beweging en vinniger DMP gemiddelde snelheid oor die ouderdomsgroepe en geslagte.

Sleutel woorde: Posturale stabiliteit, drukmiddelpunt, kinders, een-been staan, tandemstaan

Acknowledgements

I would like to sincerely thank the following people:

The participants and their parents for their time and commitment to being part of the study.

My research partner: Ms Yvonne Smith for her contribution to this study.

Dr Yolandi Brink and Dr. Marianne Unger for their support, advice, corrections and guidance provided throughout the entire study process.

The staff at the Stellenbosch FNB-3D Motion Analysis Laboratory Mr John Cockroft (Laboratory engineer) Mr Dominic Fisher and Ms Domonique Leibrant (Laboratory physiotherapists) for their time and assistance in the execution of this study.

My husband for his unfailing support.

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List of abbreviations

3D	Three dimensional
ADHD	Attention deficit hyperactivity disorder
AP	Anterior-posterior
BMI	Body Mass Index
BOT-2	Bruiniks-Oseretsky Test of Motor Proficiency
COP	Centre of pressure
CP	Cerebral Palsy
DCD	Developmental coordination disorder
EC	Eyes closed
EO	Eyes open
FASD	Foetal alcohol spectrum disorder
HIV	Human immunodeficiency virus
ICC	Interclass correlation coefficient
MABC-2	Movement Assessment Battery for Children
ML	Medio-lateral
ROM	Range of motion
SES	Socio-economic status
SD	Standard Deviation
TD	Typically developed
TUG	Timed Up and Go test

List of definitions

Postural stability: The complex ability to maintain the body's centre of mass within the limits of the base of support (Westcott, Lowes & Richardson 1997). Postural stability represents the continuous correction against the destabilizing force of gravity (Blanchet, Marchand & Cadoret 2012) and is dictated by the efficiency of the individual's balance mechanisms (Raine 2009).

Centre of mass (COM): This is a point equivalent of the total body mass in the global reference system and is the weighed average of the COM of each body segment in 3D space. It is a passive variable controlled by the balance control system (Winter 1995).

Centre of gravity: The vertical projection of the COM onto the ground is often called the centre of gravity (Winter 1995).

Centre of pressure: This is the point location of the vertical ground reaction force vector. It represents a weighted average of all the pressures over the surface of the area in contact with the ground. It is independent of the centre of mass (Winter 1995).

Chapter 1: Introduction

In children, balance both static and dynamic, is a skill required for normal motor development and acquiring fundamental movement and manipulative skills (Fisher, Reilly, Kelly, Montgomery, Wiliamson, Paton & Grant 2005; Franjoine, Darr, Held, Kott & Young 2010). Static balance is commonly assessed by measuring postural stability (Rival, Ceyte & Olivier 2005). The development (improvement) of static balance throughout childhood, with a major shift to adult-like balance strategies around the age of eight years, has been illustrated in standing postural stability studies (Riach & Starkes 1994; Rival, Ceyte & Olivier 2005; Kirshenbaum, Riach & Starkes 2001). There is evidence that balance capabilities may be influenced by socio-economic status (Habib, Westcott & Valvano 1999; Goodway & Branta 2003) and that the emergence of motor functioning may differ in children from different cultural backgrounds (Kerfeld, Guthrie & Stewart 1997; Mayson, Harris & Bachman 2007). In order to make a valid assessment of a South African child's standing balance ability it would be useful if a normative database exists with which to compare statistical data of individuals to an age and gender matched average. Currently, no such database exists in South Africa.

1.1 The development of balance in children

In children, balance is inextricably linked to motor development and fundamental movement skills (Fisher et al. 2005). Typical human motor development is characterised by variation and the development of adaptive variability (Hadders-Algra 2010). Balance capabilities advance with maturation with profusion of cerebral connectivity which is thought to be the neural basis for human behavioural adaptive variability (Hadders-Algra 2010). This allows children to select the most suitable behavioural solution, from a large available range, for a specific situation (Hadders-Algra 2010). From birth, balance skills are developed through training or play and maturation, with children learning to stand and then walk between ten and 18 months of age (Condon & Cremin, 2014). Young children refine these gross motor activities and develop running, jumping and climbing skills which continue to develop into young adulthood (Patel, Pratt & Greydanus 2002).

The development of fundamental motor skills, including balance, is not solely reliant on maturation of the nervous system but rather the interaction between constraints of the task, the child and their environment (Newell 1986). Differing environmental and social and economic factors have been shown to influence the emergence and development of motor skills (Kerfeld, Guthrie & Stewart 1997; Mayson, Harris & Bachman 2007) and balance capabilities in children from different cultural backgrounds (Habib, Westcott & Valvano 1999).

According to Hadders-Algra (2010 p. 1823) atypical motor development "is characterized by limited variation (a limited repertoire of motor strategies) and a limited ability to vary motor behaviour according to the specifics of the situation (i.e. limited variability)". As a result of a cerebral lesion, atypical delayed motor development is seen in children with cerebral palsy (Bax, Goldstein, Rosenbaum, Leviton, Paneth, Dan, Jacobsson & Damiano 2005) with the effects on gait and balance well described (Gage & Novacheck 2001; Rose, Wolff, Jones, Bloch, Oelhert & Gamble 2002). Researchers are increasingly recognising the effects on motor functioning in other neurodevelopmental conditions also associated with atypical, delayed motor development including developmental coordination disorder (DCD) (Deconinck, De Clercq, Savelsbergh, Van Coster, Oostra, Dewitte & Lenoir 2006), foetal alcohol spectrum disorder (FASD) (Viljoen et al. 2005; Wilson, Ruddock, Smits-Engelsman, Polatajko & Blank 2013), attention-deficit hyperactivity disorder (ADHD) (Jucaite, Fernell, Forssberg & Hadders-Algra 2003) and more recently children with human immunodeficiency virus (HIV) encephalopathy (Donald, Walker, Kilborn, Carrara, Langerak, Eley & Wilmshurst 2015).

1.2 The evaluation of balance and postural stability

The evaluation of balance in children is not clear cut, with many different tests and assessments available (Humphriss, Hall, May & Macleod 2011). Simple tests are often performed by clinicians to subjectively assess a component of balance ability - for example single leg standing and balance beam walking (Humphriss et al. 2011). Standardised tests; including the balance subtests of Bruiniks-Oseretsky Test of Motor Proficiency (BOT-2) (Bruininks 2005) and The Movement Assessment Battery for Children (MABC-2) (Brown & Lalor 2009) have reference data which allow for comparison but have been shown to have large variability (Deitz, Kartin & Kopp 2007). Force plate standing tests, most commonly used in laboratory settings, require highly technical, expensive equipment and provides sensitive, objective and comparable data describing postural stability which infers static balance ability (Humphriss et al. 2011; De Kegel, Dhooge, Cambier, Baetens, Palmans & Van Waelvelde 2011). Force plate derived data such as centre of pressure (COP) measurements have been used extensively to describe postural stability in both typically developed (TD) children and children with neurological and disabilities which affect motor development (Zumbrunn, MacWilliams & Johnson 2011; Roebuck, Simmons, Mattson & Riley 1998; Rose et al. 2002; An, Yi, Jeon & Park 2009; De Kegel et al. 2011).

1.3 Postural stability research in children

In TD children age related improvements in postural stability are well documented (Cumberworth, Patel, Rogers & Kenyon 2007; Rival, Ceyte & Olivier 2005; Kirshenbaum, Riach & Starkes 2001). Force plate derived COP data from postural stability studies have also illustrated gender and anthropomorphic differences. Girls have been shown to perform better in postural stability tasks compared to age matched boys (Smith, Ulmer & Wong 2012; Demura, Kitabayashi & Aoki 2008; Geldhof, Cardon, De Bourdeaudhuij, Danneels, Coorevits, Vanderstaeten & De Clercq 2006; Peterson, Christou & Rosengren 2006; Steindl, Kunz, Schrott-Fischer & Scholtz 2006; Nolan, Grigorenko & Thorstensson 2005) and obese boys demonstrate postural stability deficits specifically in tasks which challenge functional balance (Lee & Lin 2007; McGraw, McClenaghan, Williams, Dickerson & Ward 2000; Deforche, Hills, Worringham, Davies, Murphy, Bouckaert & De Bourdeaudhuij 2009).

1.4 Summary

Using TD South African children to compile a normative database of standing task force plate measured COP data may provide baseline measures useful for clinical comparison and analysis of factors including age and gender which may affect postural stability within our population. This pilot study aims to describe normative COP values for single leg standing and tandem stance in children between the ages of six and ten years and provide recommendations for larger population studies.

Chapter 2: Literature review

2.1 Introduction

Maintaining postural stability is a complex skill which involves integration and evaluation of visual, vestibular and proprioceptive information (Smith, Ulmer & Wong 2012) and the generation of the appropriate motor response (Mickle, Munro & Steele 2011). The aim of this literature review was to describe postural stability and the factors influencing postural stability of typically developing (TD) children during single leg standing and tandem stance. The following Stellenbosch University electronic databases were searched between March 2014 and March 2015: *Pubmed, Science Direct, PEDro and Cochrane.* Keywords used in different combinations included *'Postural control', 'postural stability', 'balance', 'balance control', 'balance maturation', 'single leg stance', 'single limb stand', 'tandem stance', 'force plate', 'force platform', 'centre of pressure', 'typically developed', 'children', 'age'.* Studies that were deemed appropriate for the topic were reviewed.

2.2 Defining balance and postural stability

Balance is a multidimensional concept. It refers to the ability of a person not to fall (or maintaining a posture) (Condon & Cremin 2014), facilitate voluntary movement such as transitions between postures and reacting to recovering equilibrium following external perturbations such as a trip or slip (Mancini & Horak 2010). Both static postural balance - the ability to maintain a posture such as balancing in a standing or sitting position, and dynamic balance - maintaining posture during movements, are thought to be important and necessary motor abilities (Westcott, Lowes & Richardson 1997). Balance is constantly challenged by destabilising internal perturbations from neuromuscular noise and hemodynamics, as well as by the force of gravity, perturbations from conscious movement (e.g. turning or bending) and interactions with the environment (Bryant, Trew, Bruce & Kuisma, Smith 2005). As a result, it is not possible for the body to stand completely still, and there is resultant sway over the base of support (Bryant et al. 2005). Balance can be operationally defined as the process by which postural stability is maintained (Habib, Wescott & Valvano 1999). Postural stability represents the continuous correction against the destabilizing force of gravity (Blanchet, Marchand & Cadoret 2012) and is dictated by the efficiency of the individual's balance mechanisms which includes the visual, somatosensory and vestibular systems (Raine 2009). Postural stability can be defined as the complex ability to maintain the body's centre of mass (COM) within the limits of the base of support while balance is the way in which postural stability is maintained (Westcott, Lowes & Richardson 1997).

2.3 Assessment of balance and postural stability in children

The body's COM is a calculated point (average of each body segment in 3D space) equal to the total body mass in the global reference system and when projected vertically onto the ground it is known as the centre of gravity (COG) (Winter 1995). The COP, independent of COM, is the point of application of the resultant ground reaction forces and denotes the weighted average of all the pressures over the areas in contact with the ground (Blanchet, Marchland & Cadoret 2012; Winter 1995). In standing, for example the net COP would be between the two feet, and is dependent on the relative amount of body weight taken by each foot (Winter 1995). In order to maintain the drift of the body's COM in upright standing the COP is moved around the COG in order to keep it within the body's base of support (Blanchet, Marchland & Cadoret 2012). This depends on the control of the COP movement and the ability to distinguish error or mismatch between the COP and COM (Winter 1995; Blanchet, Marchland & Cadoret 2012). Centre of pressure values therefore indirectly provide information about stability in quiet stance (Kirshenbaum, Riach & Starkes 2001), where a larger range of COP distributions usually indicates postural instability as well as the process or strategy to control the postural drift (Kirshenbaum, Riach & Starkes 2001).

The complexities of the motor and sensory systems that direct balance make identifying and isolating the source of balance problems difficult (Riemann, Guskiewicz & Shields 1999). This has led to the development of a variety of approaches to evaluate balance which can generally be considered to have either a subjective or an objective basis (Riemann, Guskiewicz & Shields 1999). Subjective tests involve an examiner judging balance performance based on qualitative criteria, whereas objective tests employ the gathering and analysis of quantitative data from devices such as force platforms and motion analysis equipment (Riemann, Guskiewicz & Shields 1999). Clinicians, in the absence of laboratory and technical equipment, often rely on clinical knowledge and experience to identify and assess children's balance deficits using simple tasks with balance constraints based on criteria such as time to the first touchdown or compensatory event, number of touchdowns per unit of time, or a general decision regarding postural sway (Riemann, Guskiewicz & Shields 1999; Humphriss et al. 2011). Most modifications involve variations in foot position (tandem or single-leg stance) which alter the participant's base of support. Clinical static tests of balance are easy to use, do not require expensive equipment and are usually quick to administer (Mancini & Horak 2010). Regardless of the performance criteria or stance modification used, these tests demonstrate ceiling effects and may not be sensitive enough to differentiate situations in which a patient's postural sway increases without the complete loss of postural stability or in movement ranges that are difficult to detect with simple observation (Mancini & Horak 2010; Riemann, Guskiewicz & Shields 1999).

Readily available standardised tests including the balance subtests of BOT-2, M-ABC-2 and the Paediatric Clinical Test of Sensory Interaction and Balance (De Kegel et al. 2011; Butz, Sweeney, Roberts & Rauh 2015) are also used in the paediatric population as measures for interpreting balance (both static and dynamic) performance (Humphriss et al. 2011). These outcome measures have reference normative scores which allow for comparison (Humphriss et al. 2011) however, large variability have been demonstrated specifically in the BOT-2 test (Deitz, Kartin & Kopp 2007) and studies have demonstrated substantial standard error of measurement for the MABC-2 (Cools, De Martelaer, Samaey & Andries 2009). These tests are used as screening tools to identify and describe motor impairments or deficits in individuals and provide an overview of functional balance (Cools et al. 2009). While these tests have been shown to be reliable they are not objective measurements of postural stability in children (Cools et al. 2009).

In research-based laboratory settings standing postural stability is inferred from force plate derived COP data which allows quantitative balance assessments (Riemann, Guskiewicz & Shields 1999). These measurements are recorded while the child performs selected balance activities or maintains stationary stance positions such as bilateral standing, single leg standing and tandem standing (Sozzi, Honeine & Schieppati 2013; Zumbrunn, MacWilliams & Johnson 2011; Nolan, Grigorenko & Thorstensson 2005, Deforche et al. 2009). In studies that have used and compared the BOT-2 balance subtest and single leg standing force plate measured COP data, have demonstrated that both tests are sensitive enough to determine the balance impairments of physically impaired children (Zumbrunn, MacWilliams & Johnson 2011). In TD children significant correlations between age adjusted COP parameters and BOT-2 scores have been demonstrated illustrating the validity of both tests (Franjoine et al. 2010).

Postural stability using force plate calculated COP parameters has been used extensively to describe balance impairments and infer balance ability in both TD children and children with neurological and physical disabilities which affect motor development including congenital talipes equinovarus (Zumbrunn, MacWilliams & Johnson 2011), foetal alcohol spectrum disorder (FASD) (Roebuck et al. 1998), cerebral palsy (CP) (Rose et al. 2002), the profoundly deaf (An et al. 2009) and hearing impaired children (De Kegel et al. 2011). The potential to incorporate standing force plate COP data in conjunction with other gross motor tests to explore neuro-behavioural differences and make differential diagnosis based on motor and balance deficits in spectrum disorders with diagnostic overlap (for example attention deficit and (FASD) is also being explored (Kooistra, Ramage, Crawford, Cantell, Wormsbecker, Gibbard & Kaplan 2009).

The movement of the COP indirectly reflects the postural correction or sway of the body’s centre of mass, providing data which gives insight into static balance ability and the process of controlling balance (Chiari, Rocchi & Cappello 2002; Riemann, Guskiewicz & Shields 1999). A multitude of variables derived from raw COP data, can be calculated allowing detailed analysis of postural stability (Pinsault & Vuillerme 2009).

Two dimensional time series of the COP displacements include COP surface area (in mm^2), COP range (in mm), COP mean velocity (in mm/s) and COP maximal velocity (Vmax) (Pinsault & Vuillerme 2009). These parameters however do not take direction of the COP displacement into account (Pinsault & Vuillerme 2009). Centre of pressure surface area is the area covered by the COP path with a 90% confidence interval (Tagaki, Fujimura & Suehiro 1985). Centre of pressure range indicates the maximal COP displacement without taking direction into account and is used as a measure of overall postural performance (Norris, Marsh, Smith, Kohut & Miler 2005). Centre of pressure mean velocity, is a measure of the amount of activity required to maintain postural stability and is formulated as the total COP displacement divided by the sample period (Geurts, Nienhuis & Mulder 1993). Centre of pressure maximal velocity represents the first time derivative of COP movement in any direction (Pinsault & Vuillerme 2009).

One-dimensional time series of the COP displacements include the same variables as for the two dimensional except that it is described only within the anteroposterior (AP) and mediolateral (ML) axes (Pinsault & Vuillerme 2009). These are widely used in clinical practice to assess postural stability ability during static standing as they require fewer calculations and are easier to interpret (Pinsault & Vuillerme 2009).

Although force plate measurements of COP has been firmly established as an appropriate method of evaluating postural stability (Birmingham 2000; Piirtola & Era 2006) to date, only a small number of studies have reported test-retest reliability of COP measures (Pinsault & Vuillerme 2009) with very few reliability studies documented in children (De Kegel et al. 2011). Reliability is important in any outcome measure to ensure that any observed differences in

COP data between sessions are indicative of real changes in postural stability ability rather than random or systematic procedural error (Dijkers, Kropp, Esper, Yavuzer, Cullen & Bakdalieh 2002). Test-retest reliability testing of COP measures during bilateral static stance with eyes closed (EC) in adults reported greater intra class coefficients (ICC) as the number of trials increased suggesting that the reliability of COP measures are dependant on experimental protocol and that the number of trials performed by each subject should be carefully considered to attain reliable COP data to assess static standing postural stability (Pinsault & Vuillerme 2009).

From the literature it is evident that there is also very little agreement on the most appropriate COP variables for interpreting or evaluating postural stability. Mean velocity and maximal velocity (two dimensional and one-dimensional in the AP direction), demonstrated high ICCs (ICC > 0.75) even when only two, 30 second trials, one hour apart were compared (Pinsault & Vuillerme 2009). Centre of pressure mean velocity was the most reliable COP parameter in a test-retest study of typically developing and hearing impaired children aged six to 12 years old (De Kegel et al. 2011). At present there is no accepted agreement on testing protocols specifically around length and number of trials in children where difficulty of the task and maintaining concentration need to be considered (De Kegel et al. 2011). Criticism for using force plate equipment to measure static balance include the high cost and availability of these systems which may limit the use of these assessment techniques outside of laboratories (Humphriss et al. 2011; Riemann, Guskiewicz & Shields1999).

2.4 Development and maturation of balance

It is known that balance is regulated by a multimodal complex sensory system including somatosensory (or proprioceptive), visual and vestibular systems. Balance changes and matures with age during infancy and childhood (Cumberworth et al. 2007). In adults the sensory system is well organised and acts in a context-specific manner (Hirabayashi & Iwasaki 1995). In children the development and organisation of these systems for balance occur at different ages (Hirabayashi & Iwasaki 1995), which is thought to be as a result of progressive cerebellar maturation or a change with aging in the activity of the brainstem reticular formation and vestibular nuclei (Cumberworth et al. 2007). A transition from immature to mature balance responses has been reported to occur from the ages of three to four years old with the somatosensory system maturing first and the vestibular system last (Hirabayashi & Iwasaki 1995). The use of somatosensory information has been shown to be comparable to adult levels by three to four years old (Hirabayashi & Iwasaki 1995; Peterson, Christou & Rosengren 2006), allowing better control with altered balance conditions compared to much younger children (Butz et al. 2015). Maturation of visual function follows and with the integration of sensory information, seven to ten year old children have shown to use more mature sensory integrated balance strategy where greater accuracy allows for shorter more frequent COP corrections to maintain postural stability (Forssberg & Nashner 1982; Assaiante & Amblard 1995; Shumway-Cook & Woollacott 1985).

Not surprisingly many studies have reported on the correlation of age with improved balance (Franjoine et al. 2010; Mickle, Munro & Steele 2011). Balance scores on paediatric dynamic balance tests (The Timed Up and Go test (TUG), paediatric reach test and paediatric balance scale) improved with increasing age in five to 12 year old children (Butz et al. 2015). Similarly, the timed performance norms of static balance tests in mainstream school-going children (aged four to 15 years) demonstrated that static balance improved with age with a distinct change in capabilities after seven years old (Condon & Cremin 2014). This study reported interquartile ranges for single leg stance with eyes open (EO) as between eight and 32 seconds for under seven years old, between 20s and 74s by eight to nine years and between 48s and 120s by age ten (Condon & Cremin 2014). Predictably the children were able to maintain overall static balance tests for longer with eyes open compared to eyes closed (EC) (Condon & Cremin 2014). The difference between timed EO and EC single leg stance increased with chronological age which supports the theory that children use visual information for balance in an adult-like manner from age ten (Nolan, Girgorenko & Thorstensson 2005; Humphriss et al. 2011; Condon & Cremin 2014)

The development of postural stability during childhood has been illustrated by a decrease in magnitude and frequency of COP variables with increasing age (Riach & Starkes 1994). Young children demonstrate principally high velocity, ballistic balance strategy, making large and fast corrections of COP to retain the COM within the base of support (Riach & Starkes 1994). It is thought that with greater skill in assessing and accommodating differences between planned and actual movement, children will progress to shorter, more frequent corrections (Shumway-Cook & Woollacott 1985; Assaiante & Amblard 1995). This improvement in postural stability with age is non-linear with a major transition around seven to eight years of age (Riach & Starkes 1994; Kirshenbaum, Riach & Starkes 2001). This can be explained by both refinement and improvement of localization and level of muscle activity (Williams, Fisher & Tritschler 1983) and the integration of postural information gained from ballistic movements and multimodal sensory feedback information (visual, vestibular and somatosensory information). This appears in seven to eight year olds (Hatzitaki, Zlisi, Kollias & Kioumourtzoglu 2002; Riach & Starkes 1989; Riach & Starkes 1993; Riach & Starkes 1994; Shumway-Cook & Woollacott 1985).

In a longitudinal study testing quiet bilateral stance (EO) in five and six year olds at three to four month intervals; data was aligned relative to the point of each participant's minimum COP mean velocity (Kirshenbaum, Riach & Starkes 2001). This illustrated a developmental pattern of improvement which may normally be masked by inter-subject variability (Kirshenbaum, Riach & Starkes 2001). Initial high readings of COP mean velocity and intra-subject trial variability values rapidly decreased indicating refinement of the ballistic balance strategy in five and six year olds (Kirshenbaum, Riach & Starkes 2001). This was followed by a transition period (between five and a half and seven years) characterised by a sharp increase in mean COP mean velocity scores (i.e. slowing of improvement) and proportionate increases in variability suggestive of exploration and experimentation with sensory feedback (Kirshenbaum, Riach & Starkes 2001). The COP mean velocity scores tapered off to lower speeds with age, suggesting skilled integration of sensorimotor information and an increasingly co-ordinated control of postural sway (Kirshenbaum, Riach & Starkes 2001). A study by Rival, Cete and Olivier (2005) also illustrated age related changes in overall postural stability between six and ten years with a transition around the age of eight years of age in standing balance with EC (30 children, six, eight, 10 years, 10 adults 24 years). In contrast to findings by Kirshenbaum, Riach and Starkes (2001), Rival, Cete and Olivier (2005) reported a non-linear decrease in COP range with eight year old children demonstrating significantly increased COP range values compared to six year old children and a linear decrease in COP velocity values with age. While both studies demonstrated a developmental improvement in overall postural stability, non-linear changes were found in COP velocity in one study and COP range in the other (Kirshenbaum, Riach & Starkes 2001) (Rival, Cete & Olivier 2005). Despite differences in the results, both studies support the idea of a transition or shift in balance strategies between seven and eight years old is characterised by a temporary slowing of improvement.

While a developmental pattern of improvement over time is well documented (Riach & Starkes 1994; Franjoine et al. 2010) older children in the study by Rival, Cete and Olivier (2005) demonstrated COP displacements that were still larger and faster compared to the adult group indicating that a mature level is not attained by age ten years. There is no consensus on the exact age when adult-like balance is reached (Nolan, Grigorenko & Thorstensson 2005; Hirabayashi & Iwasaki 1995). The maturation of standing balance in children through development and improvement of integration of sensory information is well documented using force plate data derived COP velocity and range values and has also been demonstrated in computerised dynamic posturography studies which monitor COP variation while altering sensory input (Cumberworth et al. 2007).

2.5 Influence of gender, anthropomorphic, social and environmental factors on postural stability

2.5.1 Influence of gender on postural stability

Gender differences in standing postural stability have been reported for age matched children (Smith, Ulmer & Wong 2012). Research has shown that girls exhibit lower COP scores or more steady postural stability compared to boys of similar ages (Demura, Kitabayashi & Aoki 2008; Geldhof et al. 2006; Peterson, Christou & Rosengren 2006; Steindl et al. 2006; Lee & Lin 2007). A small randomized repeated measures study by Smith, Ulmer and Wong (2012) showed that boys, who were exposed to three different balance conditions, demonstrated larger and faster COP when compared to girls indicating that girls have better overall postural stability than boys (Smith, Ulmer & Wong 2012). In a larger study by Nolan, Grigorenko and Thorstensson (2005), similar gender differences in nine to 16 years olds were reported. Boys, nine and ten years old, demonstrated significantly higher COP velocities and increased total range of COP movement during bipedal stance with EO and EC, when compared to age-matched girls (Nolan, Grigorenki & Thorstensson 2005). These COP scores showed age-related improvements indicating that postural stability continues to mature in boys at this age. Nine and ten year old girls COP scores are similar to the older groups tested suggesting the use adult-like static balance strategy by age nine to ten (Nolan, Grigorenki & Thorstensson 2005).

2.5.2 Influence of anthropomorphic differences on postural stability

Increased COP parameters for bilateral and tandem stance in obese boys, as compared to age-matched control boys were reported by Mc Graw et al. (2000). These differences were greatest in EC conditions or when base of support was altered (tandem stance) suggesting postural stability deficits in obese boys especially when base of support and visual input is challenged (McGraw et al. 2000).

Both; Goulding, Jones, Taylor, Piggot and Taylor (2003) and Deforche et al. (2009) demonstrated no significant differences in bilateral stance COP data between overweight and age matched counterparts. Both studies found lower balance test scores for the BOT-2 test in overweight boys. Deforche et al. (2009) demonstrated that overweight boys could not maintain single leg standing on a balance beam for as long as normal weight boys, similarly Goulding et al. (2003) reported that differences between overweight and normal weight boys were more apparent in tests with reduced base of support. The increased sensitivity of the balance beam test may be attributable to the narrow and raised surface when compared to floor-level force plate surface on which the participants had to stand (Deforche et al. 2009). These findings strongly suggest that a more functional, challenging aspect of balance is less efficient in heavier boys (Deforche et al. 2009; Goulding et al. 2003).

The independency of anthropometrics (specifically height and weight) in standing postural stability are supported in COP studies (Odenrick & Sandstedt 1984; Geldhof et al. 2006; Lee & Lin 2007; Nolan, Grigorenko & Thorstensson 2005) which suggest that while postural stability may be partly affected by increase in stature as children grow, the developmental maturation of the visual, vestibular and somatosensory systems may best account for the age and gender related differences (Nolan, Grigorenko & Thorstensson 2005). Lebiedowska and Syczewska (2000) reported no correlation between COP parameters and height and weight in children performing static standing with EC and EO. Poor correlations between COP variables, height, weight and BMI in six to 12 year old children have been documented where anthropomorphic characteristics accounted for approximately 20% of the variability in the scores, with age alone accounting for the largest single contribution to the variance (16%) (Peterson, Christou & Rosengren 2006).

2.5.3 Influence of social and environmental factors on postural stability

Although the sequence of child development is highly ordered and well documented, many studies suggest differences in the rate of development among different cultural groups (Kerfeld, Guthrie & Stewart 1997; Mayson, Harris & Bachman 2007). Significant differences in the emergence of developmental skills at different ages have been documented in TD Alaska Native children and age matched children from Denver in the United States of America using the Denver II test which assesses children’s performance on various age appropriate tasks (Kerfeld, Guthrie & Stewart 1997). The greatest number of significant differences were found in the gross motor domain (Kerfeld, Guthrie & Stewart 1997). In single leg balance testing for six seconds, 90% of Alaska Native children were able to perform this test by 58.6

months (4.8 years) compared to 70.8 months (5.9 years) in children from Denver (Kerfeld, Guthrie & Stewart 1997). The authors suggested that advanced gross motor development may be explained by differences in Native Alaska child-rearing practices which include living with extended family, care giving by older siblings and greater freedom to explore the environment (Kerfeld, Guthrie & Stewart 1997). This may stimulate advanced play and motor skill activity if the children copied and practiced older sibling's behaviours.

Other factors which have been suggested to influence motor development in children include the level of emphasis and importance placed on the independence of daily activities at all ages and acquiring and practicing motor skills such as ball handling and bicycle riding (Mayson, Harris & Bachman 2007). In an adoption study, Pomerleau, Malcuit, Chicoine, Séguin, Belhumeur, Germain, Amyot & Jéliu (2005) found that variables associated with a deprived environment including malnutrition, orphanage conditions and lack of experience with toys may influenced motor development and that environmental conditions could modify (improve) the developmental trajectory of young children (Pomerleau et al. 2005). These findings are supported by literature which suggests that children from disadvantaged backgrounds (based on factors including low family income, lack of parental support, unstable family situations, lack of access to open safe spaces) demonstrate delays in motor skill development (Hamilton, Goodway & Haubenstricker 1999; Goodway & Branta 2003).

While the influences on development of motor functioning in young children less than five years old is well documented, very little research has focused on the cultural, ethnic and socio-economic status influence on motor functioning of older children and specifically balance capabilities. Pakistani children aged five to 13 years scored lower in four clinical balance tests when compared to published scores from similar aged children in the United States of America (Habib, Wescott & Valvano 1999). While height differences between the two populations were not taken into account, the authors hypothesized that overall balance ability differences may be secondary to cultural influences such as less emphasis placed on physical activity by Pakistani parents (Habib, Wescott & Valvano 1999). Within the Pakistani sample, boys performed better than girls on all balance tests in the high socio-economic status (SES) group while the effect of gender was less pronounced in the lower SES group (Habib, Wescott & Valvano 1999). The authors hypothesized that a culture which encourages subdued submissive personalities in girls and restrictive traditional clothing may contribute to poor balance performance in girls (Habib, Wescott & Valvano 1999). These findings support the use of culturally sensitive norms in assessing balance abilities of children from different cultural and socio-economic backgrounds (Habib, Wescott & Valvano 1999).

2.6 Normative databases

When considering postural stability and the methods of assessing it, it is important to recognise the variation that exists in typical balance behaviour (Hadders-Algra 2010) as well as differences in motor development and abilities across different ethnic and cultural backgrounds (Kerfeld, Guthrie & Stewart 1997; Habib, Wescott & Valvano 1999; Mayson, Harris & Bachman 2007) which are all specific to the task being performed (Goodway & Branta 2003). In order to comment on a child's postural stability skill, the range of what is normal for a specific age group and gender with which to compare is important. A normative sample should be diverse, culturally sensitive and represent each ethnic origin in proportion to the actual population (Mayson, Harris & Bachman 2007). A reference database of TD South African children provides a baseline measure which can be used to evaluate individual skill and developmental level and understand how postural stability is affected in clinical populations.

The demographics of South Africa encompasses 51.8 million people of diverse origins, cultures, languages, and religions backgrounds with 79% black, 8.9% coloured, 8.9% white and 2.5% Indian or Asian descent (Statistics South Africa 2012). Of the population, 8% live in traditional dwellings, 13.6% are housed in informal dwellings with the remaining 78% housed in formal dwellings (Statistics South Africa 2012). Significant differences in average annual household incomes across the different population groups exist. Nearly one-third (31%) of the population is aged younger than 15 years (Statistics South Africa 2012). The ethnic and economic diversity of the South African population must be represented in a normative postural stability database in order to make accurate comments on a South African child's static balance development and skill.

2.7 Conclusion

Balance, both static and dynamic, is a skill required for normal functioning in all age groups (Franjoine et al. 2010). The development of balance in childhood, through the maturation and integration of the sensory system, has been illustrated using force plate studies (Assaiante & Amblard 1995; Riach & Starkes 1994). Static balance is reliably assessed by measuring postural stability (Rival, Cete & Olivier 2005) with the use of force plates which measure and record COP data (Bryant et al. 2005). The strategy used to control postural stability, is thought to mature between the ages of six and ten years old with a major transition around the age of eight years (Rival, Cete & Olivier 2005; Kirshenbaum, Riach & Starkes 2001). Age correlated improvements in static balance measured by both COP variables and functional tests have been well documented with no firm consensus on when it reaches adult-like levels (Nolan, Grigorenko & Thorstensson 2005).

Gender differences in standing postural stability have shown that girls exhibit lower COP scores or a more steady postural stability compared to boys of similar ages (Demura, Kitabayashi & Aoki 2008; Geldhof et al. 2006; Peterson, Christou & Rosengren 2006; Steindl et al. 2006; Lee & Lin 2007; Smith, Ulmer & Wong 2012). Postural stability deficits have been demonstrated in obese boys specifically in tasks which challenge functional balance (Deforche et al. 2009; Deforche, Lefevre, Bourdeaudhuij, Hills, Duquet & Bouckaert 2003; McGraw et al. 2000). Differing environmental and social experiences have shown to impact the development and level of skill of motor and balance skills in children (Habib, Wescott & Valvano 1999). As a culturally and ethnically diverse country with large differences in socio-economic status, a South African normative postural stability database should be representative of this diversity.

This pilot study will follow a publication format as per the faculty and journal guidelines (Addendum A).

Chapter 3: The manuscript

Manuscript to be submitted to South African Physiotherapy Journal

Journal guidelines included in Appendix A

Normative centre of pressure values for balance tasks in children

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Significance of work: This pilot study describes standing postural stability of typically developed children aged six to ten years old and provides recommendations for future, larger, reference database studies.

Summary: Number of words: 5189, number of pages: 25, Tables 1 – 5, Appendices: A – H.

Title: Normative centre of pressure values for static balance tasks in children aged six to ten years – a pilot study

Abstract

Background

Postural stability measured by force plate derived centre of pressure (COP) data is used to infer static balance. A South African normative postural stability reference database for age and gender will assist with the assessment of children's static balance development and improve treatment decision making.

Objective

To describe the postural stability as determined by COP values in typically developed children aged six and ten years old during single leg and tandem stance. The study also aims to describe any age and gender differences and provide recommendations for future, larger, normative database studies.

Methodology

A descriptive study design was used. Twenty eight children each performed left and right single leg standing with eyes open, eyes closed, and tandem stance while standing on a dynamic pressure mapping device. Centre of pressure range of movement and velocity parameters were used to describe postural stability. Mann-Whitney tests were used to determine significant differences between age groups and gender.

Results

For single leg standing with eyes open, significant differences were found between boys and girls for mean COP velocity AP (p=< 0.02) and mean COP velocity combined (p=< 0.022). Significant differences in mean COP velocity AP were also demonstrated between younger (6-8 yrs) and older (9-10) girls (p=< 0.03).

Conclusion

The significant differences in COP velocity AP during single leg standing with eyes open between the older and younger girls illustrates age related improvement in postural stability via slowing of COP velocity with age. This maturation of postural stability was not demonstrated for boys possibly because the boys, as a group, performed better than the girls.

Key words: *Postural stability, centre of pressure, children, single leg standing, tandem stance*

1. Introduction

Balance, both static and dynamic, is a skill required for normal functioning in all age groups (Franjoine, Darr, Held, Kott, & Young 2010). Static balance is commonly assessed by evaluating postural stability during simple static balance tasks including single leg standing (Zumbrunn, MacWilliams & Johnson 2011; Rival, Cete & Olivier 2005) and tandem stance (Sozzi, Honeine, Do & Schieppati 2013). Postural stability is evaluated with the use of force plates which measure and record centre of pressure (COP) movements (Bryant, Trew, Bruce, Kuisma & Smith 2005). The movement of the COP indirectly reflects the postural correction or sway of the body's centre of mass, providing objective data which gives insight into static balance ability and the process of controlling balance (Chiari, Rocci & Cappello 2002; Riemann, Guskiewicz & Shields 1999). Centre of pressure data is sensitive enough to determine differences between typically developing (TD) children and those with neurological and neuromuscular skeletal pathologies that affect balance (Zumbrunn, MacWilliams & Johnson 2011; De Kegel, Dhooge, Cambier, Baetens, Palmans & Van Waelvelde 2011).

The development of postural stability in childhood through the maturation and integration of the sensory system has been illustrated with age correlated improvements by decreasing range and velocity of COP movements (Riach & Starkes 1994). Children from age six to ten years demonstrates a change in the strategy used to maintain postural stability, with young children employing primarily large and fast ballistic COP movements which matures to shorter more frequent corrections (Rival, Cete & Olivier 2005; Kirshenbaum, Riach & Starkes 2001). This improvement in postural stability with age is non-linear, with a major transition around seven to eight years of age (Riach & Starkes 1994; Kirshenbaum, Riach & Starckes 2001). This transition is as a result of increased integration of postural information gained from ballistic movements and multimodal sensory feedback information (visual, vestibular and somatosensory information) (Hatzitaki, Zlisi, Kollias & Kioumourtzoglou 2002; Riach & Starkes 1989; Riach & Starkes 1993; Riach & Starkes 1994; Shumway-Cook & Woollacott 1985).

Various elements such as gender and anthropometrics have been shown to influence the standing postural stability of children. Gender differences have demonstrated that girls exhibit lower COP range and velocity values or more steady postural stability compared to boys of similar ages (Geldhof, Cardon, Bourdeaudhuji, Danneels, Coorevits, Vanderstraeten & De Clercq 2006; Peterson, Christou & Rosengren 2006; Steindl, Kunz, Schrott-Fischer & Scholtz 2006; Smith, Ulmer & Wong 2012). Postural stability deficits have been demonstrated in obese boys specifically in tasks which challenge functional balance (Deforche, Hills, Worringham, Davies, Murphy, Bouckaert & De Bourdeaudhuji 2009; Deforche, Lefevre, Bourdeaudhuji, Hills, Duquet & Bouckaert 2003; McGraw, McClenaghan, Williams, Dickerson & Ward 2000; Lee & Lin 2007)

Differing environmental and social experiences also impact on the development and skill's level of motor and balance proficiency in children (Habib, Wescott, Valvano 1999). Kerfeld, Guthrie and Stewart (1997) demonstrated significant differences in the emergence of developmental gross motor skills, specifically in single leg standing in TD Alaska Native children and age matched children from Denver in the United States of America using the Denver II test. This test assesses children's performance on various age appropriate tasks (Kerfeld, Guthrie & Stewart 1997). The authors suggested that advanced gross motor development may be explained by differences in Native Alaska child-rearing practices which include living with extended family, care giving by older siblings and greater freedom to explore the environment (Kerfeld, Guthrie & Stewart 1997).

The aim of the study was to describe the postural stability as determined by COP values in a group of typically developed children residing in the Cape Metropole between the ages of six and ten years during single leg and tandem stance. Secondly, the study also aims to describe any age and gender differences within this group of children and thirdly to provide recommendations for future, larger, normative database studies. When considering postural stability it is important to recognise the variation that exists in typical balance behaviour (Hadders-Algra 2010), as well as differences in motor development and abilities across different ethnic and cultural backgrounds (Kerfeld, Guthrie & Stewart 1997; Habib, Wescott & Valvano 1999; Mayson, Harris &Bachman 2007). These differences may be specific to the task being performed (Goodway & Branta 2003). In order to comment on a child's postural stability skill, the range of what is normal for a specific age group and gender with which to compare is important. Improved understanding of the factors influencing balance, accuracy of comparisons and recommendations for both diagnostic, early intervention purposes are possible with a representative culturally sensitive reference database. Currently, no such South African database exists.

2. Research design

2.1 Research approach

A descriptive study design was used to provide normative data of postural stability in typically developing children aged six to ten years old residing in the Cape Metropole.

2.2 Participants

A convenience sample of 30 children, between the ages of six and ten years old, were recruited from three local government co-education mainstream primary schools, two crèches and four aftercare facilities situated near the testing laboratory.

2.3 Inclusion and exclusion criteria

Boys and girls between the ages of six and ten years, with good general health, were included in the study. Overall static and dynamic balance ability has been shown to increase between the ages of six and 10 years (Figura, Cama, Capranica, Guidetti & Pulejo 1991). This age group specifically offers observations around transition to adult-like mature postural stability strategies to maintain static balance (Rival, Cete & olivier 2005, Kirshenbaum, Riach & Strarkes 2001). Children with confirmed disorders such as Developmental Coordination Disorder, Attention Deficit Hyperactivity Disorder, Cerebral Palsy, hip dysplasia, scoliosis, Foetal Alcohol Spectrum disorder, Duchenne's muscular dystrophy or any similar condition, diagnosed by a health care practitioner, were excluded. Children who had recently (past six months) reported neuro-musculoskeletal injuries or who were unwell on the day of testing were also excluded as these could affect balance.

2.4 Setting

The study was conducted at the FNB-3D Movement Analysis Laboratory at the Stellenbosch University Tygerberg Campus, Cape Town, South Africa.

2.5 Sampling

To date no sample size recommendations have been made for postural stability normative database studies. A sample of 30 was chosen based on normative walking gait database research which has demonstrated that a sample size of between 30 and 40 participants is adequate to have 95% confidence that the true standard deviation (SD) will fall within two degrees of the measured SD (Baker 2014).

2.6 Procedure

Once ethical approval for the study was granted (Addendum B) information leaflets about the study (Addendum C) and general health activity questionnaire to determine eligibility (Addendum D) was sent home with children from the schools and crèche facilities. Parents of children who were interested in participating were asked to fill in the questionnaire and return them to the school. Parents of children who wanted to participate were contacted telephonically to clarify certain statements (Addendum E), explain how the testing procedure worked and book slots for testing. Parents were asked to complete informed consent prior to testing. Forty-five minute, weekday, after school appointments were booked and transport to and from the respective schools were provided if needed. Prior to testing, children were familiarised with the venue and the protocol for testing. Children changed into T-shirts and shorts in a private cubicle and were barefoot throughout testing. A brief physical examination (Addendum F) was conducted to establish bilateral hip, knee and ankle range of movement to expose any gross hypo/hypermobility, anatomical or physical differences, which may affect postural stability. Weight and height were recorded.

2.7 Tasks

Each child performed five balance tasks while standing on a dynamic pressure mapping device in the following order: 1) left and 2) right single leg standing with eyes open (EO); 3) tandem stance with the preferred leg in front; and 4) left and 5) right single leg standing with eyes closed (EC). The starting leg for the balance tasks was assigned according to the day of appointment (for example all participants on Tuesdays started on the left leg) in an attempt to counteract any effect of bias. Prior to each task, participants were given standardised verbal instructions (Table 1), a demonstration by the principal researcher and permitted one practice attempt for each task. Data capturing began once the researcher deemed the participant stable in the correct position. The task was performed up to a maximum of ten seconds as described by Zumbrunn, MacWilliams and Johnson (2011).

Table 1: Balance task instruction sheet

TASK	INSTRUCTION
Single leg standing	Put your hands on your hips and look forward. Stand on your left leg and bend your right up so that your lower leg is next to your left knee. Stand as still as you can for as long as you can, try not to shuffle or hop.
Tandem stance	Put your hands on your hips and look forward. Stand with one foot forward and one foot back in a line so that the big toe of the back foot touches the front foot heel (child may choose which foot is in front). Stand as still as you can for as long as you can
Single leg standing with eyes closed	Position as above, once child standing on one leg looking forward, researcher asks child to close eyes and keep them closed. Stand as still as you can for as long as you can, try not to shuffle or hop

2.8 Instrumentation and Outcomes

Joint range of movement of the lower limbs was measured if discrepancy was found during manual testing using a manual medium international standard goniometer (8"). Weight (kg), using the 3D Bertec (FP6090-15) force plate and height, (mm), using a wall mounted T-bar tape measure, were recorded during barefoot standing. A dynamic pressure mapping device, MatScan Versatek (sensor model 3150E, release 2012b, Tekscan, Boston, Massachusetts) was used to record the COP displacements at a frequency of 440 Hz. This high resolution mat pressure mapping systems has been shown to be both a reliable (ICC = 0.75 to 0.76) and valid method of measuring COP (Ahroni, Boyko & Forsberg 1998).

2.9 Data processing

Raw COP data filtered using a 4th order Butterworth filter with a cut off frequency of 10Hz and exported into Matlab software (release 2012b, The Mathworks, Inc) in order to calculate the COP parameters of interest. A custom Matlab algorithm was developed to calculate the COP mean range and COP mean velocity outcomes during the stipulated time period. Six COP parameters were calculated to describe postural stability: COP mean range of movement (ROM) in the medio-lateral (ML), anterio-posterior (AP) directions and COP mean range of movement combined score (cm); and COP mean velocity in the ML and AP directions and combined COP mean velocity (cm/s) (Zumbrunn, MacWilliams & Johnson 2011; De Kegel et al. 2011; Lee & Lin 2007). The ML and AP directions were assumed to be parallel to the areas of the Matscan pressure mat as the subjects feet were aligned accordingly.

Horizontal translation or rotation of the foot relative to the surface of the pressure plate introduces errors in the measured outcomes. Therefore, periods of foot movement were identified by inspecting videos that were simultaneously recorded of the measured plantar pressures using the Matscan software. The start and end times of each period containing the valid COP data analyzed accordingly.

A shuffle, hop or the non-weight bearing foot touching the pressure mat prior to the full ten seconds of data capturing, the trial was deemed unsuccessful. Children were given two attempts for each task. Where there were two full sets of data for a task, the first trial was chosen and processed. If both trials of a task were unsuccessful, videos were inspected to determine if there was a minimum of the first seven seconds for EO trials and the first three seconds for EC trials for which there were no shuffling, hopping or grounding of the non-weight bearing foot. These successful seven or three second trials were then also included in the data processing procedure (Zumbrunn, MacWilliams & Johnson 2011).

2.10 Statistical analysis

For single leg standing there was no significant difference between the left and right sides for each of the EO and EC trials, thus the left and right trials were added, increasing the number of trials for analysis for each category. Children were subdivided into two groups: Group A consisted of the younger children aged 6-8 years and group B consisted of the older 9-10 year old children. Literature has illustrated a change in balance strategies around eight years of age (Rival, Cete & Olivier 2005; Kirshenbaum, Riach & Starkes 2001). Data was not equally distributed; therefore Mann-Whitney tests for non-parametric data were conducted to compare the COP parameters between the two age subgroups, and gender of children. Differences were considered significant if the p-value was ≤ 0.05.

2.11 Ethics

The study was approved by the Human Research Ethics Committee (S13/10/220) of the Faculty of Medicine and Health Sciences, Stellenbosch University. Written informed consent was provided by parents (addendum G) and informed assent, from children older than seven years, was obtained (addendum H)

3. Results

3.1 Sample Description

Of the 30 eligible children recruited to participate in this study, one child declined to participate and another withdrew due to illness**.** Twenty eight participants, 12 boys and 16 girls, participated in the study. The sample demographics, with mean and SD values for height, weight, and BMI per age group are presented below (Table 2). Eighteen Coloured children, seven Black children and three Caucasian children participated in the study.

Table 2. Participant demographic information

Boys (n = 12)					
Age (years)	6 yrs (n = 0)	7 yrs (n = 2)	8 yrs (n = 3)	9 yrs (n = 4)	10 yrs (n = 3)
Weight (kg) (± SD)	-	36.25 (15.91)	30.33 (14.43)	38.65 (8.71)	46.63 (20.62)
Height (m) (± SD)	-	1.29 (0.06)	1.29 (0.11)	1.40 (0.05)	1.42 (0.06)
BMI (kg/m²) (± SD)	-	21.4 (7.71)	17.67 (5.40)	19.75 (3.81)	21.2 (8.12)
Girls (n = 16)					
Age (years)	6 yrs (n = 3)	7 yrs (n = 1)	8 yrs (n = 2)	9 yrs (n = 4)	10 yrs (n = 6)
Weight (kg) (± SD)	26.37 (1.99)	20.10	28.95 (2.05)	38.20 (12.39)	44.78 (7.01)
Height (m) (± SD)	1.23 (0.06)	1.11	1.35 (0.01)	1.36 (0.06)	1.45 (0.04)
BMI (kg/m²) (± SD)	17.64 (2.60)	16.3	15.88 (1.34)	20.29 (4.85)	21.17 (3.24)

n: number of participants; SD: Standard Deviation; BMI: Body Mass Index,

3.2 General Health and activity questionnaire

The main function of this questionnaire was to assist in ensuring all of the participants met the health inclusion criteria with only a small section questioning general involvement in sport or recreational activities. No health problems, developmental delays, recent injuries, illnesses or body pain in the past six months were reported in the general health section. Participation in a range of different sporting and recreational activity was reported by the parents. A range of activity levels, from playing two types of sport/activities, four times a week, to one type of sport/activity, once a week were reported.

3.3 Single leg standing balance

3.3.1 Eyes open

For this task, there were ten successful trials among the girls 6-8 yrs (2 failed trials) and 17 successful trials among the 9-10 yrs group (3 failed trials). Among the boys 6-8 yrs there were ten successful trials (0 failed trials) and 11 successful trials in the older group (3 failed trials). The data for COP mean velocity AP ($p=<0.02$) and COP mean velocity combined with eyes open demonstrate significant differences between boys and girls for the whole group ($p =< 0.022$) indicating that girls display faster COP movement or less stable postural stability as more movement is needed to maintain stability compared to boys (Table 3). There was also a significant difference in mean COP velocity in the AP direction between younger (group A) and older (group B) girls ($p =< 0.03$) with the COP of older girls displaying slower COP movements. This suggests that the older girls displayed greater postural stability. No significant differences in COP ROM parameters between the age sub-groups (6-8 yrs and 9-10 years) and by gender were found (Table 3).

Table 3: Median and range of COP values during single leg standing with eyes open

EYES OPEN						
	Group		6 – 8 years		9 – 10 years	
	Boys (n=21)	Girls (n=27)	Boys (n=10)	girls (n=10)	Boys (n=11)	Girls (n=17)
ROM ML (cm) (range: max; min)	2.54 (8.48; 1.47)	2.30 (4.00; 1.57)	2.64 (8.48; 2.00)	2.67 (4.00; 2.08)	2.52 (3.40; 1.47)	2.29 (3.6; 1.57)
ROM AP (cm) (range: max; min)	3.22 (15.65; 1.44)	3.64 (10.30; 2.16)	3.22 (15.65; 1.82)	4.23 (10.30; 2.16)	3.26 (6.74; 1.44)	3.64 (6.76; 2.57)
ROM Combined (cm) (range: max; min)	3.51 (16.17; 1.73)	3.85 (10.30; 2.43)	3.51 (16.17; 2.14)	4.44 (10.30; 2.43)	3.67 (7.05; 1.73)	3.83 (6.81; 2.64)
Velocity ML (cm/s) (range: max; min)	2.79 (3.68; 1.7)	2.91 (5.35; 1.81)	2.87 (3.68; 2.56)	3.02 (4.97; 1.87)	2.68 (3.5; 1.97)	2.91 (5.35; 1.81)
Velocity AP (cm/s) (range: max; min)	4.10$^{\times}$ (7.60; 2.54)	4.83$^{\times}$ (8.00; 2.56)	4.10 (7.6; 2.54)	5.34** (8.00; 3.29)	4.09 (5.09; 2.85)	4.71** (5.58; 2.56)
Velocity Combined (cm/s) (range: max; min)	5.57* (9.24; 4.18)	6.32* (10.42; 3.68)	5.57 (9.24; 4.30)	7.24 (10.42; 4.93)	5.60 (6.53; 4.18)	6.31 (8.78; 3.68)

Abbreviations: ROM: range of movement; ML: medio-lateral, AP: antero-lateral, ML: medio-lateral, s: seconds, cm: centimetre, yrs: years, max: maximum value, min: minimum value

Two sample Wilcoxon rank-sum (Mann-Whitney) test - significant *p* values:
* $p>|z| = 0.0211$
$^{\times}$ $p>|z| = 0.0112$
** $p>|z| = 0.0271$

3.3.2 Eyes closed

For this task there were fewer successful trials presumable due to the increased difficulty of the task. There were a total of five failed trials, one in the younger group and four in the older group for the boys' sample. There were a total of six failed trials, four in the younger group and two in the older group for the girls' sample. There were no significant differences between the subgroups and between boys and girls for any of the COP parameters (Table 4).

Table 4: Median and range COP values during single leg standing with eyes closed

EYES CLOSED						
	Group		6 – 8 years		9 – 10 years	
	Boys (n=19)	Girls (n=26)	Boys (n=9)	Girls (n=8)	Boys (n=10)	Girls (n=18)
ROM ML (cm) (range: max; min)	2.44 (3.14; 1.19)	2.49 (4.15; 1.59)	2.51 (3.14; 1.19)	2.25 (4.15; 1.68)	2.35 (3.12; 1.34)	2.53 (3.61; 1.59)
ROM AP (cm) (range: max; min)	3.03 (6.95; 1.34)	3.36 (6.91; 1.91)	3.21 (6.95; 2.19)	3.09 (6.91; 1.91)	2.91 (4.87; 1.34)	3.48 (6.21; 2.2)
ROM Combined (cm) (range: max; min)	3.14 (6.96; 2.06)	3.73 (7.51; 2.48)	3.66 (6.96; 2.37)	3.42 (7.51; 2.68)	3.07 (4.97; 2.06)	3.73 (6.50; 2.48)
Velocity ML (cm/s) (range: max; min)	4.03 (5.80; 2.47)	3.98 (8.67; 2.7)	4.28 (5.0; 2.73)	4.90 (8.67; 2.70)	3.94 (5.18; 2.47)	3.98 (7.46; 3.18)
Velocity AP (cm/s) (range: max; min)	5.27 (20.57; 3.56)	5.86 (11.09; 4.08)	5.41 (20.57; 4.13)	6.44 (11.09; 4.71)	5.46 (6.73; 3.56)	5.76 (8.46; 4.08)
Velocity Combined (cm/s) (range: max; min)	7.39 (21.6; 5.56)	7.84 (15.85; 6.1)	8.27 (21.60; 5.56)	9.21 (15.85; 6.33)	7.39 (9.07; 5.67)	7.84 (12.37; 6.1)

Abbreviations: ROM: range of movement; ML: medio-lateral, AP: antero-lateral, ML: medio-lateral, s: seconds, cm: centimetre, yrs: years, max: maximum value, min: minimum value

3.4 Tandem stance

Each child had a successful tandem stance trial. There was no significant difference in any of the COP parameters between the subgroups and by gender (Table 5).

Table 5: Median and range COP values during tandem stance

TANDEM STANCE						
	Group		6 – 8 years		9 – 10 years	
	Boys (n= 12)	Girls (n=16)	Boys (n=5)	Girls (n=6)	Boys (n=7)	Girls (n=10)
ROM ML (cm) (range: max; min)	2.84 (3.95; 1.59)	2.61 (4.41; 1.66)	2.97 (3.2; 1.7)	2.57 (3.60; 1.86)	2.71 (3.95; 1.59)	2.77 (4.41; 1.66)
ROM AP (cm) (range: max; min)	3.33 (6.3; 1.9)	3.30 (10.45; 1.55)	3.59 (6.3; 2.12)	4.04 (10.16; 2.7)	3.14 (5.29; 1.9)	2.64 (10.45; 1.55)
ROM Combined (cm) (range: max; min)	3.87 (6.44; 1.92)	4.02 (10.45; 2.47)	4.28 (6.44; 2.59)	4.22 (10.16; 2.76)	3.67 (5.63; 1.92)	3.59 (10.45; 2.47)
Velocity ML (cm/s) (range: max; min)	2.55 (4.21; 1.69)	2.72 (3.65; 1.83)	2.16 (4.21; 1.69)	2.81 (3.56; 2.60)	3.11 (4.10; 20.3)	2.62 (3.65; 1.83)
Velocity AP (cm/s) (range: max; min)	10.70 (16.58; 6.20)	14.41 (19.94; 6.78)	8.78 (14.95; 6.2)	15.66 (19.94; 9.73)	11.83 (16.58; 8.08)	13.61 (17.36; 6.78)
Velocity Combined (cm/s) (range: max; min)	11.66 (17.83; 6.83)	15.17 (20.53; 7.55)	10.54 (15.51; 6.83)	16.42 (20.53; 10.64)	12.67 (17.83; 8.78)	14.54 (17.73; 7.55)

Abbreviations: ROM: range of movement; ML: medio-lateral, AP: antero-lateral, ML: medio-lateral, s: seconds, cm: centimetre, yrs: years, max: maximum value, min: minimum value

4. Discussion

This study's description of postural stability performance in typically developing children provides normative data which may be useful to assist with evaluation and diagnosis in other clinical population groups. This study found a significant difference between the younger and older girls for mean COP velocity in the AP direction, with girls six to eight years demonstrating faster COP movements in the AP direction indicating more unsteady, immature postural stability compared to the older girls. These results indicate an age correlated improvement in single leg standing postural stability. This result is supported by developmental motor studies which have documented increased ability to balance in single leg standing with maturation (Folio & Fewell 2000) (Condon & Cremin 2014) and postural stability studies which have demonstrated slowing of single leg standing COP velocity with age in children of similar ages to this study (Zumbrunn, MacWilliams & Johnson 2011).

In this study, no significant differences between younger and older boys were found. Nolan, Grigorenko and Thorstensson (2005) found age-related improvements in COP parameters until the age of 12 to 13 years in boys and concluded that some aspects of postural stability may still be developing at this age. Although this study by Nolan, Grigorenko & Thorstensson (2005) investigated bilateral stance, it is possible that differences between younger and older boys may have been demonstrated if this sample included older pre-pubertal boys who may have better developed postural stability strategies. The age distribution within the boy's sample (no six year olds and only two seven year olds) may have been too unequal for comparison between age subgroups.

Postural stability studies using force plate derived COP data, and functional balance studies, indicate that girls perform better in standing balance tasks (Nolan, Grigorenko & Thorstensson 2005; Smith, Ulmer & Wong 2012; Condon & Cremin 2014). However; in this study the boys as a group performed better with significantly lower COP velocity in the AP direction and

COP mean velocity compared to the girls. This may be as a result of unequal gender distribution of children younger than eight years old who utilise faster and larger COP movements to maintain postural stability. Studies investigating postural stability during bilateral standing have demonstrated a transition from immature primarily ballistic COP postural stability strategy to more controlled accurate corrections which occurs at approximately eight years of age (Rival, Cete & Olivier 2005; Kirshenbaum, Riach & Starkes 2001). In a large static balance norms study in children, Codon and Cremin (2013) found a distinct change in abilities after the age of seven years specifically in single leg standing with eyes open. Accordingly the four out of 16 girls in the sample who were younger than eight years possibly still displayed immature faster COP movements to maintain postural stability (compared to two out of 12 boys) and may have increased the group's mean COP velocity scores. The significant difference found between the younger and older girls for mean COP mean velocity AP and COP mean velocity combined supports this.

In a large study (n=534) assessing performance of timed static balance in children, interquartile ranges for single leg standing on a stable surface were reported as eight to 32 seconds (six to seven year olds); 20 to 74 seconds (eight to nine year olds), and 48 to 120 seconds (ten year olds) (Condon & Cremin 2014). According to Codon and Cremin (2014), seven seconds of single leg standing with eyes open should be attainable for all the age groups especially in the older groups. In this study there were eight failed trials in total for the single leg standing EO task due to shuffling/hopping or putting the non-supporting foot down demonstrating an inability to maintain the position for seven seconds. This may indicate that this sample of children displayed a lower level of balance skill compared to the study cohort of Condon and Cremin (2014).

All the children successfully completed the tandem stance trial, with no significant differences demonstrated between groups, which may indicate a ceiling effect for this task i.e. the test may not have sufficiently challenged the balance of the children to detect differences in age or gender. Zumbrunn, MacWilliams & Johnson (2011) suggested that double limb support tests did not sufficiently challenge the constraints of balance. This is supported by De Kegal et al. (2011) who recommended tandem stance with eyes closed as an alternative. It is also possible that the time sampled was not long enough to detect differences as many bilateral stance protocols use trial lengths of 30 seconds (Nolan, Grigorenko & Thorstensson 2005; Smith, Ulmer & Wong 2012). Increasing the trial length or using eyes closed are options that could be considered, especially for the younger children who struggled to complete the single leg standing tasks.

As expected, diminished visual input (EC) challenges postural stability and the children demonstrated increased postural sway with larger COP ROM and faster COP mean velocity values across the age groups and genders. Single leg standing with eyes closed failed to demonstrate any significant differences between the different age groups and between genders. With an increased number of failed trials across all the age groups this test may have been too difficult. De Kegel et al. (2011) reported that single leg standing with eyes closed may not be reliable enough to incorporate into postural stability testing due to the great variability demonstrated in the performance of this task.

Overweight and obese pre-pubertal boys have shown to demonstrate decreased postural stability (McGraw et al. 2000; Deforche et al. 2009). A recent obesity and overweight study conducted on a large cohort of South African primary school children (n=10195) used the method of Cole, Bellizzi, Flegal and Dietz (2000) to determine cut-off points for BMI for overweight and obesity in children (Armstrong, Lambert, Sharwood & Lambert 2006). The mean BMI values for the seven, nine and ten year old boys and the nine and ten year old girls in this study are above the South African averages reported by Armstrong et al. (2006) for the respective age and gender categories. The large standard deviations (due to small sample size) in BMI were demonstrated for boys in each age group specifically in the seven year olds and ten year olds indicating large differences in stature between boys of the same age. Accordingly the results of this study may have been skewed due to overweight and even obese children and, while this may represent a normative sample of children at the schools sampled, caution should be taken when comparing these values to children with BMI values within the normal range for their age. With the prevalence of overweight and obesity in children reported to be increasing in South Africa (Armstrong et al. 2006; Mchiza & Maunder 2013), it may be useful to analyse these datasets separately in order to further understand how obesity affects postural stability specifically in pre-pubertal girls.

A range of sports/recreational participation and activity levels were reported by parents, however the questioning was not specific enough to draw conclusions. Future studies should include a standardised physical activity questionnaire.

5. Conclusion

This study evaluated COP parameters for single leg standing and tandem stance in 28 typically developed children from the Cape Metropole. It provides normative values for these tasks and describes differences between age and gender groups. In single leg standing with eyes open, age related improvements in standing postural stability were demonstrated in the girls. Boys, as a group, performed better in single leg standing with eyes open than girls which is contrary to findings in the literature. Small sample size, unequal age distribution and overweight children may have influenced these results. No significant findings for single leg standing with eyes closed and tandem stance tasks were found. This study describes normative postural stability data of children aged six to ten years from the Cape Metropole. It provides recommendations for future larger normative studies which are needed in order to create a diverse and culturally sensitive reference database. This will assist in improved assessment of South African children's balance capabilities. This has positive implications for referral, treatment and evaluation recommendations.

Competing interests

The authors declare that they have no competing interests.

Author's contributions

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

Miss M. Nevin obtained funding, performed the data collection and writing of this manuscript.

Dr M. Unger and Dr Y. Brink supervised the project, provided statistical expertise and ensured critical revision of the manuscript.

Acknowledgements

This project was funded by Stellenbosch University. The authors wish to acknowledge the children and parents who took part in the study.

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Chapter 4: Conclusions, limitations and recommendations

This study served as a pilot study and therefore only a small number of children were recruited. A larger sample size with equal distribution in the age subgroups will allow for comparison between different ages which may better demonstrate age related improvement of postural stability and the transition from immature to adult like balance strategy around the age of eight years documented in the literature (Kirshenbaum, Riach & Starkes 2001; Condon & Cremin 2014),

Overweight and obese children were not excluded in this study despite findings in the literature which strongly suggest that a more functional, challenging aspect of balance for example single leg standing is less efficient in heavier boys (Deforche et al. 2009; Goulding et al. 2003). The average BMI values of some of the groups are above the average for age and gender matched South African children, indicating that some of the children in this sample were overweight and even obese. Children who are overweight or obese based on South African norms (ethnicity and height factored in) should not be analysed within a normative sample. With the prevalence of overweight and obesity in children reported to be increasing in South Africa (Armstrong, Lambert, Sharwood & Lambert 2006; Mchiza & Maunder 2013), it may be useful to analyse these datasets separately in order to further understand how obesity affects postural stability, specifically in pre-pubertal girls and to create an accurate reference database for both groups.

Significant differences were only found for COP mean velocity AP and COP mean velocity (combined score). This is in accordance with other research findings (De Kegel et al. 2011; Zumbrunn, MacWilliams & Johnson 2011), however other studies testing single leg standing EO and EC using COP ROM parameters (cm) have demonstrated sensitivity to determine gender and anthropomorphic differences (Lee & Lin 2007). However no COP ROM differences could be described in this study potentially due to differences in the initial foot placement on the pressure map at the start of the task which could have affected the COP ROM parameters. This could be improved by drawing AP, ML lines or a foot outline on the pressure mat as described by Nolan, Grigorenko and Thorstensson (2005) to ensure a standardised starting position. Also the small sample size and the non-randomization of participants for this study, might have influenced the findings.

No significant differences were found for tandem stance task. Codon and Cremin (2014) demonstrated a ceiling effect in timed tandem stance after the age of seven years old. It is possible that the task did not sufficiently challenge the systems that control balance or that the ten seconds measured for each trial was not long enough to elicit corrective postural movements to maintain the centre of mass within the base of support ie. Postural stability. Longer trial lengths are supported by studies which demonstrate both age and gender differences in COP parameters using quiet bilateral stance or natural standing position using multiple trials of 30 seconds (Kirshenbaum, Riach & Starkes 2001) or single trials of 60 seconds (Nolan, Grigorenko & Thorstensson 2005). In order to test static balance ability it follows that unstable balance conditions, which challenge the postural stability system by decreasing the base of support (like tandem stance and single leg standing) or limiting visual input e.g. with eyes closed, should be used. Therefore for tandem stance, using eyes closed (De Kegel et al. 2011) and/or increasing the trial length are options for further research.

No significant differences were found for single leg standing EC task. In a test-retest reliability study De Kegel et al. (2011) demonstrated low ICC scores for most of the COP parameters tested. The authors concluded that in TD children, poor reliability was as a result of the great variability in the performance of this task. The high number of failed trials for this task indicates that it may have been too difficult for some of the children. Single leg standing EC task may not be valid for younger children but may be useful to differentiate balance ability in older children. This needs to be further investigated.

In order to reflect the diversity of the South African population a normative postural stability data must include children of all races, from both urban and rural areas and those from high to low income households. This pilot study sample may be more representative of the Cape Metropole and Western Cape population with a higher proportion Coloured race compared to Black and Caucasian races. However the majority of the children in this sample come from the same school within a small geographical area and the sample is therefore not representative of the socio-economic diversity of South Africa. Future normative studies should take care to draw a sample which is be representative of the ethnic and socio-economic diversity of South Africa.

Furthermore in order to understand the influence of physical activity both sporting, recreational and day to day activity level more in depth standardised questioning needs to be employed of both the parents and children. Anecdotally the children who were transported to and from the testing venue were children who stayed after school in an after care facility and were almost always found playing on the school field or on the jungle gym when they were collected and dropped off, indicating informal activity after school. Therefore physical activity levels both formal and informal and access to safe and open spaces which may influence balance ability needs to be incorporated into pre-testing questioning. Future studies should include in depth questioning around access and use of safe and open places to play as well as formal physical activity levels needs to be included in order to comment on the influence of these factors on postural stability.

This study describes normative postural stability data of children aged six to ten years from the Cape Metropole, South Africa and is the start of a South African reference database. The recommendations provided for future larger normative studies will allow further contribution to a diverse and culturally sensitive reference database which will assist in improved assessment of South African children's balance capabilities. This has positive implications for referral, treatment and evaluation recommendations

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ADDENDA:

Addendum A

SOUTH AFRICAN JOURNAL OF PHYSIOTHERAPY GUIDELINES

Structure and style of your original research article

The page provides an overview of the structure and style of your original research article to be submitted to the *South African Journal of Physiotherapy*. The original article provides an overview of innovative research in a particular field within or related to the focus and scope of the journal presented according to a clear and well-structured format (between 3500 and 5500 words with a maximum of 60 references).

Please use British English, that is, according to the Oxford English Dictionary. Avoid Americanisms (e.g. use ‘s’ and not ‘z’). Consult the Oxford English Dictionary when in doubt and remember to set your version of Microsoft Word to UK English.

- **Language:** Manuscripts must be written in British English.
- **Font:**
  - **Font type:** Palatino
  - **Symbols font type:** Times New Roman
  - **General font size:** 12pt
- **Line spacing:** 1.5
- **Headings:** Ensure that formatting for headings is consistent in the manuscript.
  - First headings: normal case, bold and 14pt
  - Second headings: normal case, underlined and 14pt
  - Third headings: normal case, bold and 12pt
  - Fourth headings: normal case, bold, running-in text and separated by a colon.

Our publication system supports a limited range of formats for text and graphics. Text files can be submitted in the following formats only:

- Microsoft Word (.doc): We cannot accept Word 2007 DOCX files. If you have created your manuscript using Word 2007, you must save the document as a Word 2003 file before submission.
- Rich Text Format (RTF) documents uploaded during Step 2 of the submission process. Users of other word processing packages should save or convert their files to RTF before uploading. Many free tools are available that will make this process easier.

The structure and style of your original article

Page 1

The format of the **compulsory cover letter** forms part of your submission and is on the first page of your manuscript and should always be presented in English. You should provide all of the following elements:

- **Article title:** Provide a short title of 50 characters or less.
- **Significance of work:** Briefly state the significance of the work being reported on.
- **Full author details:** Provide title(s), full name(s), position(s), affiliation(s) and contact details (postal address, email, telephone and cellular number) of each author.
- **Corresponding author:** Identify to whom all correspondence should be addressed to.
- **Authors' contributions:** Briefly summarise the nature of the contribution made by each of the authors listed.
- **Summary:** Lastly, a list containing the number of words, pages, tables, figures and/or other supplementary material should accompany the submission.

Page 2 and onwards

Title: The article's full title should contain a maximum of 95 characters (including spaces).

Abstract: The abstract, written in English, should be no longer than 250 words and must be written in the past tense. The abstract should give a succinct account of the objectives, methods, results and significance of the matter. The structured abstract for an original research article should consist of five paragraphs that are labelled. These labelled paragraphs should deal with the background, objectives, method, results and conclusion.

- **Background:** *Why do we care about the problem?* State the context and purpose of the study. (What practical, scientific or theoretical gap is your research filling?)
- **Objectives:** *What problem are you trying to solve*? What is the scope of your work (e.g. is it a generalised approach or for a specific situation)? Be careful not to use too much jargon.
- **Method:** *How did you go about solving or making progress on the problem*? State how the study was performed and which statistical tests were used. (What did you actually do to get the results?) Clearly express the basic design of the study; name or briefly describe the basic methodology used without going into excessive detail. Be sure to indicate the key techniques used.
- **Results**: *What is the answer*? Present the main findings (that is, as a result of completing the procedure or study, state what you have learnt, invented or created). Identify trends, relative change or differences on answers to questions.
- **Conclusion**: *What are the implications of your answer*? Briefly summarise any potential implications. (What are the larger implications of your findings, especially for the problem or gap identified in your motivation?)

Do not cite references in the abstract and do not use abbreviations excessively in the abstract.

The following headings serve as a guide for presenting your research in a well-structure format. As an author you should include all first level headings but subsequent headings (second and third level headings) can be changed.

Introduction (first-level heading)

The introduction contains two subsections, namely the background section and the literature review. The introduction section should be written from the standpoint of readers that is without specialist knowledge in that area and must clearly state the introduction to the research and its aims in the context of previous work bearing directly on the subject. The introduction section to the article normally contains the following five elements:

- **Key focus (third-level heading):** A thought-provoking introductory statement on the broad theme or topic of the research.
- **Background (third-level heading:** Providing the background or the context to the study (explaining the role of other relevant key variables in this study).
- **Trends (third-level heading):** Cite the most important published studies previously conducted on this topic or that has any relevance to this study (provide a high-level synopsis of the research literature on this topic).
- **Objectives (third-level heading):** Indicate the most important controversies, gaps and inconsistencies in the literature that will be addressed by this study. In view of the above trends, state the core research problem and specific research objectives that will be addressed in this study and provide the reader with an outline of what to expect in the rest of the article.
- **Contribution to field (third-level heading):** Explanation of the study's academic (theoretical and methodological) or practical merit and/or importance (provide the value-add and/or rationale for the study).

Research design (first-level heading)

- **Research appraoch (second-level heading)**
- **Research method (second-level heading)**
  - **Materials (third-level heading):** Describe the type of organism(s) or material(s) involved in the study.
  - **Setting (third-level heading):** Describe the site and setting where your field study was conducted.
  - **Design (third-level heading):** Describe your experimental design clearly, including a power calculation if appropriate. Note: Additional details can be placed in the online supplementary location.
  - **Procedure (third-level heading):** Describe the protocol for your study in sufficient detail (clear description of all interventions and comparisons) that other scientists could repeat your work to verify your findings.
  - **Statistical analysing (third-level heading):** Describe how the data were summarised and analysed, additional details can be placed in the online supplementary information.

- **Reliability (third-level heading):** Reliability is the extent to which an experiment, test, or any measuring procedure yields the same result on repeated trials. Without the agreement of independent observers able to replicate research procedures, or the ability to use research tools and procedures that yield consistent measurements, researchers would be unable to satisfactorily draw conclusions, formulate theories, or make claims about the generalisability of their research.
- **Validity (third-level heading):** Validity refers to the degree to which a study accurately reflects or assesses the specific concept that the researcher is attempting to measure. While reliability is concerned with the accuracy of the actual measuring instrument or procedure, validity is concerned with the study's success at measuring what the researchers set out to measure. Researchers should be concerned with both external and internal validity. External validity refers to the extent to which the results of a study are generalisable or transferable. Internal validity refers to (1) the rigor with which the study was conducted (e.g. the study's design, the care taken to conduct measurements, and decisions concerning what was and wasn't measured) and (2) the extent to which the designers of a study have taken into account alternative explanations for any causal relationships they explore. In studies that do not explore causal relationships, only the first of these definitions should be considered when assessing internal validity.
- **Ethical considerations (third-level heading)**:Articles based on the involvement of people must have been conducted in accordance with relevant national and international guidelines. Approval must have been obtained for all protocols from the author's institutional or other relevant ethics committee and the institution name and permit numbers provided at submission.
  - **Potential benefits and hazards (fourth-level heading):** What risks to the subject are entailed in involvement in the research? Are there any potential physical, psychological or disclosure dangers that can be anticipated? What is the possible benefit or harm to the subject or society from their participation or from the project as a whole? What procedures have been established for the care and protection of subjects (e.g. insurance, medical cover) and the control of any information gained from them or about them?

- **Recruitment procedures (fourth-level heading):** Was there any sense in which subjects might be 'obliged' to participate – as in the case of students, prisoners, learners or patients – or were volunteers being recruited? If participation was compulsory, the potential consequences of non-compliance must be indicated to subjects; if voluntary, entitlement to withdraw consent must be indicated and when that entitlement lapses
- **Informed consent (fourth-level heading):** Authors must include how informed consent was handled in the study.
- **Data protection (fourth-level heading:** Authors must include in detail the way in which data protection was handled.

Results (first-level heading)

This section provides a synthesis of the obtained literature grouped or categorised according to some organising or analysis principle.
Tables may be used and models may be drafted to indicate key components of the results of the study.

- Organise the results based on the sequence of Tables and Figures you will include in the manuscript.
- The body of the Results section is a text presentation of the key findings which includes references to each of the Tables and Figures.
- Statistical test summaries (test name, p-value) are usually reported parenthetically in conjunction with the biological results they support.
- Present the results of your experiment(s)/research data in a sequence that will logically support (or provide evidence against) the hypothesis, or answer the question, stated in the Introduction.

All units should conform to the **SI convention** and should be abbreviated accordingly. Metric units and their international symbols are used throughout, as is the decimal point (not the decimal comma).

Discussion (first-level heading)

This section normally contains the following elements (it is strongly suggested that sub-headings are used in this section):

- **Outline of the results (second-level heading):** Restate the main objective of the study and reaffirm the importance of the study by restating its main contributions; Summarise the results in relation to each stated research objective or research hypothesis; link the findings back to the literature and to the results reported by other researchers; provide explanations for unexpected results.

- **Practical implications (second-level heading):** Reaffirm the importance of the study by restating its main contributions and provide the implications for the practical implementation your research.
- **Limitations of the study (second-level heading):** Point out the possible limitations of the study and provide suggestions for future research.
- **Recommendations (second-level heading):** Provide the recommendations emerging out of the current research.

Conclusion (first-level heading)

This should state clearly the main conclusions of the research and give a clear explanation of their importance and relevance, with a recommendation for future research (implications for practice). Provide a brief conclusion that restates the objectives, the research design, the results and their meaning.

Acknowledgements (first-level heading)

If, through your study, you received any significant help in conceiving, designing, or carrying out the work, or received materials from someone who did you a favour by supplying them, you must acknowledge their assistance and the service or material provided. **Authors should always acknowledge outside reviewers of their drafts and any sources of funding that supported the research.**

- **Competing interests (second-level heading):** 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 organisations that can potentially prevent you from executing and publishing unbiased research. Authors should disclose any financial competing interests but also any non-financial competing interests that may cause them embarrassment were they to become public after the publication of the manuscript. **Where an author gives no competing interests, the listing will read 'The authors declare that they have no financial or personal relationship(s) which may have inappropriately influenced them in writing this article.'**

- **Authors' contributions (second-level heading)*:** This section is necessary to give appropriate credit to each author, and to the authors' applicable institution. The individual contributions of authors should be specified with their affiliation at the time of the study and completion of the work. An 'author' is generally considered to be someone who has made substantive intellectual contributions to a published study. Contributions made by each of the authors listed, along the lines of the following (please note the use of author initials):

  J.K. (University of Pretoria) was the project leader, L.M.N. (University of KwaZulu-Natal) and A.B. (University of Stellenbosch) were responsible for experimental and project design. L.M.N. performed most of the experiments. P.R. made conceptual contributions and S.T. (University of Cape Town), U.V. (University of Cape Town) and C.D. (University of Cape Town) performed some of the experiments. S.M. (Cape Peninsula University of Technology) and V.C. (Cape Peninsula University of Technology) prepared the samples and calculations were performed by C.S., J.K. (Cape Peninsula University of Technology) and U.V. wrote the manuscript.

References (first-level heading)

Begin the reference list on a separate page with no more than 60 references. The *South African Journal of Physiotherapy* uses the **Harvard referencing style**, details of which can be downloaded from the journal website. **Note: No other style will be permitted.**

Addendum B

ETHICS APPROVAL

UNIVERSITEIT·STELLENBOSCH·UNIVERSITY
jou kennisvennoot • your knowledge partner

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.

Addendum C

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 6-10 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 D:

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 E

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 6 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 F

FNB MOTION ANALYSIS LABORATORY EVALUATION FORM

(Children 6-10 years)

Subject code: ____________________
Date: _________________________
Assessment by: __________________

Movement	**Position**	**Notes**	**ROM**	**ROM**
			Left	**Right**
Hips				
Flexion	supine			
Extension	side	knee in ext		
Abduction	supine			
Adduction	supine			
External rtn	prone			
Internal rtn	prone			
Knee				
Flexion	prone			
Extension	supine			
Ankle				
Dorsiflexion	supine	knee ext		
	supine	knee flex		
Plantarflexion	supine	knee flex		

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

____

Addendum G

INFORMED CONSENT

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.

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.

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.

- **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, I …………………………………..………….parent/ 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.

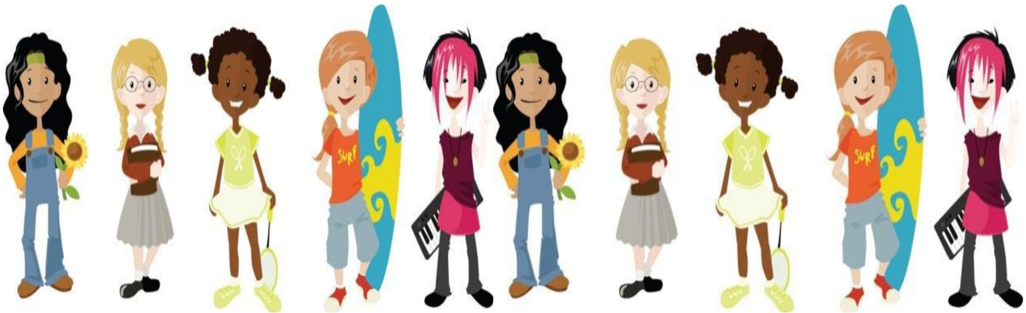
Signed at (*place*) ....…........……………….. on (*date*) …………...……….. 20...

Signature of participant   Signature of witness

______________________   ______________________

Addendum H

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.

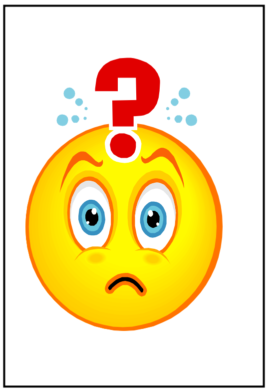
Can anything bad happen to me?

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