The contribution of gait analysis to the understanding of motor development

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Bachelor of Applied Science - Human Movement (Honours)

A thesis submitted in total fulfilment of the requirement of the degree of Doctor of Philosophy

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March 2009

ABSTRACT

Findings from two studies are presented. Both focused on the gait of Australian primary aged children and the information that this fundamental motor skill provides towards understanding the development of motor performance. In study one 87 (47 male, 40 female) children (5 – 9 years) participated. Children were tested using the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1996), and the GAITRite walkway system. Gait parameters of the motor impaired and typically developing children were compared. Walking at a self-selected normal pace the motor impaired children did not significantly differ from their typically developing peers. A comparison of the gait parameters across the three age-bands tested (4 – 6, 7 – 8 & 9 – 10 years) showed Cadence and Double support time to differ significantly between the first and second age-bands with Cadence decreasing and double support time increasing with age. The variability of walking velocity and cadence both decreased significantly from age-band 1 to 2. Further a greater percentage of the motor impaired children were classified as overweight according to their BMI.

Two important improvements in the experimental design were introduced for the larger second study (n = 218: 102 Male, 116 Female) ranging in age from 5 – 12 years. Firstly, slow and fast walking speeds were added to the normal walking speed condition to increase the task demand. Secondly, performance on the balance component only of the MABC was used as the criterion for impairment in this analysis.

Developmental trends were most evident for the stride-to-stride gait variability measurements. Specifically, the velocity, cadence, step length and base of support were all significantly more variable in the 11 and 12 year old children in comparison to the young adult group. It was suggested from these findings that the underlying process regulating the sequence of gait was not yet fully mature at age 12.

A major aim of this investigation was to identify a simple objective means to measure the motor skills of children. Using a stepwise discriminant analysis walking at the slow speed was shown to be the best discriminator between the balance impaired and non-impaired children. Using only the base of support and cadence variability measures, 72.2 % of cases were correctly predicted.

The third research question arose from the findings of study, viz. *Do overweight children have impaired balance and coordination during walking?* In this study, only a slightly larger percentage of overweight children (34.4%) were classified as motor impaired compared to the normal weight children (29.9%). It was noted that the overweight children walked with a wider base of support and a longer double support time, though they were no more variable than the normal weight children when the stride-to-stride parameters were assessed.

Three major conclusions arose from this investigation. (1) children do not exhibit mature control of the walking sequence by age 12. (2) children classified as balance impaired walked with a pattern similar to those of children from a younger age group.

(3) Overweight children although adopting a different walking strategy did not exhibit impaired control of the underlying sequence of walking.

Statement of Sources

This thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No other person's work has been used without due acknowledgement in the main text of the thesis. This thesis has note been submitted for the award of any degree or diploma in any other tertiary institution. All research procedure reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

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Acknowledgements

The author wishes to acknowledge and thank the following people who have contributed to the current study.

I would firstly like to acknowledge the staff at ACU for their guidance and support through my candidature. In particular, I would like to thank Assoc. Prof. Wayne Maschette for giving me the opportunity to begin my academic career at ACU, his open door was always appreciated. I would also like to thank Dr. Noel Lythgo for his guidance throughout the process in particular through the planning and data collection phases and for giving me the opportunity to work at the RSRC. Many thanks to Assoc. Prof. John Saunders--your help with the writing process has been invaluable. The late nights and weekend meetings were over and above the call. Thanks!!

To Morgan and Chris, you guys have been my role models throughout. The way in which you both have committed yourselves to finishing the thesis while balancing family, home and work life has been something that I have looked up to. I have gained two lifelong friends during this time.

To my 'outside of work' friends, Josh, Sim, Dom, Lou and Jamie thanks for keeping me 'relatively' sane. Looking forward to the phone call to say "it's done!".

To my family, thanks for not asking "Is it done yet?" too many times. In particular, thanks to my Mum and Dad, Chris and Ian. Your continued support with both the little and big things is always appreciated.

Thankyou to my beautiful wife Liz whose support has been unwavering. Your positive outlook has kept me going. Thanks for sharing the rollercoaster with me (keeping me 'in-line').

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CHAPTER I

INTRODUCTION I

The Australian Government has recently made "a healthy start to life" one of its goals in the National Research Priority document (Department of Education, Science and Training, 2006). This goal aims at

> "Counteracting the impact of genetic, social and environmental factors which predispose infants and children to ill health and reduce their well being and life potential"

In recent times both the social and environmental influences upon the developing child have been changing. Factors such as being driven to school, more restrictive urban environments, increased television viewing and participation in computer games are all increasing parts of children's lives (French, Story & Jeffery, 2001). In general these have predisposed children towards a sedentary lifestyle. Exercise from an early age is important and its lack may be associated with the continuing rise in obesity levels in Australian school children (Spinks, Macpherson, Bain & McClure, 2007). The prevalence of obesity has doubled in boys and girls from the decade of 1985 to 1995 to 4.5 % and 5.3 % respectively (Magarey, Daniels & Boulton, 2001).

Welk, Corbin and Dale (2000) identified a number of factors that relate to physical activity participation. They include the individual's age, gender, culture and socio-economic status, enjoyment, attitudes, peer reinforcement, genetic predisposition, fitness, environment, perceived competence and enabling motor skill (Figure 1.). Having the ability to master fundamental motor skills and participate in physical activity and organised sports as a child are important underpinnings of the process of improving well being and life potential. Inability to master the fundamental motor skills is a major potential hindrance to participation in exercise. A sound skill base is one of the enabling pathways to being physically active, outlined by the Australian Sports Commission (2004). This investigation focuses on the skills required to participate successfully and enjoyably in physical activity. It does this while acknowledging the multi-dimensional nature of the predetermination of physical activity, as outlined by Welk et al., 2000).

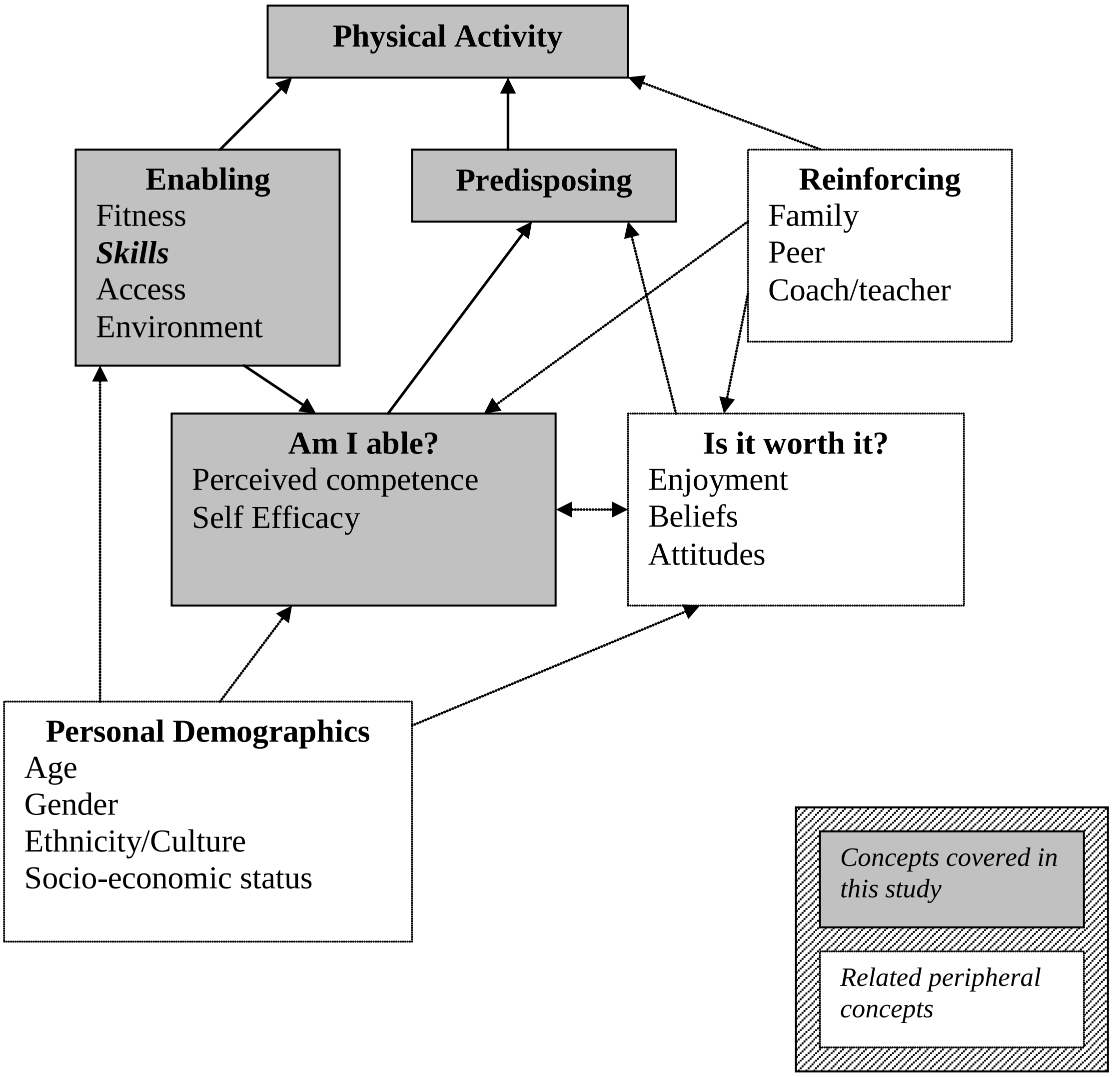


Figure 1.1 Determinants of physical activity.

**Adapted from Welk, Corben & Dale (2000)

Fundamental motor skills have been identified as the building blocks required for performing more complex motor skills (Gallahue & Ozmun, 2006). The fundamental skills can be defined and placed within three categories, locomotor, manipulative and stability activities.

These skills are refined and used in the activities of daily living as well as for recreation and sporting pursuits. A child who has failed to gain competence in the basic motor skills is less likely to participate in both organized and free play activities (Cairney, Hay, Faught, Wade, Corna & Flouris, 2005). One consequence of less physical activity involvement as a child is less opportunity to continue to develop the basic motor skills of play, thus reducing the likelihood of involvement in more complex sporting activities. This then becomes a part of a vicious cycle: Poor skills > low self esteem > less activity > less opportunity to practice > etc.

The current level of fundamental motor skill mastery in Australian school children is of concern. Models of ‘normal’ motor development suggest that the fundamental motor skills should be refined around the age of 7 or 8 years (Gallahue & Ozmun, 2006). From approximately 7 – 14 years, the fundamental skills are then applied to more specialised complex movements for daily living, recreation and sporting pursuits (Gallahue & Ozmun, 2006). Yet a study just over a decade ago claims that only 65 % of children in Victorian primary schools had been able to demonstrate a mastery of the fundamental motor skills by grade 8 (13 to 14 years) (Walkley, Holland, Treloar & Probyn-Smith, 1993). This suggests that over 35 % of children had not reached the expected level of motor skill competence for their age. This high rate, in part, can be explained by the prevalence of poor motor coordination within

Australian school children. A poorly coordinated child may have difficulty performing fundamental motor skills, such as throwing, hopping and jumping. Revie and Larkin (1995) contest that there has been a wide range of incidences of poor coordination due to the varied testing procedures and cut-off criteria. Their study investigated the incidence of poorly coordinated first grade children (n = 224 girls & n = 269 boys) using observational assessments of balancing, hopping, running and volleyball bouncing tasks. Using scores from three of the tests only 4.1 % of children were classified as poorly coordinated. The addition of the fourth test increased the prevalence to 9.3 %. Similarly, the teacher rating approach confirmed these figures by reporting that 9.1 % of these children were poorly coordinated. However, it was noted that few of the children identified by the teachers were also classed as poorly coordinated by the performance on the four motor skills assessed. This highlights the limitations of using subjective measurement techniques to classify motor skill performance in children. To be able to compare the prevalence of poorly coordinated children across different populations and periods in time, it is necessary that a common objective and valid assessment of performance is used.

The DCD title suggests that these children have ongoing ‘developmental’ difficulty ‘coordinating’ the segments of their body in a controlled way to perform specific motor skills, such as throwing, jumping and catching, etc. Children with DCD fail to acquire adequate motor skills related to their developmental stage and age, for no known medical reason (APA, 1994). Children with DCD have difficulties in one or more areas involving manual dexterity, ball skills and balance tasks. Deficits in these areas may then have a detrimental impact on day to day activities such as play, sports, dressing, eating, handwriting and locomotion.

Poor self efficacy with regards to physical activity has been shown to be associated with DCD (Cairney, et al., 2005; Skinner & Piek, 2001). Cairney, Hay, Faught, Wade, Corna and Flouris (2005) showed that children with DCD perceive themselves to be less competent in the basic motor skills and also less adequate in sporting ability. Poor self efficacy with regards to physical activity may prove to be a component of the vicious cycle of poor motor skill development by way of contributing to these children being more likely to choose sedentary activities over physical activity. Wrotniak et al. (2006) found that in a small sample (n = 65) of American children, motor proficiency was positively associated with physical activity and inversely related to sedentary behaviour. However, although the level of motor proficiency was found to explain only 8.7 % of the variance in physical activity, this study did not add self efficacy to the prediction equation. It may be that if the interaction between self efficacy and motor skill competence is included, a greater percentage of the variance in physical activity participation may be accounted for.

It is possible however, that a clinician using criterion A could classify a child with DCD without the requirement of completing a formal motor skill test. *"Delays in achieving motor milestones, dropping things, clumsiness, poor sports performance or poor handwriting"* could be observed by a parent or teacher and used as a basis for the diagnosis. Similarly, a classroom teacher noticing the poor handwriting of a pupil, could incorrectly 'diagnose' a student as having DCD, unless they confirm their judgement with some more formal objective clinical assessment.

The Movement Assessment Battery for Children (MABC) has become the most widely recognised screening tool to identify children with DCD (Geuze, Jongmans, Schoemaker & Smits-Engelsman, 2001). The MABC is administered in four age-bands (4 – 6, 7 – 8, 9 – 10 and 11 – 12 years). Each level of the test reflects an increase in difficulty appropriate to chronological development. Each age band consists of eight items from the areas of manual dexterity, ball skills and balance. Each of the items is scored on a scale ranging from 0 – 5 by an observer. The summed item scores then provide the basis for the MABC percentile rank. A score above the 15th percentile rank classifies the child as having adequate motor skills (Henderson & Sugden, 1996). While the percentile rank provided by the MABC has proven a useful screening tool, it is limited to that.

One of the major areas of concerns for children with DCD is a lack of balance. There is recent evidence to show that dynamic balance is significantly reduced for adults who continue to suffer from DCD (Cousins & Smyth, 2003). This suggests that there may not only be an immediate competency problem in childhood, but, this may presage a more serious long term lack of development in balance. Additionally, the thoroughness of the diagnosis of this critical ability is questionable. The MABC has only two dynamic balance items in each age-band. Both are scored on a scale as noted previously, 0- 5, which allows only for a gross level of analysis. A more sensitive motor skill test which is able to provide insight into this particular underlying deficit would be beneficial. This would better serve not only the early screening of impairment, but the correct course of intervention.

In more recent years some studies have attempted to use more objective testing from the exercise sciences to detail specific deficits in children with DCD. For example, lower muscular power has been reported in this population (O'Beirne, Larkin & Cable, 1994; Raynor, 2001). Raynor (2001) used an isokinetic dynamometer to test the muscular power of the legs. The children with DCD were found to have lower peak torque and power. O'Beirne, Larkin and Cable (1994) showed a decreased muscular power for children screened as having DCD while performing a cycle test (Wingate Anaerobic Test), as well as a slower 50 metre sprint time (running). To date, this is the only study to report muscular power during the actual performance of one of the fundamental motor skills.

The objective measurement of fundamental motor skills should, conceivably, begin with walking; a basic widely relied upon skill. While gait seems a simple automatic task it requires the control of the body's central nervous system, muscles and joints, sensory systems, gravity compensation and environment negotiation (Gallahue & Ozmun, 2006). The ability to gain proficiency in any motor task requires the interaction of the environmental, task and individual constraints (Gallahue & Ozmun, 2006). Having a proficient gait pattern therefore exemplifies the demonstration of the ability to integrate all three constraints.

Intuitively, for children who display poor motor skills we might expect this to be reflected in their gait. Correlations have been reported between selected gait parameters of children with a range of musculoskeletal, neurological disorders or cancer and their motor function scale score (Cintas, Siegel, Furst & Gerber, 2003). Gait speed ($r = 0.68$) and stride length ($r = 0.71$) were positively related to a higher (more proficient) Brief Assessment of Motor Function (BAMF) score, while, double support time (r = -0.40) was negatively correlated with the BAMF score. This provides an example of how musculoskeletal and neurological disorders may be implicated in some unsteadiness which in turn may translate to a gait pattern that is slower and characterized by shorter steps, wider base, increased double support time or increased stride to stride variability and asymmetry. In all populations step lengths and velocity provide insight into power generation while parameters such as base of support can provide insight into dynamic stability while walking. Generally, people with unsteady gait adopt a conservative pattern, slower, smaller steps and a wider base of support.

The characteristics of gait patterns can now be measured objectively in large samples of children with the advancement of portable gait analysis technology. Recently, instrumented gait mats have been used to analyse walking patterns of various populations (Chien, Lin, Liang, Soong, Lin, Hsin, Lee, & Chen, 2006; Dusing, Thorpe, Andrew, Gildea, Heath, Stange & Tompkins, 2005; Rao, Quinn & Marder, 2005). Gait parameters such as step length, step time, base of support and velocity can be measured accurately and efficiently. The current technology is accurate to 1.27 cm and 0.015 sec (Cutlip, Mancinelli, Huber & DiPasquale, 2000). Such objective measurements of walking can then be used to give insights into some of the underlying processes of movement.

Overt measurements of movement have started to yield important information regarding the types of deficits children with DCD face. Further movement analysis may provide more understanding of the underlying control of movement. The concept of movement variability has been emerging in the literature, as being of some relevance. Inherent in all biological systems, variability occurs in movement during repetitive tasks. Put simply, when throwing darts at a dart board, one is unable to hit the bullseye every time. The natural variation is a result of the degree of cooperation of the underlying systems involved in the control of movement (Stergiou, Harbourne & Cavanaugh, 2006). In general, the greater the degree of variability in the timing of the rhythmic movement, the less cooperation between the systems controlling movement, which can be a manifestation of underlying motor impairment. For example, children with DCD have been shown to display greater temporal movement variability in a finger tapping task than typically developing children (Geuze & Kalverboer, 1994). Similarly, variability in foot placement in the rhythmic movement of walking has been investigated as a means of distinguishing impaired walking patterns (Hausdorff, Edelberg, Michell, Goldberger & Wei, 1997; Maki, 1997; Nakamura, 1996).

In addition, in populations other than children, for example elderly fallers, gait stride-to-stride variability parameters have been used to analyse gait dysfunction. Walking is stable when the centre of mass is kept within the base of support. Variability in foot placement (short vs long, wide vs. narrow) from one step to the next will translate the centre of mass closer to the limit of the base of support (Hamill, Haddad, Heiderscheit, Van Emmerik & Li, as cited in Davids, Bennett and Newell, 2006). This, in turn, increases the opportunities for the centre of mass to be forced outside the base of support should relatively small perturbations occur, thus, causing instability. Variables such as step length, step time, base of support and velocity have all been used to identify and quantify gait variability. The measurement of step length and base of support can provide information regarding stability or instability in each of the anterior-posterior and medio-lateral planes of movement. Variability in step time and gait velocity increases understanding of the rhythm of movement. For example, a variable (inaccurate) foot placement in either the spatial or temporal domains can lead to a greater chance of hitting an obstacle. Typically, a number of walks are measured with instrumented laboratory equipment and each step is recorded. A standard deviation (SD) and a coefficient of variation (CV % = (SD / mean) X 100) are then calculated to provide a percentage measure for variability of each of the above gait parameters. Using this technique elderly populations, prone to falling, have been identified as having increased variability in step time measurement (Grabiner, Biswas & Grabiner, 2001; Hausdorff, Rios & Edelberg, 2001; Owings & Grabiner, 2004; Owings & Grabiner, 2004b). Information gained from assessments such as these may be used in the early identification of falls risk in this population. Returning to the other end of the developmental scale, Hausdorff, Zemany, Peng and Goldberger (1999) have linked the maturation of children's gait with a decrease in gait variability using the temporal parameters of step and stride time.

As one of the fundamental motor skills, it has been purported that gait should be approximately mature by the age of 7 years (Gallahue & Ozmun, 2006). Three criteria for mature walking have been proposed: (1) maximal mechanical efficiency, (2) minimal asymmetry in lower limb movements, (3) minimal variability of interlimb and intralimb coordination (Jeng, 1996). The majority of studies investigating gait maturation have found that by the age of seven, muscle activity measured with electromyography (EMG) becomes more efficient, kinematics (joint ranges of motion) and kinetics (joint moments and powers) minimise asymmetry, gait efficiency (VO_2), gait symmetry and variability are all adult like (Ganley, 2004; Jeng et al., 1996; Jeng et al., 1997; McFadyen, 2001; Sutherland et al., 1988). Bi-articular joint power generation/absorption, has been shown to be adult like at age six and step length, cadence, base of support and single support phase, at age five (Desloovere, 2004; Langerak, 2001).

A means of improving the screening and evaluation process for children with poor motor skill will provide timely and valuable assistance to both clinicians and practitioners. Reliable, efficient and valid measurement of motor impairment will facilitate the early identification of children at risk. Early identification followed by intervention is important in order to help break the ‘vicious cycle’ of poor skills > low self esteem > less activity > less opportunity to practice > and less skill development. Specific individualised intervention programs can then be developed to assist children with DCD to participate in more physical activity. In this way, improved strategies can be put in place to counteract the impact of genetic (but increasingly) social and environmental factors limiting children from participating in regular physical activity and having a healthy start to life.

CHAPTER II

LITERATURE REVIEW

The focus of the literature review begins with an examination of the current issues surrounding children having a healthy start to life. In particular, the relationship between motor skill proficiency, physical activity, fitness and self efficacy. A historical overview of motor development theory will then be presented through to a critique of the current trends and research focuses. Finally, gait analysis techniques will be reviewed in the context of their potential to add to knowledge of child motor development.

2.1 Current issues – Motor Skill, Physical Activity, Fitness and Self Efficacy

Recent statistics on Physical Activity in Australian populations have suggested that children's participation rates are increasing (ABS, 2006; Booth, et al., 2006). The Australian Physical Activity Guidelines for Children and Youth aged 5-18 years recommends that students experience at least one hour of moderate to vigorous physical activity (MVPA) every day (DoHA, 2004). Moderate to Vigorous Physical Activity has been defined as "activity that requires at least as much effort as brisk or fast walking" (Bar-Or & Rowland, 2004). The SPANS project tested approximately 5500 children for the NSW government in 1997 and 2004. The mission of the study was to estimate the prevalence of overweight and obesity in children and young people as well as fitness level, physical activity patterns, extent of sedentary behaviours, food habits, and presence of risk factors for chronic disease. A self report survey was used showing that for the year 8 children tested from 1997-2004 the prevalence of one hour per day of moderate to vigorous physical activity increased from 57-87.3% & 51.2-76.8% in boys and girls respectively during summer. The increases during winter were less pronounced, being for boys 73.7-79.9 % and for girls 55.6-66.2 %. Since 2000 the Australian Bureau of Statistics has released details of its "Children's Participation in Cultural and Leisure Activities" study every three years.

Table 2.1 Children's Participation in Cultural and Leisure Activities frequency

Item	**2000**	**2003**	**2006**
Participated in at least 1 Organised Sport	59.4	61.6	63.5
Participated in 3 or more Organised Sports	9.1	11.4	10.8
Participated in selected organised cultural activities	29.4	29.5	32.6
Did not participate in sport or organised cultural activities	30.4	28.5	29.6
Watched TV and video	96.9	98.2	97.4
Played computer and electronic games	69.8	70.7	63.6
Reading for pleasure	N/A	74.8	74.5

ABS (2006)

It was suggested from Table 2.1 that the participation in organised sports is increasing. This however is counterintuitive to the high levels of sedentary behaviours and increasing obesity rates (Magarey, Daniels & Boulton, 2001). These figures take on a different perspective too, if we look back to reported participation rates in the 1980s. The 1985 Australian Health and Fitness Survey suggested that as many as 82.5 % of children in South Australia participated in at least one organised sport (Pyke, 1987) as opposed to the 63.5 % reported in the 2006 ABS data. This distinction is amplified when changing the measure to look at the reported participation in 3 or more sports. The ACHPER (1985) study suggested that 40 % of children were involved in 3 or more organised sports, whereas the ABS (2006) data reported a mere 10.8 %.

Concerns about such a potential decrease are compounded when we consider the data for children's participation in sedentary activities such as TV watching and computer game use at home. Statistics show that Australian children on average spend 2.5 hours per day watching television (ABS, 2001). This is consistent with a wide ranging systematic review of television watching published in English speaking journals, in which was noted that contemporary youth worldwide watch approximately 1.8 – 2.8 hours of television a day (Marshall, Gorely & Biddle, 2006). This exceeds the recommended maximum time that should be spent in sedentary activity (such as playing computer games, watching TV, using the internet for entertainment) which is two hours per day for children 5-18 years of age (DoHA, 2004). An alarming statistic recently reported was that children are 3.5 times more likely to be sitting in front of a screen between 3.30pm & 6.30pm than playing sport (Australian Sports Commission – *Children and Sport Research Report*, 2004). One confounding factor for the trend inferred from the SPANS project, that children are meeting their physical activity requirements, may be due to the reporting of participation in physical activity classes during school time. This exemplifies an increasing emphasis on formally organised activity such as attendance at school PE classes. This raises issues concerning the quality of the participation which illustrates just one methodological problem with these data.

Like all teachers in a classroom setting Physical Education teachers may find themselves catering to the 'median student' and this alone disadvantages those children falling behind with their motor skill competency. Studies from the U.S. have shown that less then 10% of the time in physical education classes is spent participating in at least moderate physical activity (Simons-Morton, Taylor, Snider, Huang, 1993; & Simons-Morton, Taylor, Snider, Huang & Fulton, 1994). The U.S.

standard suggested within the Healthy People 2010 report is that children should be participating in 50% of moderate to vigorous physical activity during scheduled PE classes (United States Department of Health and Human Services, 2000). Further during out of school time it is clear that the opportunities for sedentary behaviour over those for active play are increasing (ABS, 2001). It is suggested that an ever rising number of children are accumulating their Physical Activity only from the opportunities provided during structured settings and that in general opportunities for unstructured play time are decreasing. This is a potential crisis as unstructured play activity during childhood is not only important for burning calories, it also allows children to build adequate physiological and motor readiness for participation to explore the environment within their own time and to build social networks (Ginsburg, 2007).

It is recognised that there are many facets to becoming a physically active child including, environment, motivation, parental encouragement and self efficacy (Welk, Corbin & Dale, 2000). One factor that enables children to participate in physical activity, whether it be sporting pursuits or play activity, is their fundamental motor skill proficiency. Yet, although the ‘rationality’ of this link appears undependable, the degree of this association however has been debated and to date research has shown only a limited relationship between motor skill competence and physical activity levels (Booth, et al., 1999; Booth & Patterson, 2001; Cairney, et al. 2005; Fisher et al., 2005; Wrotniak, Epstien, Dorn, Jones & Kondilis, 2006).

Using the New South Wales schools sample (Booth et.al., 1999) Okely, Booth and Patterson (2001) investigated the relationship between physical activity (PA) and fundamental motor skills. They reported that the mastery of fundamental movement skills accounted for 3 % of the variance in organised physical activity participation, and participation in non organised physical activity was not significantly associated with performance of fundamental motor skills. This finding may be limited to the validity of the motor skill battery used. The six fundamental skills assessed by observers rating components of skills (focusing on the process rather then the product) were run, vertical jump, catch, overhand throw, forehand strike and kick. However, the most popular non-organised physical activities reported were walking, swimming, cycling, pick-up basketball, surfing and rollerblading (Okley, Booth & Patterson, 2001). Of these only basketball involves the use of any of the fundamental motor skills tested.

Wrotniak, Epstien, Dorn, Jones and Kondilis (2006) reported a positive association between physical activity levels (measured with an accelerometer) and motor proficiency (measured by performance on the BOTMP). Sixty-five American children aged between 8 and 10 years were tested. The children’s motor proficiency was able to explain only 8.7 % of the variance in physical activity levels.

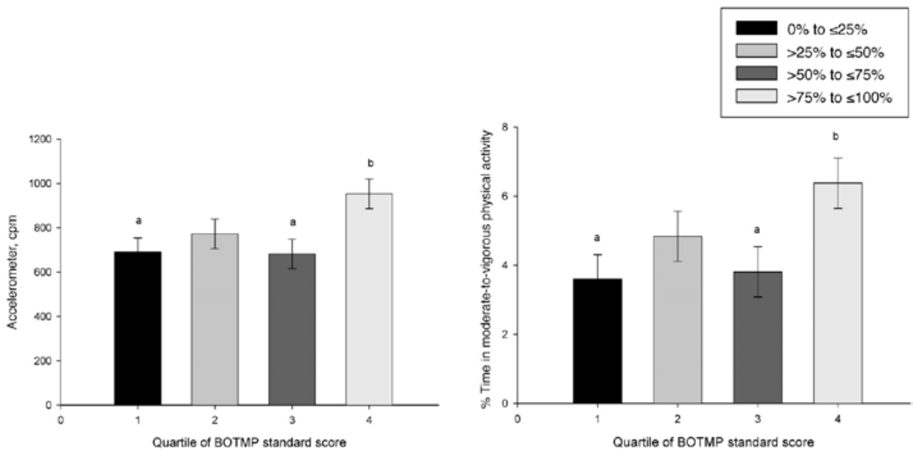


Figure 2.1 Physical activity and BOTMP score quartiles (from Wrotniak, Epstien, Dorn, Jones & Kondilis, 2006)

However, an interesting finding from this study as shown in Figure 2.1, is that the children who were the most skilful did report spending more time in moderate to vigorous physical activity and measured highest for accelerometer measurements of PA.

Fisher et. al. (2005) tested a larger sample of younger (4.2 yrs SD 0.5) British children (n = 394) aged 4 years. Weak positive correlations were found between total physical activity and MABC score (r = .10) and percent time spent in moderate to vigorous PA and MABC score (r = .18). 'Light' physical activity was not correlated at all. These low relationships may be a result of the 'ceiling effect' inherent within the MABC scoring system where a proficient child is scored the same as a highly proficient child. The highly proficient child however, may have accumulated a much greater amount of physical activity during the testing period.

Children with developmental coordination disorder (DCD) have been shown to be less likely to be physically active and have a poor general self efficacy with regards to physical activity (Cairney, et al., 2005). Cairney et al. (2006) showed that, in a sample of 9-15 year old Canadian children (n = 590) with DCD, they participated less in both organised physical activity and free play than typically developing children. This study reported that 28% of the variance in the children's physical activity could be accounted for by self efficacy and DCD alone. Self efficacy seems to be the important factor for a child with DCD becoming physically active.

More work is required to determine the association between motor skill competence and physical activity of primary aged children. While to date the degree of association demonstrated has been weak, further analysis of more sensitive and valid measurements of fundamental motor skills may identify a stronger relationship. The greatest degree of association found was from the study that used a valid test of motor proficiency, Bruininks Oseretsky Test of Motor Performance (BOTMP), and an objective measurement of physical activity (accelerometer) (Wrotniak, et al., 2006).

In a summary of preliminary findings to the Children Leisure Activity Study (CLASS) it was noted that many Australian children were only engaging in low or moderate physical activity and that physical activity was seen to decline with age (10 – 12 year old children approximately spend half as much time in moderate to vigorous physical activity than 5 – 6 year olds, 2.4 – 2 and 4.5 – 4.1 respectively). They also examined children's beliefs about the barriers to being physically active. They were (1) do too much already, (2) prefer TV & (3) look funny when physically active (approx 20 %) (Salmon, Telford & Crawford, 2004). In addition to this; approximately 10-15% of children reported that they don't think they were very good at PA and other kids made fun of them when physically active (Salmon, Telford & Crawford, 2004). An important link may be made here between the way in which children perceive themselves and their motor skill competence. Children who perceives themselves as 'clumsy' may withdraw or not actively participate in PE class time or in social opportunities to play after school times. Thus avoidance will only serve to exacerbate their slow/delayed/impaired motor skill development. The psychological dimension, therefore, plays an important mediating role in enabling children to become physically active.

2.1.1 Evidence that childhood health is in decline.

Over the last century researchers have been investigating children with motor impairments. Since Dupre's *Motor Deficiency Syndrome* (1911) researchers have been screening children with motor impairment in various populations of children using a variety of testing batteries. The most recent finding from Australia suggests that 10.2 % of children display low motor competence (Hands, 2008). Findings from a similar study from a sample of metropolitan Melbourne showed that > 30 % of children were classified below the 15^{th} percentile cut-off score assigned by the MABC (Williams, 2008). In light of this emerging research the previous assessment of the prevalence of motor impairment may be an underestimation.

2.1.1.1 Fitness

A meta-analysis by Tomkinson, Léger, Olds and Cazorla (2003) using the twenty years from 1980-2000 reported that there has been a decline in the 20 metre shuttle run test of 0.43 % per anum on average. Data on children from 11 developed countries was used to estimate maximal oxygen uptake. Dollman et al. (1999) reported similar declines in fitness using a 1600m run test. From 1985-1997 performance of 10 and 11 year old children on average declined from 0.5-0.8 % per year. A sample of 2450 Tasmanian children tested for 1600m run performance also declined up to 0.4% per year from 1985-1995 (McNaughton et. al., 1996). The Australian studies mentioned also tested performance on various anaerobic tasks, vertical jump, basketball throw, 40m and 50m sprint. There were no decreases in performance for these tests of which required strength and power. Tomkinson et al. (2003) suggests that the decline in aerobic performance is consistent with the decrease in physical activity of children.

Evidence suggests that children screened with motor deficiencies perform worse on a range of fitness tests (Haga, 2008). Nine fitness tests were used and the motor impaired children were found to score significantly worse on all of them. The standing broad jump, jumping on two feet, jumping on one foot, throwing a tennis ball, pushing a medicine ball, climbing wall bars, shuttle run, running 20 metres and the reduced Cooper test (6min walk/run) were used in the battery. The decline in performance on fitness tests in recent years of Australian children, therefore, must be compounded for children with DCD. This in turn, may be negatively impacting on their general health and wellbeing.

2.1.1.2 Obesity

The most recent study into the prevalence of obesity in Australian children and adolescents was performed in 1995 (National Nutrition Survey) consisting of 2962 children aged 2-18 years. The main study preceding that was the Australian Health and Fitness Survey (1985) with 8492 children aged 7-15 years. Using the recent (Cole, Bellizzi, Flegel & Deitz, 2001) BMI cutoff points for overweight and obesity both survey populations were investigated by Magarey, Daniels and Boulton (2001) who found that the incidence of both overweight and obese boys and girls doubled in the decade from 1985 – 1995, from 11.8 % to 21.1%. As the general worldwide trend of increasing overweight and obesity prevalence among children is increasing, it is not only important to get more up-to-date statistics in this area, but, also focus on research which combats this alarming trend (Lobstein, Baur & Uauy, 2004).

Deitz (1994) reported three 'critical periods' in childhood for the development of obesity. It was proposed that prenatal (conception – birth), adiposity rebound (5-7yrs) and adolescent (10 – 20yrs) periods of childhood were the most likely times that obesity would develop. Each are related to periods in childhood where rapid growth occurs (Gallahue & Ozmun, 2006). Importantly the adiposity rebound period from 5-7 years of age is also the period where children are mastering fundamental motor skills (Gallahue & Ozmun, 2006). As the increasing obesity rates around the world have continued to be reported (Lobstein, Baur & Uauy, 2004), the link between motor skill competence and obesity has begun to appear in the literature. The nature of this interaction raises concern. Are children overweight or obese due to their lack of motor skill competence, or, is the increased body mass hindering motor skill acquisition?

There is evidence to suggest that an increased prevalence of overweight and obesity exists within motor impaired children. Overweight and obese children have performed worse on the KTK, in two German studies (Graf et al., 2004 & Kretschmann et al., 2001). Interestingly, the Kretschmann et al. (2001) conference paper reports that 90 percent of obese children tested were classified as having at least a moderate disturbance in motor behaviour. The mean score of the obese children placed this group in the severe disturbance classification. Goulding (2003) also reported children with increased adiposity scoring worse on the Bruininks-Oseretsky (B-O) balance test. The children with increased adiposity in this study performed at a normal level on the sensory perception balance test (Equitest), which suggests that the main factor that hindered balance performance on the B-O test was increased body mass. A follow-up weight reduction intervention study in balance impaired adults supports this notion (Sartorio et al., 2001). When BMI was reduced by 4.1% in this group balance scores improved by 20.5%. Increasing adiposity moves the centre of mass away from the base of support, which seems to be the main hindrance to balance within overweight populations. Moving a large bulk with a relatively smaller muscle mass also decreases the rate of force production therefore, hindering the ability to recover once unbalanced.

A recent study investigated the dynamic and static tests of balance and postural sway in boys with previous wrist fractures and high adiposity (Goulding et al., 2003). While no associations between wrist fracture and posture or balance were found, the children with increased adiposity scored lower on the Bruininks-Oseretsky balance test. All measures of adiposity were negatively correlated to B-O scores. The differences in balance were more pronounced in the functional B-O test when compared to the proprioception or sensory tests (Equitest), suggesting that the overweight children may not have altered somatosensory perception from disturbed vision, proprioception or vestibular function, just inadequate musculature relative to body size.

2.1.1.3 Social Relationships

Self efficacy has been defined as the individual's beliefs in his/her capabilities to execute necessary courses of action to satisfy situational demands (Bandura, 1997).

Berger, Pargman and Weinberg (2007) have used a behavioural concept map to relate the global interrelationships between the environment, the person and the behaviour. The way in which a child perceives their skill directly relates to how they behave in the environment. The Dynamic Systems Theory of motor development explains the interaction and organisation of the systems within and between the three – under the headings of individual, environment and task.

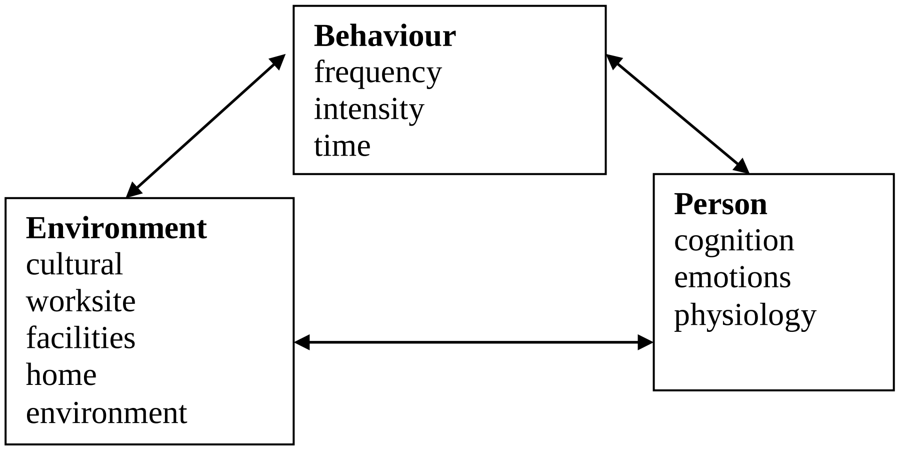


Figure 2.2 Global interrelationships between behaviour, person and environment (Berger, Pargman & Weinberg, 2007).

Children identified as having poor coordination or Developmental Coordination Disorder have been shown to: perceive low classmate support; perceive less parent teacher support (Rose, Larkin & Berger, 1994), exhibit less happiness with their lives; place less value on themselves (Skinner & Piek, 2001); (in the case of boys) be three times more likely to have adolescent anxiety (Sigurdsson, van Os & Fombonne, 2002); be more introverted; make judgements of themselves to be less competent physically and socially; be more anxious (Shoemaker & Kalverboer, 1994); have lesser likelihood to be physically active and have poor general self efficacy with regards to physical activity (Cairney et al., 2005).

The children in the Cairney et al. (2005) study who had low or poor motor skill competence reported lower self efficacy which may, in turn, lead them to be less physically active. This self-perception creates a 'vicious' cycle that may further inhibit the normal rate of motor skill development, creating an ever divergent path from the typically developing children.

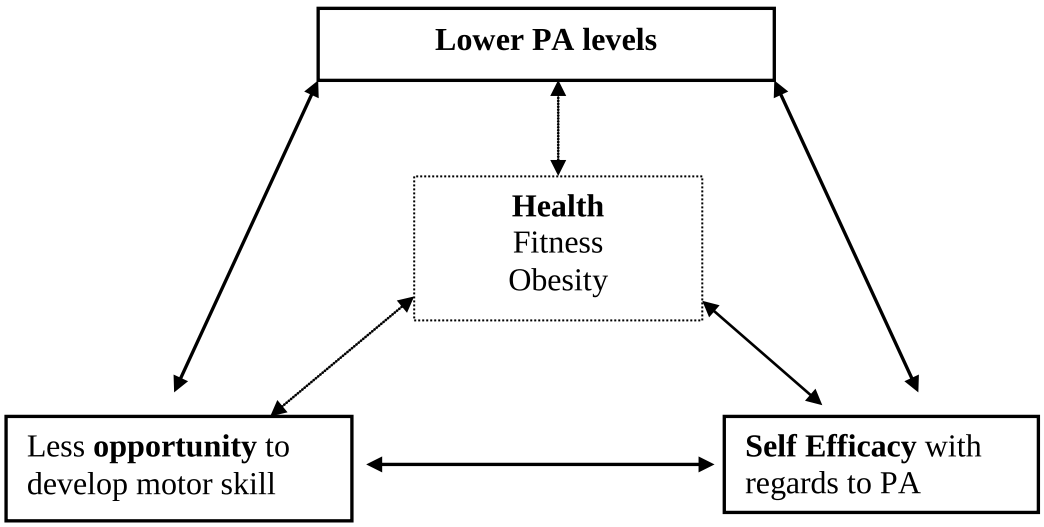


Figure 2.3 The 'vicious' cycle of self efficacy, physical activity & motor skill and impaired health outcomes

2.1.1.4 Value of Intervention

There is some evidence to suggest that children with DCD continue to suffer into teenage years. Losse et al. (1991) reported that children (n = 17) with motor problems at age six still exhibited motor difficulties ten years later at sixteen. This finding highlights the need to intervene early to break the cycle. Four meta analyses/review articles since 1993 have investigated the effectiveness of various intervention strategies to improve the motor skills of children with DCD (Kaplan, et al., 1993; Miyahara, 1996; Pless & Carlsson, 2000a; Wilson, 2005). The earlier meta-analysis by Kaplan et al. (1993) reviewed both perceptual motor and sensory integration interventions. Perceptual motor training has been defined as:

> "systematic instruction or therapy that uses integrated processes of sensation, perception, and movement to enhance the basic determinants of movement skill potential…" (Sherrill, 2004. p 333).

Sensory integration therapy aims to improve the capability to process sensory input; it usually involves activities such as balancing on beams or swinging in hammocks (Dempsey & Foreman, 2001). Both intervention groups improved similarly when compared to the control group who did not improve their motor skills. Similarly, Miyahara (1996) reviewed four studies investigating intervention strategies for children with DCD, categorised as either task oriented (focussing on the movement outcome) or process oriented (focussing on the processes required for the correct movement). Both intervention strategies showed improvements, though, no one group improved more than another. Pless and Carlsson (2000) included 13 studies in their review comparing three intervention techniques, general, sensory integration and specific skill approaches. The general abilities approach was similar to the perceptual-motor training defined by Sherrill (2004), using balance and other physical training in specific perceptual and motor tasks. The sensory integration approach aimed to improve brain function to increase the ability to process sensory input. The specific skills approach included task-specific instruction. The individual actively repeats the skill guided by a facilitator. Once again, the conclusion was that any form of intervention was useful, though; the specific skill approach was the most effective in this review. Wilson (2005) reviewed five approaches to motor assessment and treatment for children with DCD: Normative Functional Skill Approach, General Abilities Approach, Neurodevelopmental Theory, Dynamic Systems Theory and the Cognitive Neuroscientific Approach. Each were shown to be useful for either the screening or intervention of children with DCD, however, the multi-level approaches to movement assessment and treatment were recommended. These approaches provide an illustration of the different levels of motor development across a range of functional abilities, be it, behavioural, neurocognitive and(or) emotional. The use of biomechanical analysis was advocated for cases where serious limitations existed in a child's movement patterning (Wilson, 2005).

With evidence that children do not necessarily grow out of DCD together with the findings from the intervention studies, it is clear that early screening for DCD, as a basis for early intervention, is critical for the optimal development of children with movement problems.

2.2 Child Motor Development Theory

In order to contextualise the current literature regarding the development of motor skills a brief history of motor development theory is presented here. Clark and Whitall (1989) summarise three different periods in the study of the motor development of children. The early research from 1930s-1945 they label the "maturational period" because of an emphasis on the underlying processes which governed maturation. The period of time from the end of World War II to the 1970s is identified as the "normative/descriptive period" wherein research was focussed on the movement product and the description of the mechanics of motor performance. From the 1980s to the present the focus has switched, explaining the processes underlying change in motor behaviour over time. This was labelled the "process-oriented period".

One of the notions central to the maturational period was that the development of both intellect and motor function were closely linked to the development of the central nervous system (Gabbard, 2004). Gessell (1928, 1954) hypothesised that the nervous system was the main driver for growth. The maturationists contended that the biology of the child played the major role in motor development. Little emphasis was placed on environmental influences. It was believed that though the environment may inhibit or facilitate the rate of change, the outcome itself was biologically determined. The naturally occurring sequences of change were the focus of this theoretical view. The transition from crawling-creeping-walking provides an example of such a sequence - the trigger for the onset of walking being the development of the central nervous system. Twin studies during the 1930s-1940s investigated the use of early practice and skill instruction (Gessell & Thompson, 1934; McGraw, 1935). These findings suggested that the degree to which twins were trained related to the rate at which skills were acquired, although the sequence of the skill acquisition was not altered and the non-trained twin soon caught up once training ceased. As a result of such an understanding of motor development it was natural that educators would use age group norms as a means to describe motor development. This perspective was popular from the 1940s to the 1970s (Haywood & Getchell, 2005) and has been described by Clark and Whitall (1989) as the normative descriptive period.

One of the earliest references to children with motor impairments was made by Dupre (1911) (as cited in Ford, 1966). He used the term "*Childhood Motor Deficiency Syndrome*" to identify children who were awkward in their voluntary actions, displayed excessive tendon reflexes and had mild hypertonicity (increased muscle tension). The reference to tendon reflexes and muscle hypertonicity is consistent with a causal relationship with the CNS, whereby the biology of the child has adversely affected their movement. Lippitt (1926) and Orton (1937) used similar terms such as 'poor muscular coordination' and 'apraxic' to describe a similar deficit. Again these are consistent with the related maturational theories which predominated at the time.

Early motor performance batteries were developed to test for both ‘motor abilities’ and ‘motor defectives’ (sic) (Oseretsky, 1923; Yarmolenko, 1933). Oseretsky (1923) developed a measurement scale of motor abilities using a selection of various tests which were ranked for age difficulty. A motor-age coefficient was then calculated as a basis for comparison with chronological age. As with the phase stage theories, the expectation was that a child should perform at a certain level by a certain age.

Yarmolenko, (1933) used the term of “Motor Defectives” from Homburger (1926) to define someone who is “unable to use his limbs, his static mechanisms, his voluntary innervation, and who is limited by a small number of simple motor actions”. This definition was used in conjunction with the development of a battery of motor tests (Dernowa-Yarmolenko, 1933). The battery included tests in five broad categories: (1) Speed, (2) Strength, (3) Exactness, (4) Motor Endurance (static & dynamic) & (5) Work Tempo. From this battery of tests Yarmolenko calculated coefficients of both walking speed and walking exactness. The walking speed measure related to the speed (m/s) on average covered while the child negotiated a pattern of zigzags, squares and circles marked on the floor. The walking exactness coefficient was the total distance covered from the test divided by the number of mistakes made. These are not dissimilar to some of the dynamic balance tests seen in today’s MABC (Henderson & Sugden, 1996). Among other coefficients calculated were: grasping speed, grasping exactness, lying down speed, lying down exactness, exactness of throwing, length of jump, transported weight (carried), dynamic endurance (hops), average muscular work tempo and static endurance (standing with arms out).

From the figures produced by Yarmolenko (1933), only the endurance and tempo coefficients had reached a plateau by age 15. This suggests that the children tested (n

= 420) aged 8 – 15 years were still developing their skill within various motor tasks (including walking). Thus, their gait was not yet 'mature' according to the measurements recorded. This may be indicative of the measurement of gait maturation in general. The age of 'maturation' may largely reflect the measurement rather then the skill.

Although some researchers were still investigating the neural dysfunction of children during the 1960s – 1970s (Ayers, 1960; Ayers, 1972; Bax & MacKeith, 1963; De Ajuriaguerra & Dtambak, 1969; Paine, Werry & Quay, 1968), post World War II researchers in motor development began to focus less on the underlying process of motor development and more on the description of school aged children's motor skills. The British Medical Journal's (1962) paper 'clumsy children' was one of the first to use a scientific approach to studying children with poor motor skill behaviours with no known link to any neurological disorders. Espenschade, Glassow and Rarick, all physical educators, investigated the outcomes of motor development in school aged children (Gallahue & Ozmun, 2006). The standardised tests and norms used today are largely based on those developed from this period by Espenschade, Glassow and Rarick (as cited in Rarick, 1981). Children were tested against the average performance of children of similar age and gender. Average throwing distance and running speed are examples of some of the measurements used to focus on the outcome of movement rather then the process and the production of a quantitative score as a basis for comparison. Keogh and Oliver (1968) used normative data as a basis for comparison for 'physically awkward' boys. The performance on six performance tests (beam balance, beam walk, standing broad jump, alternate foot hopping and simultaneous foot-finger tapping) was compared to that of 'regular' children of the same age. Later Keogh, Sugden, Reynard and Calkins (1979) used a classroom teacher checklist, observational methods and a motor performance test to identify ‘clumsy’ children. Little agreement was noted between the three types of identification used suggesting that the validity and reliability of one or all of the items was questionable. The authors noted that the lack of agreement identified here precluded any definitive statements on the nature of clumsiness.

During this period the developmental psychologists were theorising that each child passed through universal age based stages characterised by certain forms of performance (Erikson, 1963, 1980; Havinghurst, 1972; Piaget, 1969). Stages are passed through sequentially during development. The order is invariant although stages can be skipped. A child may walk without learning to crawl. This stage-like approach was similar to the early maturationalist motor development theories. Although the maturationalists contend that the sequence of the acquisition of movement skills was ‘invariable’ (Gessell & Thompson, 1934). The emerging notion that developmental stages could be ‘skipped’ implies that the rate and sequence of development may not be linear or continuous. This idea was later further explored by the ecological theorists. The limitations of these stage theories relate to their broad, inflexible nature. Each child develops through stages characterised by an ‘average’ individual. While relevant for most, not every child will develop at an ‘average’ rate. The invariance of the length of time and onset of each stage has also been identified as a limitation of these theories. Some children may need more time to hone certain skills or develop the systems required to perform movement tasks then others.

Halverson (1966) began to research the longitudinal changes observed in the biomechanics of some of the fundamental motor skills, such as jumping patterns, during this era. Description of the mechanics of the movement pattern was the focus rather then the product of the final skill. This research yielded normative information regarding the age related changes in gross movement patterns of the developing child. Wickstrom continued in this vein focusing on this aspect of fundamental motor skill development. An interesting note regarding Wickstrom (1977) defined Motor Development as “changes over time in motor behaviour that reflect the interaction of the human organism with its environment”. This acknowledgement of the interaction of the human biology (heredity) and its environment foreshadowed more contemporary theories such as the dynamic systems approach. Within this framework, researchers in the 1970s set about describing ‘normal’ development in the fundamental motor skills according to stages (Wickstrom, 1977). It was Wickstrom’s (1977) belief that the sequence of development was predictable and approximately the same for all children, but the rate at which specific changes occur varied between children.

Roberton (1978) contested the developmental stage theory by testing the development of an overarm throw in first grade children. A longitudinal analysis of 6-13 year old children’s throwing patterns was performed. It was suggested that a stage sequence was evident in arm motion but not for trunk movements. The trunk movement was considered to be the control parameter for change in the movement pattern. This then gave rise to Roberton’s model which says that developmental stages can only be meaningfully identified in the individual components within the pattern as a whole. The component model of development was adopted in the belief that the individual child could combine developmental levels across components in different ways. Using the overarm throw as an example, a child may have a mature arm action, though, he/she may not be using their lower body and trunk to an optimal level.

The popularity of information processing as a means to understanding and explaining skill development began to increase around this time from the 1970s and 1980s. The initial information processing theories were born from the use of the first computer around the time just after World War II (Dineen, 1955) and then later developed by psychologists (Newell, Shaw & Simon, 1958). A notion that the brain acts like a computer inputting information, processing it and selecting an appropriate movement response as output.

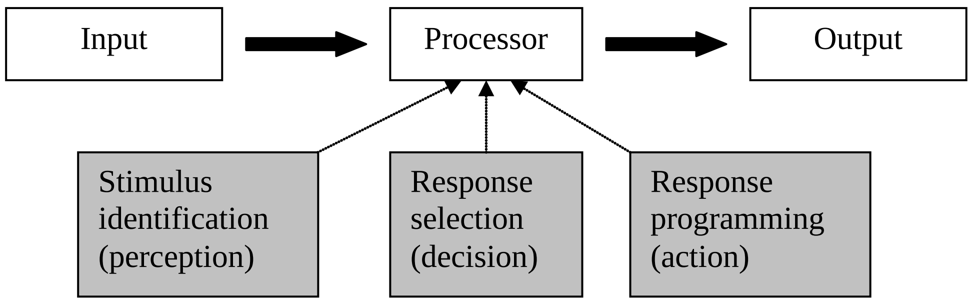


Figure 2.4 Simple Information Processing model

In actuality, however, the information systems model includes a more complex interplay between the processing of the perception, decision making, the selection of specific motor programs, transmission of information, and intrinsic and extrinsic feedback. The following Figure details these associations.

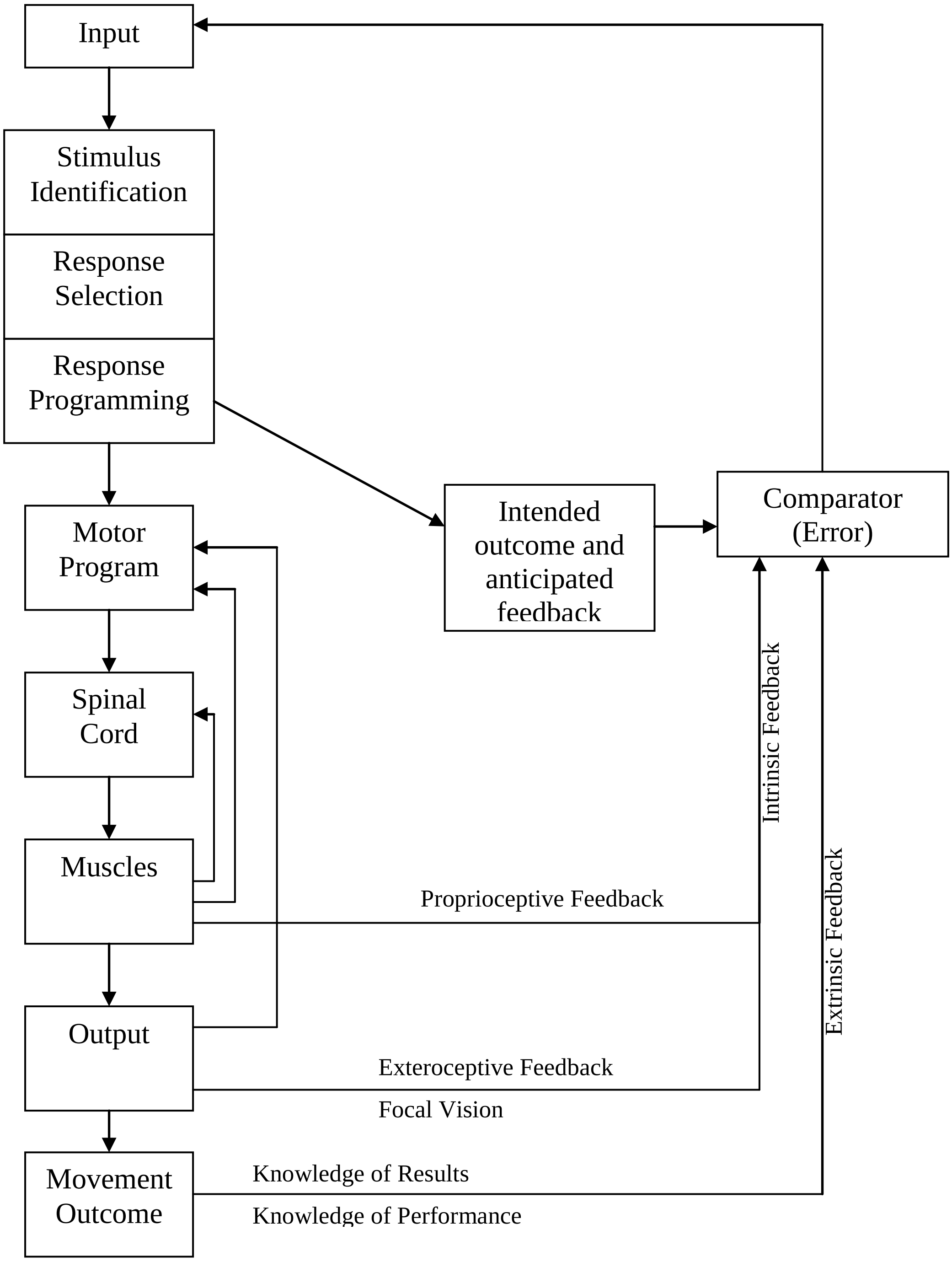


Figure 2.5 Expanded Information Processing model Adapted from Schmidt & Wrisberg (2008)

The four main components of information processing models are then: sensory input, the reception of perceptual information, the interpretation and decision making and the overt motor response. Each component is mediated by attention, memory, processing speed and programming. In general, as children progress towards adulthood they are able to process more information in a shorter time period (Gabbard, 2004). Attention has therefore, been a focus as the major influence and limitation on the information processed. As children mature they are able to process increasing amounts of (relevant) information. Young children focus on one stimulus and are easily distracted, older children attend to too much information (some irrelevant), early adolescents attend to relevant information in complex situations. A young child may only focus on taking one step at a time while walking and an older child may focus on too many environmental stimuli both causing instability. The more the child practices the skill and is placed in varied environments the more experience they have to call upon, from memory, to negotiate challenging situations.

The rate at which information is processed can be measured by reaction time, which usually improves with increasing age to adulthood but subsequently declines into old age. The programming aspect of information processing theory relates to specific schemas which are rules or sets of rules providing a basis for skill performance. Schmidt's schema theory suggests that these rules govern the type of movements performed as an outcome (Magill, 1998). For example, a set of rules governing the force required to throw a ball different distances is said to be a schema (Schmidt & Wrisberg, 2008). As previously mentioned, the more movement experience a child has the more schemas they have to call on at any one time. A child will process the information in the immediate environment and select the appropriate schema to deal with the situation. This ability to process environmental information and improve through practice sets apart Information Systems theory from the earlier maturational theories.

The successful performance of a certain skill is based on the quality of the perception of numerous sensory inputs and then making a decision based on these inputs with a correct motor outcome. Little emphasis is placed on the individual's innate biology and the impact that this has on the development of skill.

While the theorists moved the framework back to a process oriented approach to motor development some researchers were still using the normative descriptive style of screening tools to identify children with motor impairments (Larkin, Hoare, Phillips & Smith, 1988; Sugden & Waters, 1985). Others were still focussing on the neurological deficits of previous decades (Denckla, 1984; Dermak, 1985). This 'mixed' approach to the explanation of and screening motor development has continued over the past 20 to 30 years.

The most recent of theoretical frameworks to emerge has been the ecological perspective. This perspective relates the development of specific skills with regards to the relationships between the individual, the environment and the task being performed. It suggests that to understand the development of motor skills all of the elements (individual, environment and task) must be considered. In some way each of the elements plays a role in development, some may play a larger role then others in specific tasks.

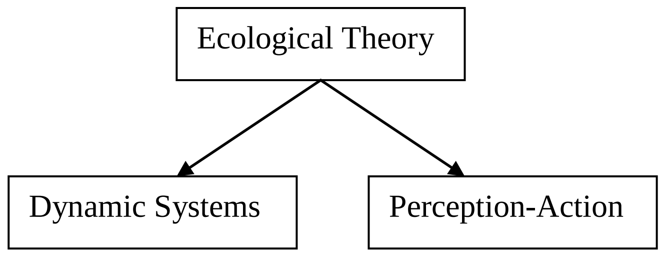


Figure 2.6 Dynamic systems and perception-action as branches of general ecological theory.

The dynamic systems approach is one of two branches of ecological theory that deals with motor control and coordination. Dynamic systems theory is based on the work of Bernstein (1967) who wrote about the physical and chemical constraints to behaviour. Behaviour is said to be self-organising and arising from the interrelationships between the constraints applying to the individual, the environment and the task. The development of a particular behaviour relies on the mature relationship between all of the factors in the systems involved. The systems relating to task competence are: performance demands, movement pattern formation and degrees of freedom. The individual systems include: anatomical and growth factors, physiological factors, mechanical factors and perceptual-motor factors. The environmental systems consist of the opportunity to practice, encouragement and motivation, instructional cues and context within the environment. Each system however, may interact at a different rate. For example, the individual begins to walk when all of the systems involved reach a certain point. Only when the 'slowest' of the systems reaches that point of 'readiness' can the individual walk within that particular environment. It may be that the child has all the attributes to walk, though does not have the strength to propel themselves, an individual constraint. Not until the child develops the strength can they walk (Thelen, 1989).

One of the major differences to previous developmental theories is the way in which the dynamic systems theorists explain the rate of development. Previously, development has been explained largely as linear and continuous. You first crawl then walk then run within limiting timeframes relating to chronological age ranges. From the dynamic systems perspective the development of an individual over time may not, however, be smooth or progress in order of complexity (Thelen, 1989). The dynamics of change occur due to the influence of rate limiters and affordances. Both are unique to the individual, task and environment. The rate limiters hinder development, the affordances promote development or change in the system (Gibson, 1979). Using the development of walking as an example, several systems are required to be in interaction and 'controlled' to perform the skill (vision, balance, strength, motivation, structural, cognitive, environmental, etc.).

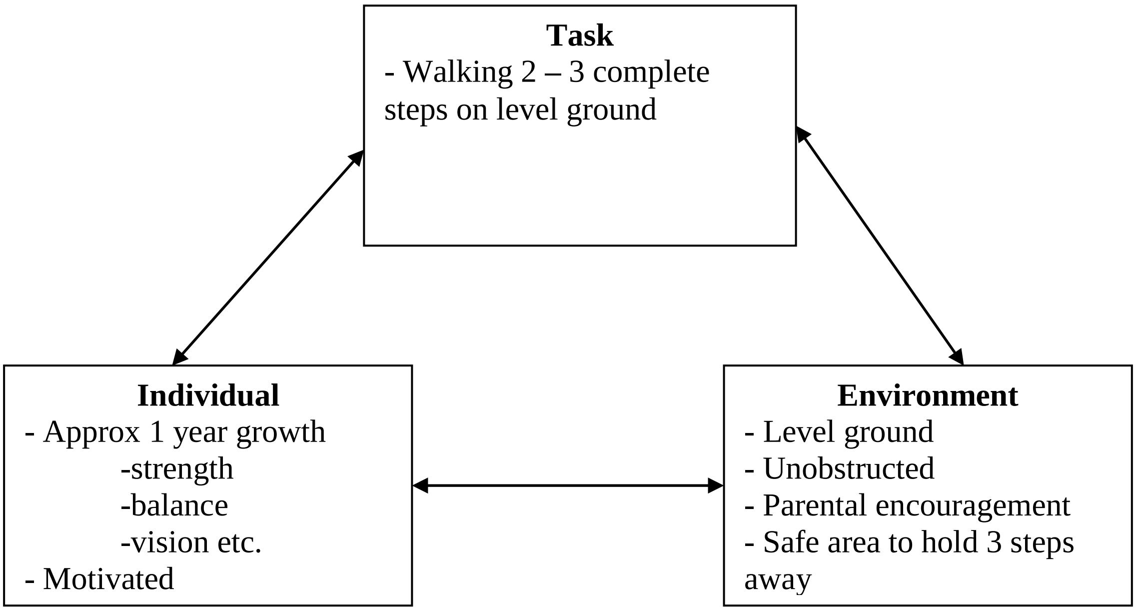


Figure 2.7 Dynamic systems - Walking development

Each of the systems listed under the task, individual and environment could possibly be an affordance (helping performance) or rate limiter (hindering performance). It is only when the last of the systems is 'ready' that the task can be successfully completed. If, for example, each of the systems is ready, though the child has not developed the muscular strength to support their body weight, this rate limiter needs to become an affordance, before he/she can walk successfully.

The second branch of ecological theory that complements dynamic systems is the perception-action approach. This approach suggests that there is a close interaction between the perceptual system and the motor system. The perception of the environment relates to the individual within the environment. The term used to identify an object within a particular environmental setting that the individual perceives allows them to perform a certain task has been called an affordance (Gibson, 1979). An affordance for one particular person in one particular setting may not be the same for another. For example, one person may perceive a pile of books to be small enough to lift (within their own muscular capacity), while another (an infant) would not. This emphasises the relationship between the perception of the environment and body size of the individual. The ecological perspective, however, maintains that an 'executive' would be overwhelmed directing all movement and change. Ecological theory contends that the environmental perception is direct, with the muscles self-assembling into groups reducing the number of decisions needing to be made by higher brain centres (Haywood & Getchell, 2009)

2.2.1 The Fundamental Motor Skills

Magill (1998) defines skills as "a task that has a specific goal to achieve" (p.7). In the context of movement the term motor skill is used and is "a skill that requires voluntary body and/or limb movement to achieve the goal" (p.7). Guthrie (1952) defines being skilled as "the ability to bring about some end result with maximum certainty and minimum outlay of energy or of time and energy".

The fundamental motor skills developed during childhood (2 – 7 years) are the basic components of movement. They include locomotor activities, manipulative activities and stability activities. Each can be in turn classified into initial, elementary and mature stages of development (Gallahue & Ozmun, 2006).

Locomotor activities: a movement pattern permitting exploration through space including, walking, running, jumping, hopping, galloping and skipping (Gallahue & Ozmun, 2006).

Manipulative activities: a movement pattern that permits gross and fine motor contact with objects, including, reaching and grasping, throwing, catching, kicking and striking (Gallahue & Ozmun, 2006).

Stability activities: a movement pattern that place a premium on gaining and maintaining one's equilibrium including, static balance (maintaining equilibrium while the centre of gravity is stationary), dynamic balance (maintaining equilibrium while the centre of gravity shifts for example the forward roll) and axial movements (maintaining balance while bending, stretching, twisting and turning) (Gallahue & Ozmun, 2006).

Development of fundamental motor skills is influenced by a range of factors including maturation, opportunity to practice, encouragement, instruction and the ecology of the environment (Gallahue & Ozmun, 2006). Gaining competence in fundamental movements is a developmental stage in the Gallahue and Ozmun (2006) hourglass model seen in Figure 2.7. The model describes the general development of skill. It is acknowledged, however, that there is scope for intra-individual variability. For example, some fundamental skills develop faster then others and within skills some components develop at different rates. Competency in the fundamental motor skills ultimately leads to the more advanced specialised movement phase (7 – 14 years) in which skills are refined and applied to complex recreational and sporting movements and their lifelong utilization. Gallahue's model has incorporated the phase-like structures of the early motor development models with the more modern dynamic systems approach by including environmental, individual and task systems.

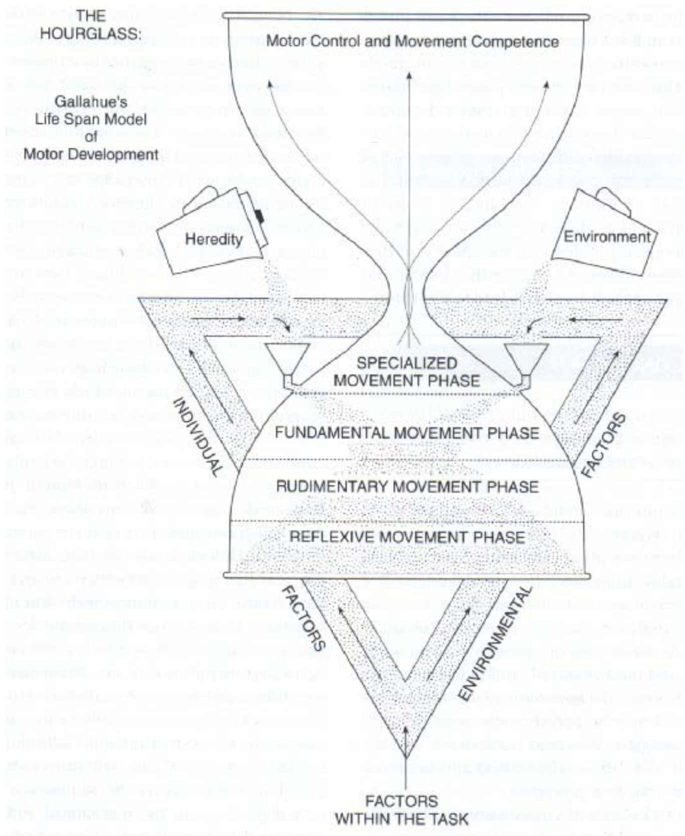


Figure 2.8 A Lifespan Model of Motor Development (Gallahue & Ozmun, 2006) pg 56.

The Gallahue model specifies that the reflexive movement phase begins in utero and continues to approximately 1 year. The rudimentary movement phase can continue to 2 years. Fundamental movements are refined from the age of 2 – 3 years and mature by approximately 7 years and the specialised movements continue to develop to 14 years and above.

The factors that influence the development throughout these phases can be explained using the dynamic systems theory of motor skill development. Motor skills develop within the system consisting of a task performed by the learner with individual characteristics in a specific environment. Within the learner many factors can influence motor development such as motivation, strength and neurological development. Environmental factors are also numerous and include elements such as, equipment, urban setting and instruction (Newell, 1984; Newell, 1986). In addition, a compromise in any or all of these factors limits the rate of motor skill development.

2.2.2 Recent Research Focus

As technology has become more sophisticated in the last few decades, so has the analysis of the movement of children. Some studies have begun using scientific measuring tools and developing measurement techniques to more objectively describe and quantify the characteristics of motor impaired children. Force production, anaerobic performance, walking indices, movement variability and limb movement variability have all been used to describe the performance of motor impaired children in comparison to that of the typically developing (Cintas, Siegel, Furst & Gerber, 2003; Geuze & Kalverboer, 1987; Gueze and Kalverboer, 1994; Lundy-Ekman, Ivry, Keele & Woollacott,1991; O'Beirne, Larkin & Cable 1994; Piek & Skinner, 1999; Raynor, 2001; Rosengren, Deconinck, DiBerardino, Polk, Spencer-Smith, De Clercq and Lenoir, 2008; Volman & Geuze, 1998; Volman, Laroy & Jongmans, 2006; Williams, Woollacott & Ivry, 1992; Woodruff, Bothwell-Myers, Tingley & Albert, 2002).

Raynor (2001) studied the levels of maximum isokinetic/isometric force production, power and coactivation (concurrent activation of both agonist and antagonist muscle groups) in both DCD and control children aged 6-7 and 9-10 years. Children with DCD produced significantly lower max isokinetic and isometric knee extensor and flexor force compared to that of the control group. The DCD children (n = 20) produced less power during both extensor and flexor stages, with the difference between the control group (n = 20) increasing with increasing speed of movement. An increase in coactivation was noted for the DCD children though this was not significant. The lower levels of strength and power were attributed to some degree to the increased levels of coactivation, though the author called for future investigations into muscle fibre distribution, fast/slow twitch ratios and how these are affected by a limited movement experience.

O'Beirne, Larkin and Cable (1994) tested the anaerobic performance of children (n = 24 boys) who were poorly coordinated compared to controls (n = 24). The children who were classified as poorly coordinated using the McCarron Assessment of Neuromuscular Development (MAND) (McCarron, 1982) demonstrated significantly lower peak power, lower absolute and normalised mean power and higher fatigue index (Wingate test). The poorly coordinated children were also slower performing a 50m sprint.

In a recent study that investigated the reliability and concurrent validity of a new motor function test (BAMF) Cintas, Siegel, Furst and Gerber (2003) reported correlations between gait parameters of a pathological population and BAMF scores. Gait speed r = 0.68, Stride length r = 0.71 and duration of double support r = -0.40, were all significantly correlated to the BAMF score. The sample (n = 38), however, only consisted of children diagnosed with osteogenesis imperfecta, a disorder relating to brittle bones due to an inability to produce the required protein (Rauch & Glorieux, 2004). The BAMF is a simple 10-point ordinal scale that identifies the level of both pre and walking development.

An index of walking performance has been developed by Woodruff, Bothwell-Myers, Tingley and Albert (2002) to examine the gait classification of children with DCD. The index was developed using the Sutherland et al. (1988) database for children aged 1-2.5 and 3-7 years. This was used to compare children aged 6 – 7 years with children classified as having DCD. Most of the children with DCD displayed abnormal gait patterns. However, although the means of the spatio-temporal data did not differ between the two groups, children with DCD displayed larger variation around the mean compared to the children from the control database (Sutherland, et al., 1988). This large inter-individual variability indicated that the children with DCD presented with a wide range of gait deficits and that they needed to be investigated case by case. It is impossible to make inferences for the wider population of children with DCD from this very small sample however.

Geuze and Kalverboer (1987) were the first to investigate movement variability and DCD. Children with DCD have been shown have greater movement variability (finger tapping) than a control group (Piek & Skinner, 1999). The authors suggest that the increased variability was due to an increased amount of co-contraction of the agonist and antagonist muscles. This may have impaired the fine control of the timing. Gueze and Kalverboer (1994) also investigated the variability of finger tapping for children with DCD and dyslexia. The DCD children displayed a slight increase in finger tapping variability when compared with those of the control group (approximately 10%). The children with dyslexia were more variable compared with those of the control group on only one of the three tasks measured. Rhythmic coordination of hand and foot and movement variability (finger tapping) has been used to screen children with DCD (Lundy-Ekman, Ivry, Keele & Woollacott, 1991; Piek & Skinner, 1999; Volman & Geuze, 1998; Volman, Laroy & Jongmans, 2006;

Williams, Woollacott & Ivry, 1992). These findings serve as a basis for further study into movement variability and motor impairment.

Rosengren, Deconinck, DiBerardino, Polk, Spencer-Smith, De Clercq and Lenoir (2008) measured the variability of both shank and thigh movements of 10 children diagnosed with DCD (mean = 7.4 years, S.D. = 0.86) and 10 age-gender matched controls (mean = 7.5 years, S.D. = 0.85) while treadmill walking. Children with DCD exhibited greater variability of movement in both segments (greater at the shank) then the control group. It was suggested that the children with DCD had significantly greater difficulty producing a consistent gait pattern. Once again, the small sample size and treadmill protocol limit the inferences that can be made to the wider population and to walking as a fundamental skill.

Fundamental motor skills are the building blocks for the more specific motor skills required for lifelong utilisation (Gallahue & Ozmun, 2006). The following sections of this Chapter will discuss the use of gait analysis as a tool for the description and process underlying the specific movement pattern of walking. The majority of children do not have any difficulty developing a competent walking pattern, and thus, are able to ambulate successfully around their environment. The development of gait analysis in recent decades, however, has allowed for gait to be measured with increasing sensitivity. This has enabled researchers to identify otherwise imperceptible areas of impairment (e.g., timing and balance – Hausdorff, Zemany, Peng & Goldberger, 1999) during development, which can provide insights into the control of walking and maybe other fundamental motor skills.

2.3 Current Measurement – Gait analysis

2.3.1 General Gait

Having the ability to successfully ambulate over both short and long distances is essential for maintaining health throughout the lifespan. Providing the independence to interact with the environment, walking is one of the most important motor skills to master for a developing child. With the invention of instrumented gait analysis, clinicians and researchers have been able to diagnose, prescribe intervention and identify deficits which impede development (Whittle, 1996). In order to understand the various problems associated with walking it is first necessary to understand the mechanisms behind the development of normal gait. Gait may be described in relation to the 'gait cycle'. One complete gait cycle contains a stance phase followed by a swing phase (Figure 2.9). Throughout the cycle there are periods where there is either one foot (single support) or both feet (double support) in contact with the ground (Whittle, 1996).

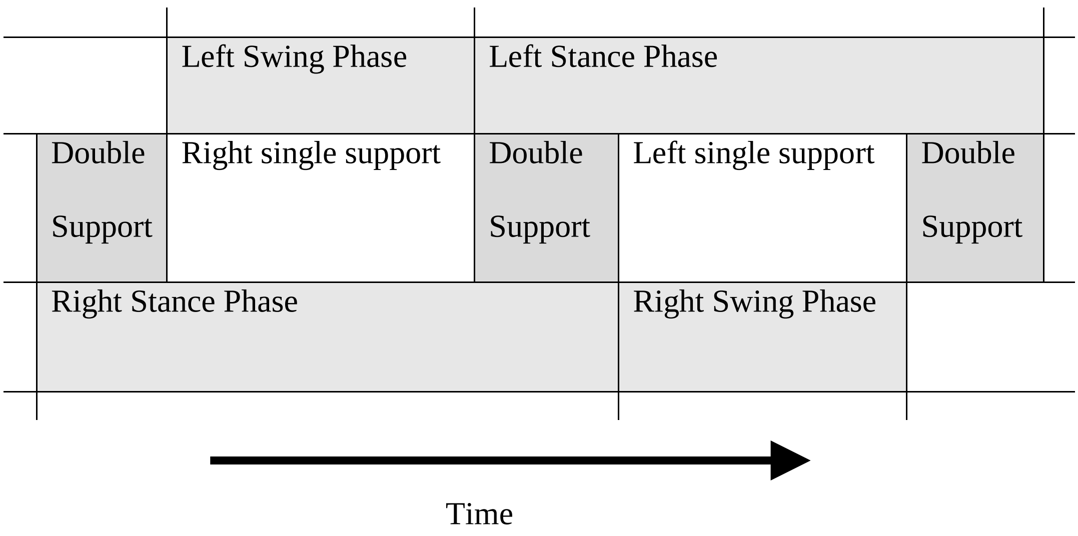


Figure 2.9 Timing of stance and swing phases of the gait cycle.

Two basic principles govern the act of walking, 1) continuing ground reaction forces that support the body, and 2) periodic movement of each foot from one position of support to the next in the direction of progression.

Inman, Ralston and Todd 1981 (cited in Rose & Gamble, 2005) hypothesised that "the human body will integrate the motions of the various segments and control the activity of the muscles so that the metabolic energy required for a given distance walked is minimised" (p.1). In most cases interference with the normal relationship between segments increases the metabolic cost. These can occur as the body moves over the support limb movement in each of the three planes occurs. The body moves up and down a few centimetres each step, weaves side to side and slightly slows down and speeds up (Inman, Ralston & Todd, cited in Rose & Gamble, 2005). These variations translate to a stride that, in any one cycle, can widen or narrow, shorten or lengthen and (or) quicken or slow.

2.3.2 The Development of Gait

Sutherland et al. (1988), in his landmark paper, detailed the gait pattern of children and outlined the changes from early childhood to being a mature walker. Six areas of immature walking were found to differ from those of the adult pattern:

1) Wider walking base
2) Slower speed, smaller steps and a shorter cycle time (higher cadence)
3) Early walkers do not contact the ground with a pronounced heel-strike. The mid-foot makes initial contact.
4) Less flexion of the knee during the stance phase
5) Swing leg is externally rotated
6) Absence of reciprocal arm swing.

The first and last characteristics were said to mature by age 4 years, the 3rd, 4th and 5th by two years of age. The speed, step length and cycle time continued to mature to age 15 years.

Early walking patterns can also be characterised by the blocked movement of limbs (arms and trunk moving together) and co-activation of muscles. This in part can be explained by simplification of the motor problem (reduction in degrees of freedom to be controlled). This in turn limits the components of the skill to be learned (Newell, 1996). The outcome, in terms of the stride characteristics, is a shorter and wider stepping pattern to compensate for the relative instability (Sutherland et al., 1988). Young children lacking motor control and limb coordination display inconsistent walking speed and also actively explore various movement patterns while walking, often producing a more variable walking pattern (Bril & Breniere, 1998; Clark, Whittle & Phillips, 1998; Diop, et. al., 2004).

Of relevance to the parameters of the current study, the walking velocity, stride length and single support time increase while cadence and double support time decrease with increasing age (Sutherland et al., 1988). The growth of leg lengths and height contribute to a further increase in step length and velocity (Beck et al., 1981; Sutherland et al., 1988). Each of these spatio-temporal parameters continue to change with growth throughout childhood. The rate of change is significantly slower after three years of age (Preis, Klemms & Muller 1997; Sutherland, 1988; Thelen & Cooke, 1987; Wheelwright et al., 1993).

The developing child walks with varied limb movements in comparison to adults. The head has minimal movement initially, the trunk and upper extremities exhibit greater lateral sway with a wider base of support to compensate, greater anterior pelvic tilt, increased hip flexion and increased knee flexion during stance (Kermoian, Johanson, Butler & Skinner, 2006). Early walkers with 3 to 6 months of walking experience have been shown to have increased energy expenditure in comparison to teenagers and adults. The greater muscle activity/co-contraction of the agonist and antagonist muscle groups and larger ground reaction forces upon foot contact are thought to contribute to the elevated energy required to walk (Kermoian, Johanson, Butler & Skinner, 2006).

The description of 'normal' walking for children is limited due to wide range of variability within the various age groups. Rates of growth and motor skill acquisition are widely varied within 'normal' children (Vaughan, Langerak & O'Malley, 2003). Normal walking speed may vary from one attempt at walking to the next. The selection of 'normal' walking speed is variable among children, and this impacts on the variability of the measurement (van der Linden et al., 2002). In an attempt to minimise the effect of limb length and height differences, Hof and Zijlstra (1997) have applied normalisation scaling to raw gait data. Therefore, any differences in the parameters of gait can be attributed to factors other then height and leg length. This might include neurological, proprioceptive, visual and kinaesthetic deficits.

Thelen et al. (1989) applied a dynamical systems approach to the development of locomotion. It was noted that locomotion is a result of many interacting complex processes, such as, sensory, motor, perceptual, integrative, respiratory, cardiac and anatomical systems. Gaining control over the various degrees of freedom precedes movement competence and mature gait. The dynamic systems perspective forms the basis for the description of gait development that follows.

2.3.3 Early Gait Development

Walking patterns may begin to develop prenatally. Alternating leg movements (similar to walking) develop in the infant around the 16 week embryonic age (De Vries et al., 1982; Prechtl, 1984). As the neural pattern (walking/stepping) is evident it has been suggested that the primary rate limiter on emerging locomotor behaviour is an immature posture, thus upright stability is not achieved (Shumway-Cook & Woollacott, 2001). This is also apparent when looking at the stepping pattern that newborn – two month old infants display, which disappears then re-emerges later at the onset of self-generated locomotion (Forssberg, 1985; Prechtl, 1984; Thelen et al., 1989). This exemplifies the non-linear development of motor skill. It is recognised that the main constraint to the development of locomotion is primarily limitations in balance control and possibly also limitations in strength (Frossberg, 1985; Thelen et al., 1989; Woollacott et al., 1989). It has been suggested that there are three requirements to afford the development of successful locomotion:

(1) a rhythmic stepping pattern (progression),

(2) the control of balance (stability), &

(3) the ability to modify gait (adaptation) (Shumway-Cook & Woollacott, 2001).

It is reasonable to contest, therefore, that deviation in any or all of the rhythm, balance control, or the adaptability limits successful walking. The effect of variability in the stepping pattern (rhythm) is summarised in section 2.3.4.

It has already been noted that walking development may be multifaceted in nature (Thelen, 1989). From a dynamical systems perspective, new forms of motor behaviour appear as a result of dynamic co-operation of various factors linking the subject, task and environment. Using the first steps of an infant as an example, the task constraints (2 to 3 continuous steps, unassisted, unhurried, etc) are dynamically integrated with environmental affordances (level, soft flooring, items to grasp in immediate surrounds, external motivation from parent, etc) and individual affordances (rhythmic stepping motion, strength, internal motivation, etc) to produce independent walking. The optimization of these factors minimises the cost to the system. Jeng, Liao, Lai and Hou (1997) state that both children (7-12 years) and adults naturally adopt a walking frequency and movement pattern that minimises physiological cost, asymmetry, and variability of inter-intra limb coordination (Holt, 1991; Holt, 1995; Jeng, Holt, Fetters & Certo, 1996). Jeng et al. (1996) suggest that physiological cost measures physiological function, while symmetry and stability are measures of neuromuscular coordination. They measured both temporal and angular bilateral parameters. Further to the three requirements of the development of successful walking (Shumway-Cook & Woolacott, 2001), three optimality criteria have been proposed for non-disabled human walking. These criteria relate to the refinement of and already mature walking pattern which should: (1) maximize mechanical efficiency conservation, (2) minimize asymmetry in lower limb movements, and (3) minimize variability of interlimb and intralimb coordination. One of the conclusions from this study was that walking is determined by the cooperation of multiple systems including sensory, motor, perceptual, integrative, respiratory, cardiac and anatomical.

2.3.4 Gait Maturation

Using the Dynamic Systems model to describe the maturation or mastery of a skill, all degrees of freedom must be controlled in each of the systems required for movement. Each system however, develops and matures at a different rate. Gait can therefore only be mature when the child has gained control or fully developed the last of the systems. Various authors have investigated each of the systems involved in the development of gait and determined the age of maturation or optimisation of each.

Looking at the general rate of fundamental motor skill development it has been said that most children reach the mature stage of fundamental skill development at age 7 years (Gallahue & Ozmun, 2006). Using more specific gait measurements some authors have supported this as the age of maturation, however, both earlier and later ages have found some support as outlined below.

Table 2.2 Summary of research findings on maturation of gait parameters

Author (Year)	Sample	Gait Parameters	Age of Maturation
Dierick, Lefebvre, van den Hecke & Detrembleur (2004)	N = 21, age 1 – 9 years (Belgium)	- Centre of mass vertical amplitude - length from hip to ground Centre of Mass - frontal plane amplitude Centre of Mass	4 years 7 years
Sutherland, Olshen, Biden & Wyatt (1988)	N = 309, 10 age groups 1 – 7 yrs	Muscle and kinematic analysis	7 years
Langerak, Leskens, Deib, Martinez & Vaughan (2001)	N = 204, age 14 – 169 months (1 – 14 years)	Scaled gait parameters: stride length, cadence, base of support/pelvis span, single limb stance	6.7 years (80 months)
Desloovere et al. (2004)	N = 65, 3-4 yrs, 5-6 yrs, 7-8 yrs, 9-11 yrs & 16-17 yrs (Belgium, Australia)	EMG muscle activity	3 years
Jeng, Liao, Lai & Hou (1997)	N = 45 children (3 – 12 yrs) N = 9 Adults	Walking frequency	7 years
Ganly & Powers (2004)	N = 15, 7 yr olds N = 15, adults	Joint angles, moments and powers	7 +, Most variables adult like at 7, however ankle power not. Children lack neuromuscular maturity.
McFadyen, Mlouin & Dumas (2001)	N = 8, 7-8 yrs	Kinematic, kinetic, muscle mechanical power & EMG during obstacle avoidance	8+, Clearance of moderate obstacle ‘adult like’, hip, knee, ankle sagittal interaction not yet ‘adult like’

Two studies have presented evidence to suggest that gait is still maturing past the suggested seven year mark. Ganley and Powers (2004) suggested that kinetic differences (power generation and absorption) observed at the ankle were a result of a lacking neuromuscular maturity. Further work identifying the rate of maturation of the various systems involved in walking can aid clinical practitioners recognize appropriate screening tests and intervention for children with maturational delays.

An interesting side to the age of the maturation of walking can be found in the much earlier Yarmolenko (1931) paper investigating the 'motor sphere of school-aged children'. Among other tasks (jumping, grasping, static and dynamic balance tasks) Yarmolenko looked at the speed, exactness, strength and motor endurance of walking. The following figures represent his findings.

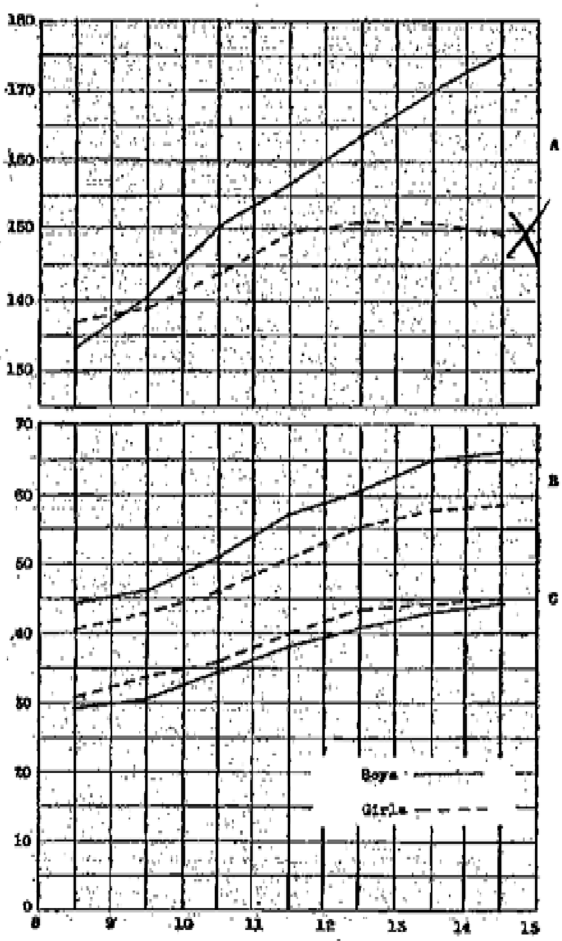


FIGURE 2
SPEED COEFFICIENTS
A—lying-rising (number of movements in 10')
B—walking (number of meters walked in 1')
C—grasping (number of movements in 10')

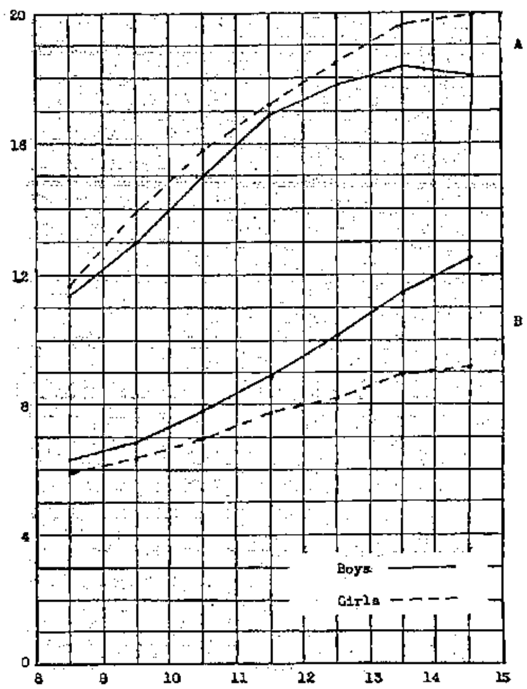


FIGURE 5
EXACTNESS COEFFICIENTS
A—exactness of walking (number of meters with one mistake)
B—exactness of ball-throwing

Figure 2.10 Yarmolenko (1931) motor speed and exactness coefficients

Both motor speed and exactness figures show that there was no noticeable plateau in the walking performance before 15 years of age. This finding contradicts the majority of more current research suggesting gait is largely mature by 7 or 8 years of age. The measurement tools used impact greatly on the concept of 'mature' walking.

2.3.5 Gait Variability

Historically, a number of measurements have been used to assess gait function across the lifespan and across various pathologies (Banta, 2001). The simplest form of analysis, step length and time, walking velocity and cadence, can be measured quite easily and are prevalent in the literature (e.g., Dusing, Thorpe, Andrew, Gildea, Heath, Stange & Tompkins, 2005; Sutherland, Olshen, Biden, & Wyatt, 1988). More complex measurements have since been used, such as ground contact and joint forces, muscular activity and centre of mass projection (e.g. Callaghan, Patla & McGill, 1999; DeLuca, Davis, Ounpuu, Rose & Sirkin, 1997). In an attempt to explain more of the underlying processes of walking, the variability of the gait pattern has been measured. Two forms of variability measurements exist (Davids, Bennett & Newell, 2006). The first 'outcome variability' determines how variable individual measurements are from foot placement data, such as step length and time. The second, 'joint variability', uses the motion of joints relative to each other throughout a number of cycles (Davids, Bennett & Newell, 2006).

The following sections will outline the use of 'outcome variability' as a measure of gait stability. Two general methods are used to assess gait variability measuring footfall placement data. The first method which is the major focus of this investigation involves the calculation of the standard deviation (SD) and or the coefficient of variation (CV) of numerous footsteps of continuous walking. Using step length as an example, walking over a distance of 50 metres at a steady speed, each individual step is not exactly the same length. Measuring either the SD or CV of individual step lengths over the 50 metres gives an estimation of gait variability.

The second method used to measure gait variability involves using complex mathematics to determine long range relationships or patterns across thousands of steps with fractal dynamic calculations (Hausdorff, 2005). This method is beyond the scope of this investigation, although the outcomes from previous investigations using this measure will be reported.

2.3.5.1 General Gait Variability

The measurement of the variability of locomotion is an emerging area of investigation; it provides an outcome measure of the function of the neuromuscular control mechanisms and may contribute to the understanding of gait control. Movement variability has been used as a discriminating factor between non-impaired and those with various clinical pathologies limiting the ability to accurately adopt a rhythmic stepping pattern (Gabell & Nayak, 1984; Heiderscheit, 2000). Gabell and Nayak (1984) reported variability in stride characteristics as a rate limiter to successful locomotion, whereas variability in joint coordination could be an essential component, affordance, providing the necessary flexibility to execute various tasks (Clark & Phillips, 1993; Turvey, 1990; van Emmerik, 1999).

Initial studies into the usefulness of measuring the stride-to-stride variability of gait uncovered that increasing the task demand increases the outcome variability of the walking pattern (Gabell & Nayak, 1984). Simply, the harder the task, the more stress the system is under and this can be reflected in a greater amount of variability.

The simplest ways to alter the demand of walking are to increase or decrease the speed or to constrict the normal frequency of stepping outside a comfortable range. Sekiya, Nagasaki, Ito and Furuna (1997) investigated the relationship between optimal walking and variability. The study specifically examined the spatial variability in step length and width during free walk at a variety of speeds, as well as during forced walking with an imposed cadence. It was noted that variability in step length was at a minimum when walking speed, cadence, and step length were close to those of preferred walking speed. Overall it was concluded that free walking speed was optimal for minimising both temporal and spatial variability. Walking at a self-selected normal pace is also optimal for reducing energy expenditure (Zurrugh & Radcliffe, 1978), and attentional demand (Zurrugh, Todd, Ralston, 1974). Therefore, the increased attention required to walk at speeds other then normal can be categorised as a rate limiter.

Not only do increases and decreases from normal walking speeds increase variability, increases can also be seen when in transition from one state of movement to another such as walking-to-running (Brisswalter & Mollet, 1996; van Emmerik, 1999), further evidence to suggest that increased variability reflects that the locomotion system is perturbed.

Specific inferences regarding the control of walking have been made when studying the direction of instability caused by limiting sensory input. Bauby and Kuo (2000) looked at the lateral stability of walking with eyes open (EO) and eyes closed (EC). Lateral variability was found to be greater than the fore-aft variability (step width and length respectively). This result was explained by the lateral balance requiring stabilisation from visual-vestibular feedback, though fore-aft required little or no feedback from this system. This was evidenced from the EC condition increasing the lateral variability measurements. The authors suggest as there were large differences in the lateral variability associated with the EC condition that it may provide a useful measurement of sensorimotor control.

Similarly, Thies, Richardson and Ashton-Miller (2004) investigated the effects of environmental affordances and rate limiters on gait. Surface irregularity and lighting were changed and step variability measured. Healthy elderly and young women were tested over an uneven walkway in various lighting conditions. Gait variability parameters were calculated using SD. In both age groups the irregular surface type significantly increased the step width variability, step length and step time variability, while light level had no effect. The increased task difficulty was reflected in a more variable walking pattern in both the young and older women. As people age the simple task of walking becomes increasingly difficult. The following studies outline the relationship between decline in elderly gait and increasing gait variability.

2.3.5.2 Elderly Gait Variability

The majority of papers in stride-to-stride gait variability have explored the link between the decline of either elderly or pathological gait patterns. Generally, increased stride-to-stride variability is an indication of a loss of stability.

Studies comparing healthy young adults and healthy older adults have found that the variability of walking increases with increasing age (Grabiner, Biswas & Grabiner, 2001). Older adults have exhibited increased step width variability in comparison to younger adults (Owings & Grabiner, 2004). Step width variability was further used to correctly classify, using discriminant analysis, 16 of 18 young adults and 7 of 12 older adults (Wilk's lamda = 0.854, p = .037) (Owings & Grabiner, 2004b). The variability in step length was also measured and was smaller then the amount of step width variability (sd = 1.56± 0.94cm & sd = 2.25± 0.64cm respectively).

Brach, Berthold, Craik, VanSwearingen & Newman (2001) investigated the spatial gait variability (sL and sWidth) in older adults and its relationship with gait velocity. Step length variability was found to be greatest in those who walked slowest, while step width variability was greatest in those who walked fastest. This, in part, may be due to the faster walkers being constrained by the limit of step length, and therefore, altering step frequency and step width when perturbed. The slow walkers were less constrained by the length of step and consequently this translated to greater variability. Further investigation into the used of both measurements was advocated to determine disability risk and the effectiveness of therapeutic intervention.

2.3.5.3 Falling and Pathology Gait Variability

A link between increased falling risk or fear of falling and increasing gait variability has been established in the following papers. However, the mechanisms leading to falls is still unclear. One explanation may be that deficits in the underlying neuromuscular control system produce a more varied stepping pattern. This then, translates to a more inaccurate foot placement, which may increase the likelihood of hitting an obstacle.

Gabell & Nayak (1984) noted increases in stride-stride variability within subject, which is regarded as an indicator to unsteady gait, and as a predictor of falling. Specifically, they split the variability up into balance (stride width and double support time) and gait patterning (step length & stride time). Increased stride width and double support time variability was associated with balance impairment. Larger step length and stride time variability related to impairment with the production of a consistent (stable) gait pattern. Hausdorff, Edelberg, Mitchell, Goldberger & Wei (1997) found that temporal gait variability of elderly fallers was significantly higher than that of non-fallers. Maki (1997) & Nakamura (1996) suggest increased variability in spatial parameters was associated with increased falling risk.

Maki (1997) hypothesised that pre-existing fear of falling would be associated with increased stride length and speed, increased stride width and double support time and future fall risk would not. Although, the stride-to-stride variability was hypothesised to have a causal link to future falls. A variable foot placement pattern may increase the likelihood that an obstacle may be hit, due to the inaccuracy. The measured gait parameters were recorded from two walkthroughs over an 8m walkway, with footswitches recording temporal data and an "ink and paper" method recording the spatial parameters. A logistic regression was performed to identify the best independent predictor of future falling, which was stride-to-stride variability in velocity (71%).

Herman, Giladi, Gurevich & Hausdorff (2004) compared the gait patterns of older adults with a ‘cautious gait’ and controls. Cautious gait was classified as having mild to moderate slowing, reduced stride length and a wider base of support (Nutt, 2001). The patients with cautious gait were classified as having a higher-level gait disorder (HLGD). Gait variability was significantly higher in HLGD subjects compared to controls. In the HLGD group the gait variability was not associated with age, gender, MMSE score, muscular strength, balance, cerebellar signs, but was significantly associated with scores from a fallers vs. non-fallers scale. It was also found that patients who walked slower had increased gait stride-stride variability

High stride-to-stride variability has also been related to measurements that contribute to the stability of gait. Hausdorff, Rios & Edelberg (2001) measured the temporal stride variability of older adults over a one-year period, relating it to the increased risk of falling. They found that increased gait variability was related to various measures that contribute to a high falling risk, such as strength, balance as well as measures of vitality and mental status. This was thought to reflect the similar nature of the level of neural control required to perform each activity, therefore stride time variance could be viewed as a final integrated output of the locomotor system.

Variability has also been associated with neurological diseases, such as Parkinson's and Huntington's. Both patient groups displayed increases in stride-stride variability in stride time and also in double support time (Hausdorff, Cudkowicz, Firton, Wei & Goldberger, 1998). Both spatial and temporal characteristics have shown to be more variable in adults with cerebella ataxia, subcortical arteriosclerotic encephalopathy and congestive heart failure (Hausdorff, 1994; Palliyath, 1998; Ebersbach, 1999) as well as children with spastic Cerebral Palsy (Steinwender, et.al, 2000).

Niechwiej-Szwedo, Inness, Howe, Jaglal, McIlroy & Verrier (2007) looked at the changes in gait variability for patients with traumatic brain injury (TBI). Compared to controls patients with TBI showed significantly greater amount of gait variability (CV %) in step time and length. The variability also increased with the complexity of the task, as a function of fast walking and eyes closed conditions. Both controls and TBI groups showed increased step width variability during the eyes closed condition which was said to reflect the greater challenge to maintain dynamic stability during walking.

Dingwell & Cavanagh (2001) examined the relationship between patients with sensory loss and locomotor variability in both temporal and spatial dimensions. They found that patients with sensory loss displayed a slight increase in gait variability though the sensory loss was not significantly related to gait variability when range of motion, speed, strength were taken into account. It was noted that while variability may be associated with an increased risk of falling, its biomechanical role in instigating falls was not understood. One explanation offered was that even though an increase in variability may not indicate a decrease in dynamic stability it may indicate a loss in the precision of movement (fine motor coordination). Therefore, increases in the variability of foot placement might result in more chance of hitting an obstacle, therefore falling. This is consistent with the cepholacaudal/proximodistal order of motor development. Control of the trunk, head and neck precede the control of the extremities, when the decline during old age occurs it begins with loss of control of the fine movement in the extremities (Gallahue & Ozmun, 2006).

2.3.5.4 Child Gait Variability

Only few studies to date have investigated the degree of variability associated with children's walking patterns. The following papers show that children decrease their stride-to-stride variability with increasing maturity. Increased variability also has been suggested as an outcome of a system in transition due to morphological or skill development. Using a lifespan developmental model, the maturational improvement in walking during childhood may provide a mirror of the decline in old age. The increase in stride-to-stride variability in gait parameters reported previously in elderly and pathological populations mirrors the decrease in variability associated with child walking maturation.

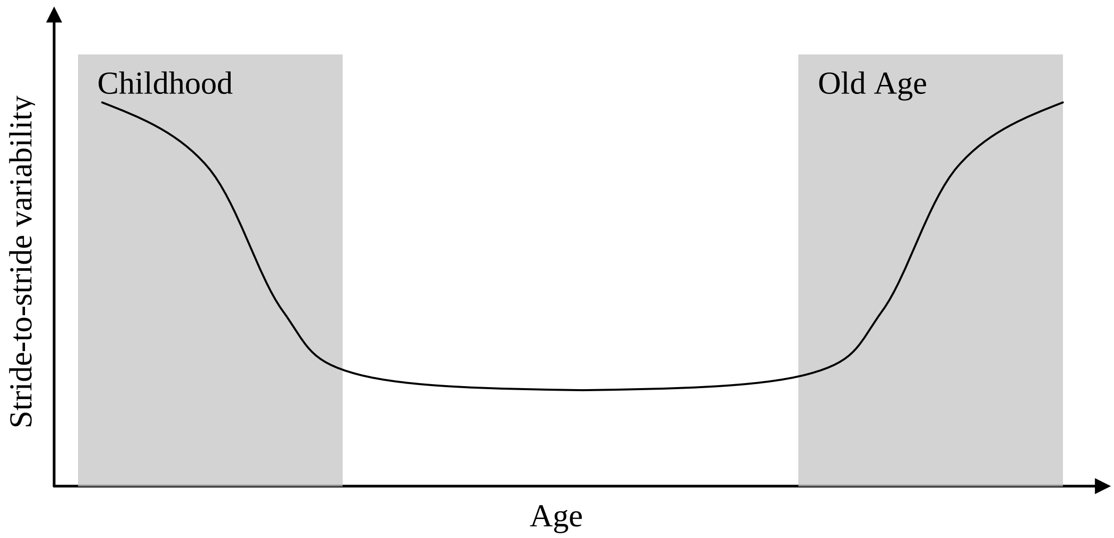


Figure 2.11 Lifespan development and stride-to-stride variability

Cheron, Bouillot, Dan, Bengoetxea, Draye & Lacquaniti (2001) investigated the intersegmental coordination of the lower limbs and trunk with respect to the vertical. Twenty-one children from 11 to 114 months of age and 19 healthy adults were measured. It was noted that the intersegmental coordination and trunk stability are immature at the onset of independent walking though mature quickly during the first few weeks of locomotion. The maturation of the individual patterns of the segments develops at a much slower rate, from months to years. This suggests that the toddler can successfully walk with immature coordination of the lower limbs. The maturation of the kinematics of the child minimises the energy expenditure approaching adulthood. The large stride-to-stride variability displayed by toddlers may allow for an exploration of their environment allowing the lower limbs to 'calibrate' the sensory motor system through proprioception. The results suggest that maturation of gait has a rapid early phase, followed by a gradual refinement in parallel with morphological and neuronal maturation.

Clark & Phillips (1993) investigated the development of locomotion with regard to the dynamical systems approach to motor control. The dynamical systems approach covers four areas of developing skills, constraints, self-organisation, patterns and stability. A stable pattern is low in variability; increasing variability indicates an increasingly unstable system. This increased variability of the system is characteristic of a system in transition eg, crawl – walk. New walkers were found to have a 50% temporal phasing of inter-limb coordination though it was highly variable around the mean. New walkers displayed 9% variability around the mean, this decreased with age down to just over 3% at six months of unassisted walking, which compared to an adult was approximately 1.5% (Clark et. al., 1988). In the same study, while a researcher supported the new walkers the variability in the temporal phasing decreased to that of a one month old, suggesting that posture is one of the limiting factors to the early development of gait.

Looper, Wu, Barroso, Ulrich & Ulrich (2006) measured step length and width variability in typically developing children (n = 9), new to walking, and children with Down's syndrome (n = 6). It was found that the children with DS exhibited larger variability in step length variability though not step width variability.

Hausdorff, Zemany, Peng and Goldberger (1999) used foot switches, to measure the timing of foot placement, while children walked 800m around a running track to assess the stride-stride variability in gait cycle duration. Three age groups (3-4, 6-7 & 11-14yr olds) were compared. It was found that the variability decreased significantly throughout the increasing age groups. This finding was also evident when the gait patterns were normalised for both height and leg length. Fatigue experienced by younger children was taken into account using detrending analysis.   The authors stated that studies that include assessment of motor control and balance as well as other aspects of the locomotor control system may help to clarify the role of potential contributing factors to the development of mature gait. It was suggested that the children may exhibit different degrees of motor control development which may explain the differences in gait variability between the age-groups. Further, it was suggested that the dynamics of gait may provide a means to quantify the stage of maturational development. Gait may be 'mature' when all aspects are fully developed, displaying a minimal amount of variability.

One of the conclusions from Wilson's (2005) review of DCD assessments and treatment was that there was a need to develop new instruments that better reflect current motor control thinking. Specifically, he called for better measures that index variability of movement skill between children. This therefore became a research aim of the current study.

Gait, as one of the most fundamental of motor skills has been used regularly in the past to evaluate the movement competence of individuals across the lifespan. The rate of maturation of various aspects of gait performance is well documented. The majority of investigators suggest that child gait resembles an adult like form around seven years of age. There is evidence however, that children could still be developing their walking patterns into their teens. One of the aims of the current study was add to the understanding of motor development using the measurement of gait variability.

2.4 Identifying Motor Impairment in Children

Wright (1997) and Henderson and Barnett (1998) have reviewed the history of the study of motor impairment in children. They noted that the terms used to identify children with motor impairments have varied in part due to the focus of the research (clinical, educational or scientific) (Table 2.3), an analysis of this three way classification is appropriate. A consensus in the earlier literature was to use ‘Clumsy’ as the descriptor. However, in line with prevalent educational thought other terms have been used in order to remove the negative ‘stigma’ of being labelled ‘clumsy’. These terms such as Developmental Coordination Disorder and Motor Impairment have become more commonly used.

Table 2.3 History of motor impairment terminology

Terms	Authors
Clumsy Children	British Medical Journal (1962)
	Gordon (1969)
	Dare and Gordon (1970)
	Morris and Winter (1975)
	McKinlay (1978)
	Keogh et al. (1979)
	Knuckey and Gubbay (1973)
	Henderson (1987)
	Lord and Hulme (1987)
	Hall (1988)
	Henderson et al. (1991)
	Losse et al. (1991)
	Barnett and Henderson (1992)
	Dwyer and McKenzie (1992)
	Geuze and Kalverboer (1994)
	Schoemaker and Kalverboer (1994)
Clumsiness	Gubbay (1965)
	Henderson and Hall (1982)
	Van Dellen et al. (1990)
	Powell and Bishop (1992)
	Cantell et al. (1994)
Clumsy child syndrome	Gubbay (1975)
Coordination problems	O'Beirne et al. (1994)
Coordination difficulties	Sugden and Henderson (1994)
Physically awkward	Wall (1982)
	Wall et al. (1990)
Motor Infantilism	Annell (1949)
Motor coordination problems	Maeland (1992)
Motor coordination difficulties	Roussounis et al. (1987)
Poorly coordinated children	Johnston et al. (1987)
Motor defectives	Yarmolenko (1933)
Motor Impaired	Whiting et al. (1994)
Movement skill problems	Sugden and Sugden (1991)
Movement problems	Wright et al. (1994)
Movement difficulties	Henderson et al. (1989)
	Sugden and Keogh (1990)
Perceptuo-motor dysfunction/difficulties	Laszlo et al. (1988)
	Domrath (1968)
Dyspraxia	Henderson and Sugden (1991)
Developmental dyspraxia	Denckla (1984)
	Cermak (1985)
	McGovern (1991)
Developmental apraxia	Orton (1937)
	Iloeje (1987)
Developmental apraxia and agnosia	Walton et al. (1962)
Delays in motor development	Illingworth (1968)
	Silva and Ross (1980)
Minimal brain damage	Forsstrom and von Hofsten (1982)
Minimal brain dysfunction	Rasmussen et al. (1983)
Minor neurological dysfunction	Schellekens et al. (1983)
	Touwen (1993)
Developmental coordination disorder	DSM-III-R (1987)
	Henderson (1992)
	ICD-10 (1992a, 1992b, 1993)
	DSM-IV (1994)
	Hoare (1994)
	Missiuna (1994)
	Mon-Williams et al. (1994)
	Rosblad and von Hofsten (1994)
	Sugden and Wright (1995; 1996)
	Williams and Burke (1995)
	Wright and Sugden (1996a, 1996b, 1996c)

Adapted from Wright (1997) & Henderson & Barnett (1998).

While recent consensus has been made with the labelling of children with developmental coordination disorder, the underlying mechanisms are still up for debate. This is either due to (1) ‘real’ variation within children who have already been screened as having DCD or (2) due to the myriad of screening tools previously used identifying different children.

The lack of consensus with regards to the labelling of children with motor impairment in the past has lead to a lack of agreement in the way in which motor impairment has been evaluated. This has, in turn, lead to a lack of consensus to the way in which the prevalence of motor impairment within various populations has been reported ranging from 3.1 % – 35 % (Maeland, 1992 & Walkley, Holland, Treloar & Probyn-Smith, 1993). The following Table 2.3 gives a representation of the degree of variability of both the reporting methods and prevalence over the last 40 years.

Table 2.4 Testing procedure and prevalence of motor impairment.

Author (Year)	Sample/Country	Skills tested	Impairment
Gubbay (1975)	(n = 922) Australia WA	8 motor skills	6% Girls 6.2% Boys
Keogh, Sugden, Reynard & Calkins (1979)	(n = 41) USA	Teacher Checklist Observations Motor Performance Test (MPT)	9% Boys
Short & Crawford (1984)	(n = 1474) Australia SA	Developmental Indicators for the Assessment of Learning (DIAL)	7-10%
Hoare & Larkin (1990a)	Australia WA	MAND	15% mild to marked movement disability
Maeland (1992)	(n = 360) Norway	BOTMP	3.1 % 5.0 % (with borderline)
Walkley, Holland Treloar & Probyn-Smith (1993)	(n = 1182) Australia VIC	Catch, throw, kick, 1 hand strike & 2 hand strike	<65% mastery (35% impairment?)
Revie & Larkin (1995)	(n = 493) Australia	Balance, bounce and catch, hop, run	4.1% (3 of 3) 9.3% (3 of 4 tests)
Piek & Edwards (1997)	(n = 171) Australia	MABC	18.7%
Rose, Larkin & Berger (1998)	(n = 380) Australia	MAND	17.9%
Kadesjo & Gillberg (1999)	(n = 409) Sweden	Medical Motor Dysfunction Score	13.5%
APA (2000)			6%
Kaplan, Dewey, Crawford, Wilson (2001)	(n = 179) Canada	MABC BOTMP DCDQ	14.7%
Sigmundson, Hansen, Talcott (2003)	(n = 54) Norway	MABC	24% Clumsy (15%ile)
Piek et al. (2004)	(n = 238) Australia WA	MAND	11.8%
Hay, Hawes, Faught (2004)	(n = 209) Canada	CSAPPA scale; BOTMP	8.3%
Cairney, Hay, Faught, Wade, Corna & Flouris (2005)	(n = 564) Canada	BOTMP	7.8%
Cairney, Hay, Faught & Hawes (2005)	(n = 578) Canada	BOTMP	7.5%
Cairney, Hay, Faught, Corna & Flouris (2006)	(n = 581) Canada	BOTMP	7.5%
Tsiotra, Flouris, Koutedakis, Faught, Nevill, Lane & Skenteris (2006)	(n = 591 Canada) (n = 329 Greece)	BOTMP	8% Canada 19% Greece
Hands (2008)	(n = 186) Australia WA	SIS – stay in step Balance 1 foot Bounce and catch Hop (distance) 50m run	10.2% Low Motor Competence (DCD)

*Shaded studies represent Australian samples

While it has been important to be able to distinguish children with DCD from those with other disorders such as ADHD, dyslexia and cerebral palsy it has been noticed that not all children classified with DCD show impairments in the same motor skills. Thus, the DCD group is not necessarily a homogeneous one (Hoare, 1994; Wright & Sugden 1996a). A meta-analysis performed by Wilson and McKenzie (1998) revealed several different information processing operations associated with DCD. Pronounced deficits were found in the areas of complex visuospatial, visuoperception, kinaesthesis and(or) cross-modal perception. These variations manifest into behaviours in which children with DCD are actually performing. Macnab, Miller and Polatajko (2001) used a cluster analysis to identify sub-groups of DCD within 62 cases (mean age 9.1 ± 1.3 years). Five subcategories of DCD were identified:

The five subgroups suggested for DCD were:

(1) children with better gross skills than fine, both below normal levels. Standing balance and visual-perceptual skills both within normal ranges;

(2) high scoring on upper limb speed and dexterity, visuomotor integration, and visual perception skills, though were below normal on measures of kinaesthetic ability and balance;

(3) difficulty with both kinaesthetic and visual skills;

(4) poor performance on tasks requiring visual and dexterity skills; &

(5) poor performance for running speed and agility.

The identification of sub-groups of children with DCD further clouds the overall reporting of prevalence. Particular subgroups of children will perform better with particular testing procedures. A child who has poor gross motor skills, though who is within normal limits for the other domains can be labelled as having DCD alongside a child who displays poor fine motor skills with normal performance in the other domains.

Compounding the heterogeneous nature of DCD itself, is the way in which it has been previously classified and screened. Wright (1997) in her review of DCD suggests that the classification of the disorder is contentious according to the two major manuals, ICD-10 (1993) and the DSM-IV (1994). The ICD-10 states that the child must score below 2 standard deviations on a standardised test for motor coordination in comparison to their chronological age. While the DSM-IV states that the disorder must interfere with academic or activities of daily living. The DSM-IV criteria to classify children with DCD is dominant in the literature (Geuze et al., 2001). Until 1999 no study had used the ICD-10 (1993) criteria to classify children with DCD (Geuze et al., 2001).

The DSM–IV has four criteria for defining DCD:

> A – motor coordination is substantially lower than expected given the person's chronological age, and measured intelligence. Delays in achieving motor milestones, dropping things, clumsiness, poor sports performance or poor handwriting
>
> B – the disturbance in criterion A significantly interfering with academic achievement or activities of daily living.
>
> C – disturbance must not be due to a general medical condition (cerebral palsy, muscular dystrophy) and does not meet the criteria for a Pervasive Development Disorder.
>
> D - if mental retardation is present the motor difficulties are in excess of those usually associated with it. (p. 56)

These criteria are limited in their application due to their broad nature. As each are qualitative measures it is difficult to set the cut-off for the detection and classification of DCD. The heterogeneous nature of DCD is also not recognised in either of the classification manuals. The vague nature of the classification criteria of DCD allows lax guidelines to be set for the classification and assessment of such children in real world settings.

Prior to Geuze, Jongmans, Schoemaker and Smits-Engelsman (2001), the DSM-IV criteria for distinguishing children with DCD did not provide specific cut-off values for either clinical or research purposes. Gueze et al. (2001) proposed a 15 percentile cut-off on a standardised fine or gross motor performance test detecting motor problems, and an IQ above 69. These criteria have been used in the literature since (e.g. Kaplan, Dewey, Crawford & Wilson, 2001; Sigmundson, Hansen & Talcott, 2003).

Wilson (2005) in his review of the assessment methods of children with DCD notes that the MABC is the most commonly used test for research papers. It has largely been used as a screening tool to identify children at risk for some type of developmental problems. The Bruininks-Ozeretsky Test of Motor Proficiency (BOTMP) was the most widely used tool for diagnostic purposes by therapists.

Up to the year 1999 approximately 50% of all studies on children with DCD or equivalent used either the MABC or its predecessor the TOMI (Stott, Moyes & Henderson, 1984).

2.4.1 MABC – measurement & critique

The MABC evolved from the Test of Motor Impairment (TOMI) (Stott, Moyes & Henderson, 1972; & Stott, Moyes & Henderson, 1984) and the work of Sugden

(1972) and Sugden and Sugden (1991) to its current form including a quantitative test and a qualitative observational checklist. The MABC quantitative test consists of a battery measuring manual dexterity, ball skills and both static and dynamic balance. The items in each battery progress in difficulty through four age-bands (1) ages 4 – 6 years, (2) ages 7 – 8 years, (3) ages 9 – 10 years & (4) ages 11 – 12 years. A score from 0 – 5 is given of each of the items according to level of competence. A score of 0 indicates complete competence, any score above that indicates errors committed while performing skill. All of the item scores contribute to the total impairment score. The total impairment score is then converted to a percentile rank according the table provided in the MABC manual (Henderson & Sugden, 1996).

Important to note that instruction in the MABC manual is to not label low percentile rank scores with diagnosis other then, movement difficulty, motor impairment, motor delay or developmental coordination disorder (Henderson & Sugden, 1996). The nature of its assessment is based, however, on the product of movement, not the process. This then does not permit a direct classification of a child's 'motor impairment' or 'coordination', both which imply a deficit to the underlying 'process' of movement. The MABC may best only be used to classify children with 'movement difficulty'. The qualitative assessment of the MABC may provide insight to the underlying processes of movement, however. Observations such as the 'control of force', 'timing of actions' and 'spatial accuracy' all provide information regarding the process of movement. While these may be particularly useful for clinicians working with individual children, it is difficult for researchers to make meaningful inferences regarding children with DCD as a group without a valid objective quantitative assessment of that relates directly to the control (process) of movement.

The main alternative to the MABC is the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP), mainly used as a diagnostic tool for clinicians (Bruininks, 1977). The BOTMP consists of 46 separate items scoring children in 8 subsets, running speed and agility, balance, bilateral coordination, strength, upper-limb coordination, response speed, visual-motor control and upper-limb speed and dexterity. Three composite scores are used for assessment of, gross motor, fine motor and general motor proficiency. The labelling of some of the subsets implies that coordination is directly being measured. Although, in some cases the assessment consists of a score of pass or fail (e.g. Bilateral Coordination – tapping feet alternatively while making circles with fingers). Thirty of the fourty-six items are either scored as pass or fail or on a likert scale from 0 – 5 (or less). Meaningful inferences regarding the coordination of the movement process are limited in these items. It has been reported that the BOTMP also underestimates the degree of impairment due to its allowance of verbal prompting from the tester (Barnhart, Davenport, Epps & Nordquist, 2003). The tester is allowed to correct the child verbally during the assessment. A second edition of the BOTMP has been released recently to improve efficiency of testing, equipment quality, ease of administration and importantly, an expanded age range to 21 years. The insensitivity of assessment of both the MABC and the BOTMP has lead to discrepancies in reporting the prevalence of DCD within the same sample. In one study (n = 202) the MABC and the BOTMP only concurrently classified 67 % of the same children as having DCD (Crawford, Wilson & Dewey, 2001). In 2007 the MABC was revised to the MABC-2 (Henderson, Sugden & Barnett, 2007). The revised version of the test has updated norms and an increased age range from 3 to 16 years (Henderson, Sugden & Barnett, 2007).

In Australia the McCarron Assessment of Neuromuscular Development (MAND) has also been used to identify children with motor difficulty (MD) (Hoare & Larkin, 1990a; McCarron, 1982; Piek et al., 2004; Rose, Larkin & Berger, 1998). The MAND is a standardised test which comprised five gross motor skill tasks and five fine motor tasks.

The lack of consensus in the past with regards to the measurement and reporting of prevalence may also be due to the conceptual delay with regards to the testing batteries using the theoretical frameworks of previous decades.

2.4.2 Summary, Aims and Hypotheses

The motivation for the current study arises from 1) preliminary evidence that has given rise to a belief that the measurement of the variability of gait may be used to discriminate children with developmental coordination disorder and 2) from gaps in the current understanding of motor development. The studies measuring gait variability in children have been limited and have generally used small sample sizes, none larger then n = 50 (Hausdorff, Zemeny, Peng & Goldberger, 1999). In some cases, the studies have been performed on a treadmill, a context which can alter the gait pattern (Dingwell, Ulbrecht, Boch, Becker, O'Gorman & Cavanagh, 1999). The majority have examined temporal variables and the spatial gait parameters have yet to be extensively investigated with regards to step-to-step variability measurements. To date, only one study reports both temporal and spatial gait variability in children. Looper, Wu, Barroso, Ulrich and Ulrich (2006) recorded the variability in step length and step width in new typically developing walkers (n = 9) and children with Down's syndrome (DS) (n = 6). The children with Down's syndrome exhibited larger step length variability then the typically developing children. Step length variability was reduced in children with DS following a treadmill training protocol, to the levels recorded in the typically developing children. This finding, although in a small sample, highlights the possibility of stabilising (reducing variability) the walking pattern of children with increased walking experience (training). Gait variability, however, has yet to be reported within the Australian school age population. This study aims to develop an understanding of the link between motor development and gait in primary aged children. Specifically it aims to identify whether, gait variability, may be a useful tool to: (1) determine the level of walking development & (2) screen for motor impairment.

Hypothesis 1.

There will be a significant difference between the gait parameters of velocity, cadence, step length, base of support and double support time for children in each age-band 1, 2 & 3

Hypothesis 2.

There will be a significant difference between the stride-to-stride variability of the gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD) & double support time (SD) for children in each age-band 1, 2, & 3.

Hypothesis 3.

There will be significant differences between the gait parameters of velocity, cadence, step length, base of support & double support time for children classified as motor impaired and for the typically developing children.

Hypothesis 4.

There will be a significant difference between the stride-to-stride variability of the gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD) & double support time (SD) for children classified as motor impaired and for the typically developing children.

CHAPTER III

METHOD I

3.1 Participants

Approval for the study was first gained from the Australian Catholic University Human Research Ethics Committee (V2002.03.28). Information letters were sent out to ten principals of primary schools in metropolitan Melbourne (Appendix A). One school (approximately 300 children enrolled) only responded to the invitation and thus was selected as the participating school. This school was in a middle socioeconomic area. The most popular categories of employment in this area were Professionals 11.0%, Intermediate Clerical, Sales and Service Workers 10.5% and Tradespersons and Related Workers 7.1%. The median weekly income was $800 - $999 per household which was representative of the median household income in metropolitan Melbourne (Australian Bureau of Statistics, 2001).

Information letters and consent forms were sent home with all children from grades prep to grade three (Appendix B). Approximately 55 % of pupils (87: 47 Male, 40 Female) returned the forms and participated in the study.

The data collected from the MABC were used to categorise the children as motor impaired or non-motor impaired. Children were classified as motor impaired if they scored below the 15th percentile. Three age-bands were used for comparison. These were based on the MABC categorisation: (1) 5 & 6 year olds; (2) 7 & 8 year olds; & (3) 9 & 10 year olds. It should be noted that there were no 10 year olds in the sample.

Age, stature and mass were recorded for all participants. These are reported in Table 3.1 according to gender.

Table 3.1 Age, stature and mass according to gender

	Mean (SD)	**Range**
Males (n = 47)		
Age (yrs)	7.8 (1.0)	5.6 – 9.6
Stature (cm)	130.6 (7.3)	116.5 – 144.8
Mass (kg)	27.8 (6.0)	19.4 – 47.7
Females (n = 40)		
Age (yrs)	7.4 (1.1)	5.7 – 9.1
Stature (cm)	128.3 (8.3)	113.0 – 146.3
Mass (kg)	26.5 (5.3)	16.4 – 37.8

No anthropometrical differences were noted between the genders. This was expected as, in general, gender differences are minimal in early childhood (Haywood & Getchell, 2005). The results from both genders were combined for the remainder of the investigation and gender was not considered to be a confounding variable in this study.

Identification of Groups

The mean and standard deviation of the age, stature, mass and BMI measurements for the children tested across the three age-bands was collated in Table 3.2 below

Table 3.2 Age, stature, mass and BMI measurements of children across age-bands

	Age-band 1 (n = 26)	Age-band 2 (n = 55)	Age-band 3 (n = 6)
Age (years)	6.284 (0.39)	8.096 (0.507)	9.197 (0.19)
Stature (cm)	121.5 (5.4)	132.1 (5.5)	138.3 (6.3)
Mass (kg)	22.79 (3.67)	28.6 (5.15)	32.07 (7.0)
BMI	15.35 (1.5)	16.32 (2.44)	16.68 (3.0)

A progressive increase in each of the four measurements taken was observed from Table 3.2

The Movement ABC data for all children were analysed. Of the eighty-seven children tested twenty-five scored below the 15th percentile for the MABC, thus meeting the criteria for being classified as motor impaired. This equated to 28.7 % of the sample.

The age, stature, mass and BMI of the impaired and typically developing children can be seen below (Table 3.3).

Table 3.3 Summary of anthropometric measurements of motor impaired and typically developing children.

	MI (n = 25)	TD (n = 62)
Age (years)	7.791 (1.06)	7.566 (1.023)
Stature (cm)	130.4 (7.2)	129 (7.9)
Mass (kg)	29.31 (7.3)	26.22 (4.65)
BMI	17.11 (3.39)	15.36 (1.45)

Group Matching Process

In order to compare the gait parameters of the motor impaired and typically developing children of varying ages the motor impaired children were matched for gender, age (± 0.5 years) and stature (± 5 cm) with non-impaired participants.

Table 3.4 Summary of anthropometric measurements of motor impaired and age-matched typically developing children.

	MI (n = 25)	TD (n = 62)
Age (years)	7.791 (1.06)	7.630 (0.83)
Stature (cm)	130.4 (7.2)	130.1 (6.9)
Mass (kg)	29.31 (7.3)	27.0 (3.8)
BMI	17.11 (3.39)	15.9 (1.5)

3.2 Measures

Data were gathered from four sources (1) Parent/Guardian questionnaire, (2) Anthropometric measurements, (3) Movement Assessment Battery for Children (MABC), & (4) spatio-temporal kinematics of gait measured by the GAITRite™ walkway.

1. Parent/Guardian questionnaire –

The questionnaire consisted of items relating to the age, presence of any neurological impairments, activity levels, sporting involvement if relevant and weeks/days the child was born pre/post term (Appendix C). No analysis was performed on the items from the questionnaire and it was used only as a screening tool for possible neurological impairments which could impede children's performance on the testing battery. None of the respondents presented with impairment, therefore, no children were omitted from the study.

2. The following anthropometric measurements were collected - stature (m), mass (kg) and bilateral leg lengths (m).

Stature – A portable stadiometer was used to measure the stature of each participant (Mentone Education Centre, Design number 1013522). The measurement was taken from the ground (barefoot) to the vertex of the participant's head. Measurements were recorded to the nearest 0.1 cm.

Mass – Portable electronic scales (The Tanita HD-316 model) were used to measure body mass to the nearest 0.1 kg (Tanita Corporation, Japan).

Body Mass Index –

The Body Mass Index (BMI) was chosen as a convenient, non-invasive method of identifying overweight and obesity. Pietrobelli, Faith, Allison, Gallagher, Chiumello and Heymsfield (1998) used dual energy X-ray absorptiometry (DXA) to validate the use of BMI for the prediction of body fatness in children aged 5-9 years. It was found, using a regression analysis, that BMI independently explained 85% and 89% of between individual differences in total body fat for boys and girls, respectively. One of the limitations of the BMI is its inability to distinguish between a person who has a high fat free mass and a person with a high fat mass. For example, elite weight lifters are often categorised at an 'obese' level due to increased body mass in relation to stature. However, as large increases in muscle mass usually only occur during adolescence (Gallahue & Ozmun, 2006), the chance of misrepresenting children as overweight or obese is reduced. BMI was calculated using the following equation.

$$BMI = \frac{(Mass(kg))}{(Stature(m))^2}$$

Cole et al. (2000) created a sliding scale to identify overweight and obesity during childhood based on z-scores from the adult cut-off values (Overweight = 25 kg.m^{-2} & Obese = 30 kg.m^{-2}). The curves were based on data from children living in 6 countries both male (n = 97,876) and females were included (n = 94,851) (Figure 3.1). Children participating in the current study were classified according to their BMI status (normal, overweight and obese) using this method.

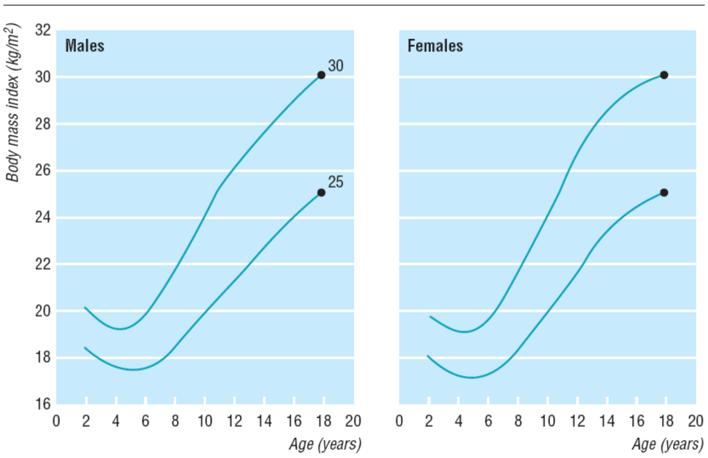


Figure 3.1 International cut off points for body mass index by sex for overweight and obesity, passing through body mass index 25 and 30 kg/m^2 at age 18 (data from Brazil, Britain, Hong Kong, Netherlands, Singapore, and United States) (Cole et. al, 2000)

Bilateral Leg Length –

Leg length was measured bilaterally for each participant. Each leg was measured using a retractable tape measure from the greater trochanter to the floor. Measurements were taken to the nearest 0.5 cm as per the GAITRite instruction manual. Three measurements for each side were taken and averaged for the analysis.

3. *Movement Assessment Battery for Children (MABC) –*

The MABC is split up into four levels based on age-band; (1) 4 – 6 years, (2) 7 – 8 years, (3) 9 – 10 years and (4) 11 – 12 years. Each age-band consists of similar tests progressing in difficulty. As the oldest child was nine only the first three age-bands were used in this study. The following table lists each test showing the progression in task difficulty with increasing age.

Table 3.5. MABC items in each age-band.

Subscale	Age-band 1	Age-band 2	Age-band 3	Age-band 4 (N/A - Study 1.)
Manual Dexterity	Posting coins	Placing pegs	Shifting pegs by rows	Turning pegs
	Threading beads	Threading lace	Threading nuts on bolt	Cutting out elephant
	Tracing (bike trail)	Tracing (flower trail)	Tracing (flower trail)	Tracing (flower trail)
Ball Skills	Catching bean bag	One hand bounce and catch	Two-hand catch	One-hand catch
	Rolling ball into goal	Throwing beanbag into box	Throwing beanbag into box	Throwing at wall target
Balance (static)	One-leg balance	Stork balance	One-board balance	Two-board balance
(dynamic)	Jumping over cord	Jumping in squares	Hopping in squares	Jumping and clapping
	Walking heels raised	Heel-to-toe walking	Ball balance	Walking backwards

Refer to Appendix D for complete record forms for each age-band.

All equipment used in the MABC analysis was provided within the test kit (Henderson & Sugden, 1996). Croce, Horvat & McCarthy (2001) established the reliability and concurrent validity of the MABC. The MABC was validated against the Bruininks-Oseretsky Test of Motor Proficiency (Bruininks, 1978), which was considered the "Gold Standard" of motor ability tests. At least 20 participants were used in each of the four age bands. It was concluded that there was high trial-to-trial reliability for the MABC and concurrent validity, using both the long and short forms of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Croce, Horvat & McCarthy, 2001). Crawford, Wilson and Dewey (2001) also reported moderate agreement with the BOTMP. The MABC manual itself reports sound re-test reliability, across the first three age-bands the median percentage of children who scored the same over a two week period were 90, 84 and 80 % respectively (Henderson & Sugden, 1996).

4. GAITRite™ portable walkway –

The standard length (6 pads) walkway was used for this investigation; specifications are listed in Table 3.6. The walkway contains embedded sensors recording both spatial and temporal individual footfall data. The GAITRite software uses pattern recognition software to identify each foot contact on the walkway.

Table 3.6. GAITRite walkway specifications

Overall Dimensions:	[LxWxH] 457.0 x 90.0 x 0.6cm
Active Area:	[LxW] 366 x 61cm
Weight:	17 kg
Sampling Rate:	80 Hz
Communications:	RS-232, 57.6 Kbps or 19.2 Kbps
Power Requirements:	12Vdc. Use only the power supply provided with your system.
Number of Sensors:	13,824 sensors are placed on 1.27cm centers arranged in a 48x288 grid.
Sensor:	1cm square, dual control.
Walkway Indicators:	Green light = Power Indicator, Yellow light = Program Status Indicator
Top cover:	Vinyl with square thread reinforcement. Waterproof and chemical resistant.
Bottom cover:	Open cell foam rubber. Avoid contact with any liquid.

The set-up of the GAITRite system is represented below in Figure 3.2

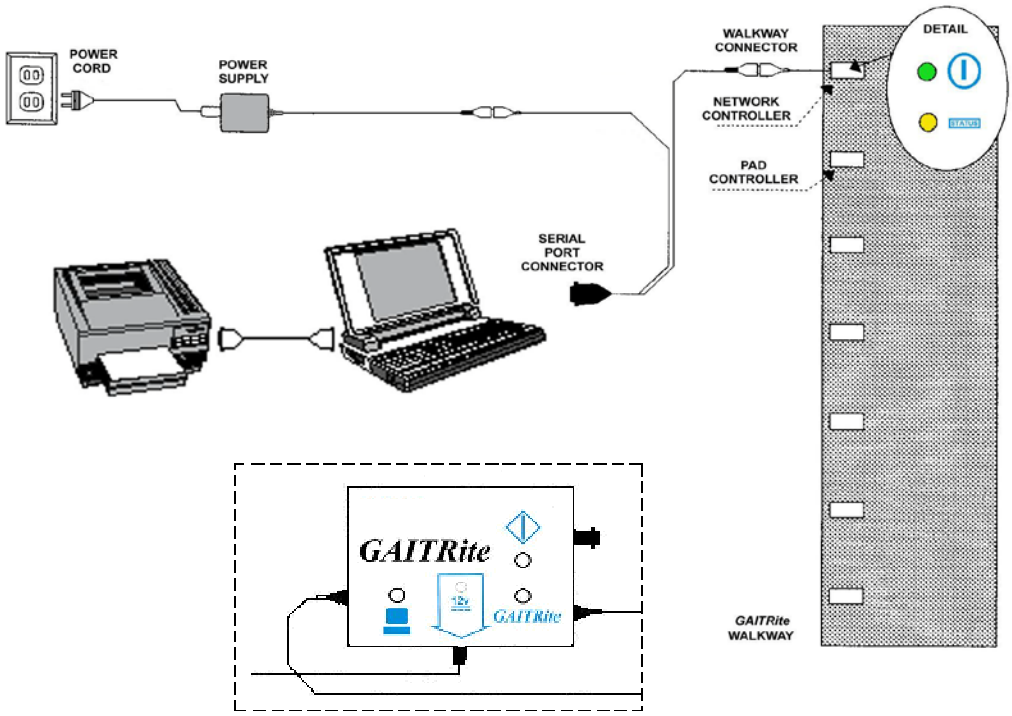


Figure 3.2. Schematic representation of the GAITRite walkway system

Initially, the sensors, positioned 1.27cm from centre to centre are identified as either ‘on’ or ‘off’ (Figure 3.3).

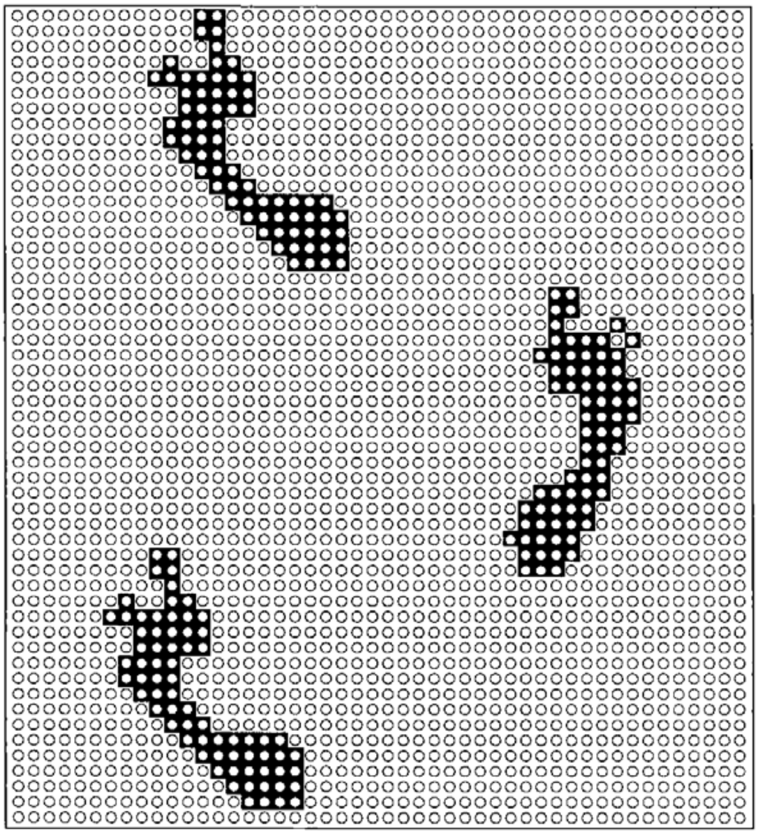


Figure 3.3 Representation of sensor activity from two small steps across the GAITRite walkway.

Algorithms beyond the scope of this investigation are used to recognise these objects as footprints and identify left and right feet. Within each footprint further algorithms are used to divide the foot up into twelve trapezoids. The rear four trapezoids are used to find the centre of the hindfoot, the middle four are used to find the centre of the midfoot and the forward four are used to find the centre of the forefoot (Figure 3.4).

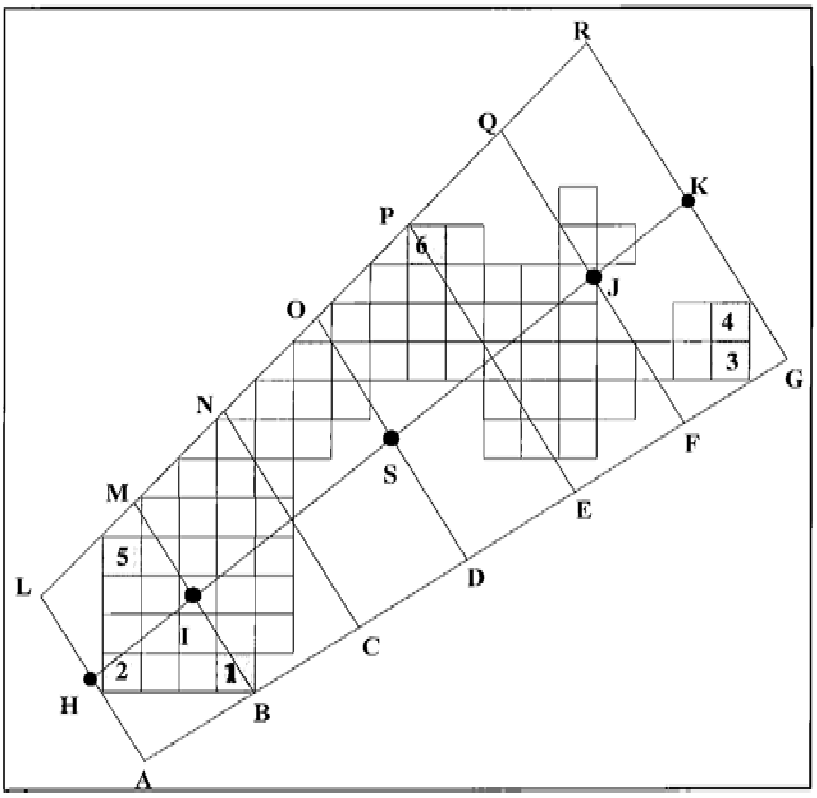


Figure 3.4 Geometric centre position (hindfoot, midfoot and forefoot)

The footfalls are identified by the GAITRite software. The spatial and temporal footfall data are calculated from the timing and position of the individually identified footfalls.

Spatial definitions

The spatial gait parameters can be defined from the following figure 3.5.

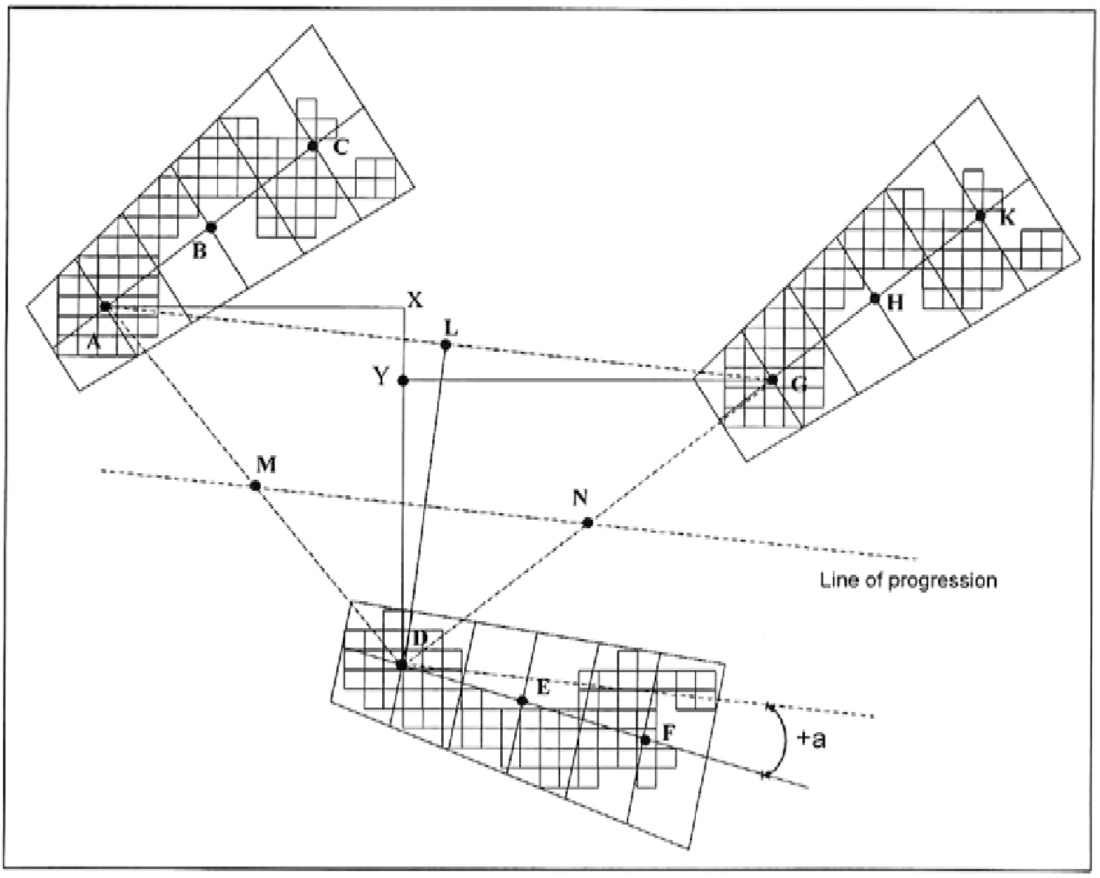


Figure 3.5 Spatial definitions reference points for footfall data.

Step Length (sl) – the measurement along the horizontal axis from the geometrical heel centre of the current footfall to the heel centre of the previous. The line A-X is a representation of a right step length and is recorded in cm.

Base of Support (bos) – can be defined as the perpendicular distance from heel point of one footfall to the line of progression of the opposite foot. The line D-L represents the base of support for the right foot and is reported in cm.

Temporal definitions

The temporal gait parameters are measured from the activation of sensors relating to specific events of the gait cycle during the foot contact time.

Step time (st) – is the time elapsed from the first contact of one foot to the first contact of the opposite foot and is measured in seconds.

Velocity (vel) – is the distance walked divided by the time. It is recorded in centimetres per second.

Double support time (dst) – is the amount of time during the gait cycle when both feet are in contact with the ground.

Cadence (cad) – is the division of the number of steps taken across the walkway by the time taken. It is reported in steps per minute.

All gait variables used were exported from the GAITRite software in ASCII format and managed in Microsoft Excel spreadsheet software (Microsoft Corporation, 2003).

The validity and reliability of the GAITRite walkway system has been reported in several papers (Bilney, Morris & Webster, 2003; Cutlip, Mancinelli, Huber, & DiPasquale, 2000; McDonough, Batavia, Chen, Kwon, & Ziai, 2001; Menz, Latt, Tiedemann, Mun San Kwan & Lord, 2004; van Uden, & Besser, 2004; Webster, Wittwer & Feller, 2005; Wilson, Lorenzen & Lythgo, 2002). Both Cutlip et al. (2000) and McDonough et al. (2001) reported large discrepancies in the spatial data from the GAITRite system compared to motion analysis systems. The step length differences between the GAITRite and 2-D motion analysis for example ranged between 4.6 cm to 16.7 cm. Such large differences can be explained by the perspective error in the camera set up as noted by Wilson, Lorenzen and Lythgo

(2002). Bilney et al. (2003) and Webster et al. (2005) both report strong concurrent validity of the GAITRite system when referenced against a clinical stride analyser and the Vicon 512 motion analysis systems respectively. Webster et al. (2005) reports individual step parameters (step length and step time) with intra-class correlation coefficient's (ICC) ranging from 0.91 – 0.99. It was noted that when using the two systems (GAITRite and Vicon 512) values within 1.5 cm and 0.02 seconds of each other were reported on 80 - 94 percent of occasions (p. 320).

The test-retest reliability of the GAITRite system was reported by Menz et al. (2004) and van Uden (2004) after two and one weeks respectively. Menz et al. (2004) reported good reliability with gait speed, cadence and step length ICC's between 0.82 – 0.92. The base of support and toe in/out however displayed large coefficients of variation between trials of up to 33%. Van Uden et al. (2004) reported similar findings across normal and fast walking trials. The ICC's for normal walking parameters were all above 0.92, except base of support with an ICC of 0.80. The fast walking trials showed ICC's above 0.89, except base of support which was 0.79. While reported as test-retest reliability of the GAITRite system, the inherent variation in human performance can not be accounted for. Recent work has shown that the protocol by which walking procedures are administered can alter the performance on some gait parameters (Paterson, Hill, Lythgo & Maschette, 2008). Performing walkthrough trials (10 trials) in either a discrete or continuous manner provides a consistent performance (ICC's ranging from 0.84 – 0.95). Although, performing the walkthroughs in a discrete manner may increase the likelihood of systematic bias. A continuous walking protocol was chosen for the current study outlined in section 3.3. The reliability of the actual measurement system should be lower then what has been reported to date. The accuracy of the GAITRite can only be reported for its spatial (1.27cm) and temporal (0.0125 sec) resolution.

3.3 Procedure

One week prior to the commencement of testing the questionnaire was administered to parents/guardians to complete and return. Along with the questionnaire an information sheet and consent forms were given out to advise parents/guardians of the intent and procedures of the investigation.

All testing took place at the school. This allowed for minimal distraction from the day to day activities of each participant. Participants were collected (in groups of 5 or 6) from their classroom and escorted by a research assistant to the gymnasium/general purpose room for testing. Two areas were provided one for the GAITRite walkway and one for the MABC testing. One child at a time had anthropometric measurements taken and was tested on the walkway (approx 20 min). The rest of the group was split up, one child – one research assistant, to complete the MABC (20-30 min). This may provide a source of inter tester error or bias. To control for this, each of the testers underwent training, one week prior to testing, on the interpretation of each item. Once the first child had completed the walkway test they were changed around with the MABC children and visa-versa. The total time for testing was less then an hour for each individual participant.

Prior to the GAITRite protocol, bilateral leg length measurements were taken. The protocol for the GAITRite walkway testing required the children to walk at their self selected (normal) walking speed. The walking was completed barefoot to negate the effects of varying footwear. The instruction for each walking condition remained constant. Each child was instructed to "walk at your normal pace, as if you were walking to school".

The GAITRite software was set to "auto-suspend each trial", this allowed for ten continuous walks across the mat to be collected at once for each condition. Approximately fifty individual footfalls could be captured for each walking speed. This protocol was chosen to counteract the effects of gait initiation and termination and to reduce the cognitive effect of remembering walking pace. Starting and stopping between each pass over the mat may effect the overall gait variability measured (Paterson, 2008). To further reduce any initiation and termination effects the distance prior and post the mat were set at 4 metres (Figure 3.7). Previous work has suggested that steady state walking is reached after two body lengths (Furness, 2003).

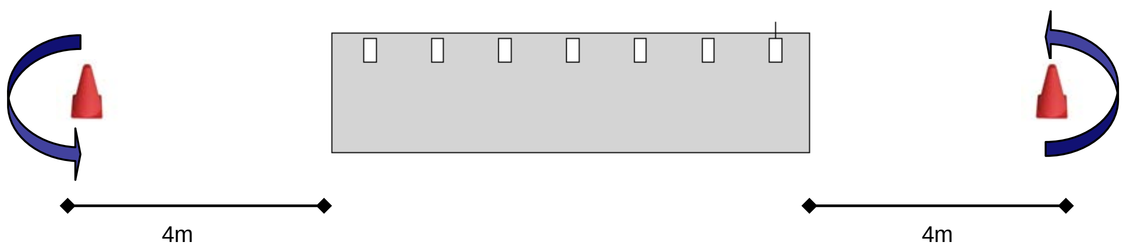


Figure 3.6 Representation of the distance walked prior and past the mat.

3.4 Data Analysis

3.4.1 Dependent Variables

An average velocity for each of the 10 trials was recorded together with the individual footfall data for sl, bos and dst. In each case the mean, standard deviation (SD) and coefficient of variation (CV) were calculated for each child. The average of the mean gait parameters and the average of the gait variability parameters were then used as the basis for comparison between groups.

Stride-to-stride variability

The CV for the individual footfall data for the ten trials was used as the stride-to-stride variability measurement.

$$CV = \frac{SD}{Mean} \times 100\,\%$$

The CV could not be calculated for the base of support and toe in/out variables due to the effect of negative values on the mean. Those trials with negative values reduced the mean considerably without reducing the SD in the same proportion thus resulting in a disproportionate CV value. Therefore, the SD was used as the measure of stride-to-stride variability for base of support and toe in/out. The CV was a useful measurement as it provided a percentage variability measure. This allowed for comparison between variables and across age groups.

3.4.2 Gait normalization

Comparing the walking patterns of children of varying ages can be problematic due to the electrophysiological, biomechanical, physical and neurological changes that occur during childhood (Zijlstra, 1996). Walking patterns are also impacted in children by their smaller leg lengths. This can induce smaller steps and a higher step frequency when compared with fully grown adults. The interpretation of the origin of this difference could be related to any one of the previously mentioned factors (electrophysiological, etc). However, in order to account for the morphological changes in children (stature and leg length) the data were compared across age-bands only after a scaling process (Hof, 1996) (Table 3.7). Any differences in the data can, therefore, be attributed to variables other then those associated with physical size.

Table 3.7 Normalisation formulae used to scale gait data

Quantity	Dimensionless Number Calculation
Length, Distance (Step length, Base of support)	$\hat{l} = \frac{l}{l_0}$
Time (Double support time)	$\hat{t} = \frac{t}{\sqrt{\frac{l_0}{g}}}$
Frequency (Cadence)	$\hat{f} = \frac{f}{\sqrt{\frac{g}{l_0}}}$
Speed, Velocity (Velocity)	$\hat{v} = \frac{v}{\sqrt{g.l_0}}$

* where l_0 = leg length (from greater trochanter to floor); g = acceleration due to gravity (9.81 m.s^{-2})

3.5 Descriptive Statistics

All statistical analysis was performed using the SPSS for Windows version 12.0.1 software package (SPSS, 2004).

3.5.1 Assumption Testing

Normality

To determine the statistics met the necessary assumptions for the analyses performed a Shapiro-Wilk test was used. A significant value $p < .05$ indicated a non-normal sample (Field, 2005). Additionally, skewness and kurtosis values were observed. Both skewness and kurtosis values were divided by their associated standard error providing a z-score. In both cases a z-score within ± 1.96 was taken as evidence of normality.

Multivariate

The use of multivariate statistics required additional assumption testing. Initially each of the dependent variables were assessed for univariate normality as seen above. Levene's test of homogeneity of variance (univariate) ($p > .05$) was also used. The Box's test was used to account for multivariate covariance ($p > .05$) (Field, 2005).

CHAPTER IV

RESULTS I

4.1 Movement ABC Score Breakdown

Scoring on the MABC is based on points accrued for errors in performance. Zero points scored indicated an error free performance. To compare the breakdown in scoring for the motor impaired and typically developing children across the three dimensions of the MABC scales the following figures were constructed.

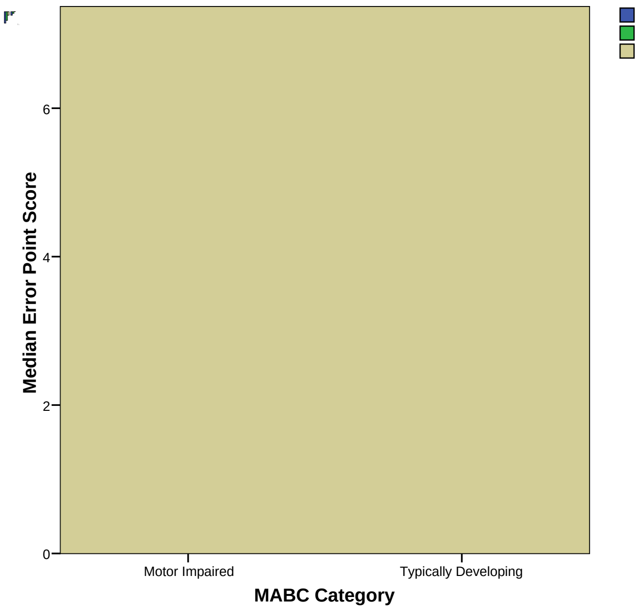


Figure 4.1 Breakdown in MABC sub-scale scores for the motor impaired and typically developing children.

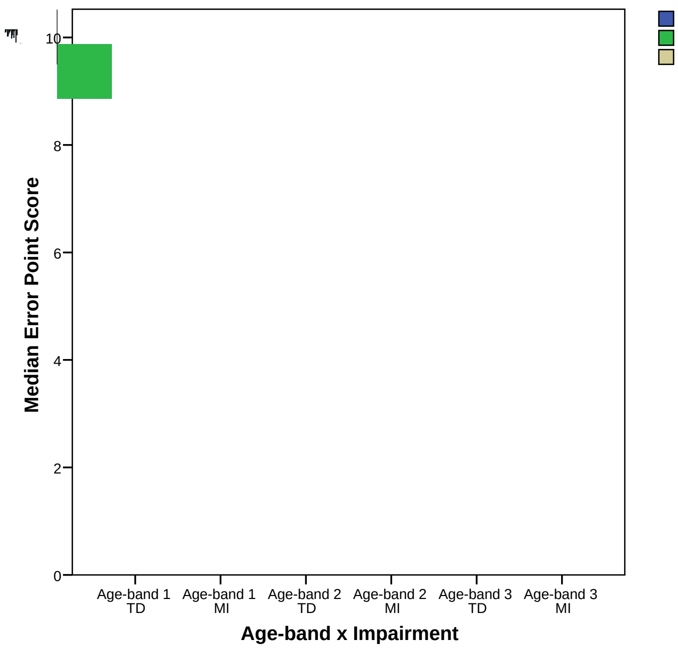


Figure 4.2 Breakdown in MABC sub-scale scores for the motor impaired and typically developing children across age-bands.

It can be seen from Figure 4.1 that when impairment was broken down in to the underlying sub-scales the breakdown in impairment on the MABC was the highest for manual dexterity. This seemed to be the major discriminator between the two groups. The relative proportion of typically developing children's median balance score was zero. This was replicated across the breakdown by age (Figure 4.2)

4.2 Group Comparison and Matching Process

As outlined in the method section there were two forms of group comparisons. The first, using the full sample (n = 87) involved the normalisation of the dependent variables (gait parameters) to enable direct comparison between children in different age-bands controlling for size (Hof, 1996). In order to test for differences between the motor impaired and typically developing children the twenty-five participants classified as motor impaired were matched pairwise with typically developing peers. Matching was undertaken on the basis of age and stature. This process was followed so as to control for the effect of morphological bias on the gait parameters of the two groups. The following table reports the breakdown of the two groups that were used in the analysis following the matching process.

Table 4.1 Comparison of groups on matched variables of age and stature

	MI (n = 25)	TD (n = 25)
Age (years)	7.79 (1.06)	7.63 (0.83)
Stature (cm)	130.36 (7.20)	130.07 (6.85)

Table 4.2 reports the means of the anthropometric variables for the two groups.

Table 4.2 Related anthropometric variables.

	MI	TD
Mass (kg)	29.3 (7.3)	27 (3.8)
Leg Length (L & R mean)	70.6 (4.6)	70 (4.3)
BMI	17.1 (3.4)	15.9 (1.5)

It can be noted that the motor impaired children as a group were 8 % heavier and had a BMI 7 % greater then the typically developing children, however this was not statistically significant ($p < .05$).

4.3 Hypothesis Testing

Hypothesis 1.

There will be a significant difference between the gait parameters of velocity, cadence, step length, base of support and double support time for children in each age-band 1, 2 & 3

A trend towards increasing velocity, step length and base of support with decreasing cadence was observed for children increasing in age. However, few differences were noted between the age bands when the data were normalised with the exception of, cadence which was faster and double support time, which was shorter in the youngest age band.

Table 4.3 Comparison of gait parameters across age groups

Gait Parameters Raw & *Normalised*	Age-band 1	Age-band 2	Age-band 3
Velocity (cm/s)	133.9 (16.1)	133.9 (17.3)	140.1 (11.6)
Velocity (normalised)	*(0.53 (0.06))*	*(0.51 (0.06))*	*(0.52 (0.03))*
Cadence (steps/min)	156.2 (16.8)	139.1 (11.1)	137.7 (7.8)
Cadence (normalised)	*(0.67 (0.07))*	*(0.62 (0.05))*	*(0.63 (0.04))*
Step Length (cm)	51.6 (5.6)	57.7 (5.4)	61.1 (4.3)
Step Length (normalised)	*(0.79 (0.08))*	*(0.81 (0.06))*	*(0.82 (0.03))*
Base of Support (cm)	6.4 (1.7)	6.9 (1.7)	8.5 (2.0)
Base of Support (normalised)	*(0.10 (0.03))*	*(0.10 (0.02))*	*(0.11 (0.02))*
Double Support Time (sec)	0.09 (0.02)	0.11 (0.02)	0.10 (0.02)
Double Support Time (normalised)	*(0.03 (0.01))*	*(0.04 (0.01))*	*(0.04 (0.01))*

Two of the normalized gait variables violated the assumption of normality, base of support and double support time in Age-band 2. A log transformation was therefore considered in an attempt to meet normality. However, base of support still violated normality. As such the non transformed data were used for the analysis, but therefore need to be interpreted with caution. MANOVA identified significant differences between age-bands for the normalized gait data ($F(10,162) = 2.196$, $p = .02$, $\eta_p^2 = .119$).

The univariate analysis identified cadence ($F(2,84) = 5.596$, $p = .005$) and double support time ($F(2,84) = 4.313$, $p = .016$) as being significantly different across the age-bands. The velocity ($F(2,84) = 1.410$, $p = .250$), step length ($F(2,84) = 0.529$, p

= .591) and base of support (F(2,84) = 1.228, p = .298) were not significantly different between the three age-bands.

Pairwise comparison revealed that for both cadence (p = .001) and double support time (p = .004) age-bands 1 & 2 were the source of the observed difference. No significant differences were found between age-bands 1 & 3 or 2 & 3 for either gait parameter (p > .05).

Hypothesis 2.

There will be a significant difference between the stride-to-stride variability of the gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD) & double support time (SD) for children in each age-band 1, 2, & 3.

Table 4.4 shows the stride-to-stride variability changes across the three age-bands for each of the gait parameters measured.

Table 4.4 Stride-to-stride variability parameters across age groups.

	Age-band 1	Age-band 2	Age-band 3
Velocity (CV)	7.93 (2.83)	5.87 (2.50)	4.49 (2.15)
Cadence (CV)	5.84 (2.67)	3.65 (1.79)	3.27 (1.02)
Step Length (CV)	6.99 (2.15)	5.93 (1.87)	6.19 (2.62)
Base of Support (SD)	2.63 (0.95)	2.36 (0.81)	2.80 (1.04)
Double Support Time (SD)	0.02 (0.00)	0.02 (0.00)	0.02 (0.01)

All five of the stride-to-stride gait variability parameters violated the assumption of normality in at least one of the three age-bands. Consequently a log transformation was performed across all age-groups. Subsequently, only the variable cadence in age-band 1 still violated normality. As such the transformed data were used for the analysis. The non-transformed data however are presented in Table 4.4 for ease of interpretation. MANOVA showed that there were significant differences between the three age-bands for the stride-to-stride variability gait data ($F(10,162) = 2.364$, $p = .012$, $\eta_p^2. = .127$)

From the univariate analysis velocity($\log_n$) ($F(2,84) = 7.568$, $p = .001$) and cadence($\log_n$) ($F(2,84) = 8.354$, $p < .001$) were significantly different across the age-bands. Pairwise comparison revealed that the difference for both velocity ($p = .002$) and cadence ($p < .001$) was between age-bands 1 & 2 and 1 & 3, but not 2 & 3 ($p > .05$).

Hypothesis 3.

There will be significant differences between the gait parameters of velocity, cadence, step length, base of support & double support time for children classified as motor impaired and for the typically developing children.

Hypothesis three was tested by MANOVA. The comparisons are reported in Table 4.5.

Table 4.5 Comparison of gait parameters for children classified as typically developing and motor impaired

Gait Parameter	MI	TD
Velocity ($cm.sec^{-1}$)	133.0 (15.1)	133.6 (16.0)
Cadence ($steps.min^{-1}$)	144.5 (14.8)	139.4 (12.6)
Step Length (cm)	55.3 (5.1)	57.6 (6.0)
Base of Support (cm)	7.1 (2.3)	6.7 (1.6)
Double Support Time (sec)	0.11 (0.03)	0.11 (0.02)

(where: MI = Motor Impaired; TD = Typically Developing)

MANOVA identified that the mean gait parameters did not differ significantly between the two groups ($F(5,44) = 1.046$, $p = .403$, $\eta_p^2 = .106$).

Hypothesis 4.

There will be significant differences between the stride-to-stride variability of the gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD) & double support time (SD) for children classified as motor impaired and for the typically developing children.

This hypothesis was also tested by MANOVA. Table 4.6 shows the results of the comparison of the stride-to-stride variability between the two groups.

Table 4.6 Comparison of stride-to-stride gait variability parameters for children classified as typically developing and motor impaired

	MI	TD
Velocity (CV)	6.6 (3.1)	6.5 (2.7)
Cadence (CV)	3.9 (2.2)	4.4 (1.8)
Step Length (CV)	6.9 (2.4)	6.1 (1.5)
Base of Support (SD)	2.8 (1.1)	2.7 (0.7)
Double Support Time (SD)	0.02 (0.01)	0.02 (0.00)

MANOVA found no differences between the groups ($F(5,44) = .714$, $p = .671$, $\eta_p^2 = .075$)

CHAPTER V

DISCUSSION I

5.1 Motor Impairment Classification

A higher than expected percentage of children within the sample were classified as motor impaired (Age-band 1 – 30%; Age-band 2 – 37.5%; Age-band 3 – 66.7%). Although, the nature of the sample prevented any meaningful inferences being made, the results still give grounds for some concern. The prevalence of motor impairment as measured in Australian samples from 1993 to 2004 has ranged from 4.1 – 35 % (Piek & Edwards, 1997; Piek et al., 2004; Revie & Larkin, 1995; Walkley, Holland, Treloar & Probyn-Smith, 1993). The current findings therefore fall at the upper end of previously measured impairment within Australian populations. The school involved in this study was located in a typical 'middle' socio-economic area. No specific confounding factors were noted that might serve to inhibit the physical ability and development of the children at this particular school. However, recent findings from another study conducted in a similar socio-economic region of Melbourne suggest that the current estimation of motor impairment may not just be indicative of this sample alone. Williams (2008) who tested the jumping performance of children with DCD, reported that out of his total sample (n = 167) 37.6 % of children were classified as having DCD when using the MABC 15th percentile cutoff as the criterion. This issue, therefore, is worthy of further enquiry.

It was observed that the motor impaired children had a body mass (29.3 kg) and BMI (17.1), while not significant, which was greater than the typically developing children's body mass (27.0 kg) and BMI (15.9). Supplementary investigation found the degree of overweight and obesity within the sample was 9.2% (8 of 87) using their BMI score. Of the eight children classified as overweight, five were also classified as motor impaired. A chi-squared test confirmed a significant association between children being classified as overweight and the likelihood of their being identified as motor impaired $\chi^2(1) = 4.905$, $p = .027$. Overweight children were 4.13 times more likely to be motor impaired. With such small numbers this result, of course, must be interpreted with caution but it does suggest a need for further enquiry into this relationship.

5.2 Gait Analysis

A comparison of the children's gait parameters between each of the age-bands was also made. The first hypothesis that: *There will be a significant difference between the gait parameters of velocity, cadence, step length, base of support and double support time for children in each age-band 1, 2 &* 3 was partially supported. Differences in normalised values for Cadence (lower) and double support time (higher) were found from age-band one to two, the remainder of the dependent variables were not significantly different. This signifies that even when the size of the child was taken into account the cadence and double support time were different for children aged from AB1 to AB2. This finding is consistent with previous studies which suggest that the gait parameters do not mature until seven years (Dierick, Lefebvre, van den Hecke & Detrembleur, 2004; Desloovere et. al., 2004; Ganley & Powers, 2004; McFadyen, Malouin & Dumas, 2001; Olshen, Biden, & Wyatt, 1988; Sutherland, Jeng et al., 1997). The change in double support time with age can be explained, in part, by the decreasing cadence. The slower the rate of steps the greater amount of time is spent with both feet in contact with the ground. An exaggerated example of this can be seen when observing the transition between walking and running. The faster the person walks the less time both feet are in contact with the ground. This pattern continues to a point where there is no longer a dual contact phase in the cycle. This is the point at which walking becomes running.

It should be noted that neither velocity nor step lengths changed as a function of age when body size was taken into account. The children walked at a pace and with a step length appropriate to their size. The higher cadence values for body size seen in the younger children (5 – 6 age group) may be due to a 'catch-up' period of growth. Figure 5.1 shows the height gain per year of children to age 18 years. It can be seen that the initial rapid growth period from early childhood begins to plateau from 4 years of age (Haywood & Getchell, 2005). These large growth changes prior to the ages of 4, 5 and 6 may precede an adaption in walking patterns. If a child experiences a rapid growth spurt they may still persist in the previous (old) stepping rate for a period of time until the newer one becomes learned.

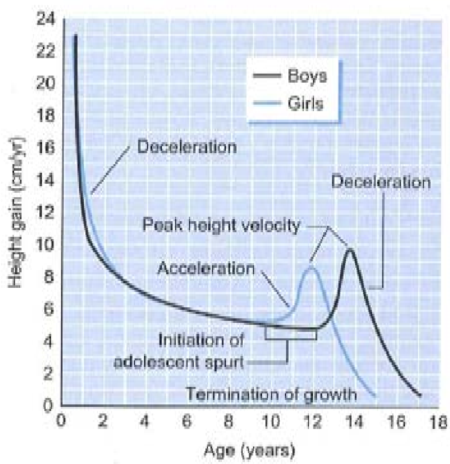


Figure 5.1 Yearly changes in height (cm) during childhood from Haywood & Getchell (2005).

The analysis of the stride-to-stride variability of children across age-bands revealed a greater source of difference. Therefore the second hypothesis that: *There will be a significant difference between the stride-to-stride variability of the gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD) & double support time (SD) for children in each age-band 1, 2, & 3* was partially supported. Differences between age-bands were seen especially in the variability of velocity and cadence, however, the step length, base of support and double support time stride-to-stride variability were not significantly different. A tendency towards decreasing variability with age was also observed (Figure 5.2). Both the second and third age-bands were found to be significantly different to the first in both measures.

Figure 5.2 Velocity and Cadence variability across age-bands

The stride-to-stride variability of step length between age-band 1 (6.99 ± 2.15) and age-band 2 (5.93 ± 1.87) was not however different. The results from the third age-band should be interpreted with caution due to the small numbers (n = 6). A small decrease was noted in variability from age-band 1 to 2 which corresponds with the findings of Hausdorf, Zemany, Peng and Goldberger (1999). They reported that stride time variability decreased with increasing age for children 3 – 4yrs (6.1 ± 0.5 %), 6 – 7 (3.3 ± 0.2 %) and 11-12 years (2.1 ± 0.1 %). Looper, Wu, Barroso, Ulrich and Ulrich (2006) found that typically developing children walked with greater step length variability then children with Down's syndrome (≈ 8 %). Clarke (1995) reported that the variability in temporal phasing (timing of strides) decreased from that found in new walkers (9 %) to that found after six months of independent walking (3 %). This in turn differed from that of adults (1.5 %). To date, these are the only papers to report on the stride-to-stride variability of children.

The third hypothesis that: "*There will be significant differences between the gait parameters of velocity, cadence, step length, base of support & double support time for children classified as motor impaired and for the typically developing children*" was not supported. It was the expectation that the motor impaired children would exhibit an unsteady gait pattern characterized by shorter steps and a wider base. Although, the motor impaired children tended towards exhibiting shorter steps and a wider base, the gait parameters in this study were shown not to differ between the motor impaired children and typically developing ($F(5,44) = 1.046$, $p = .403$, $\eta_p^2 = .106$). These observations, however, may be worthy of further assessment with a large sample given the moderate effect size.

The fourth hypothesis that: *There will be a significant difference between the stride-to-stride variability of the gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD) & double support time (SD) for children classified as motor impaired and for the typically developing children* was also not supported. No significant differences were found in the variability of the motor impaired and typically developing children's stride-to-stride gait parameters. It was the expectation that the motor impaired children would exhibit greater stride-to-stride variability, however (not significant) the cadence tended to be slightly less variable for the MI children (3.9 ± 2.2%) in comparison with that of the TD children (4.4 ± 2.7 %) and the step length variability was higher for the MI children (6.9 ± 2.4%) compared to that of the TD (6.1 ± 1.5 %) though neither were significant. These ‘suggestions’ that the motor impaired children were walking with a more consistent cadence and a more variable foot placement then the typically developing children is worthy nonetheless of further inquiry with a larger sample. A variable foot placement while walking in a closed environment without distraction or obstruction may be negotiable for the developing child. However, when the attention is divided or the child needs to negotiate obstacles a variable foot placement may cause problems. Footsteps too close to a kerb or crack in the pavement could initiate a trip. Footsteps which are significantly smaller then the norm can bring the centre of gravity closer to the limit of the base of support, causing instability.

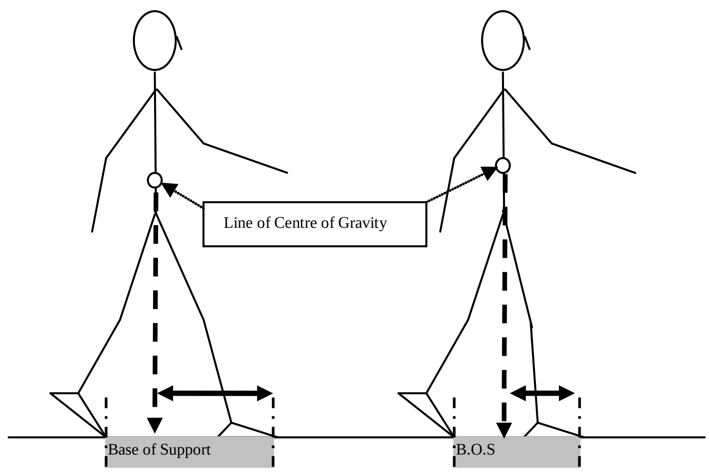


Figure 5.3 Long and short step length, distance of line of centre of gravity to edge of base of support

Several papers, have reported increased stride-to-stride variability within various populations with unsteady gait (elderly, fallers, Parkinson’s, Huntington’s, Cerebral Palsy, Diabetic Neuropathy, Sensory Loss and Traumatic Brain Injury) (Bauby and

Kuo, 2000; Gabell & Nayak, 1984; Heiderscheit, 2000; Dingwell, Cusumano, Sternad, Cavanagh, 2000; Dingwell, Ulbrecht, Boch, Becker, O'Gorman & Cavanagh, 1999; Ebersbach, 1999; Grabiner, Biswas & Grabiner, 2001; Hausdorff, 1994; Hausdorff et al., 2003; Hausdorff, Edelberg, Mitchell, Goldberger & Wei, 1997; Hausdorff, Rios & Edelberg, 2001; Herman, Gurevich, Baltadjieva, Giladi & Hausdorff, 2002; Herman, Giladi, Gurevich & Hausdorff, 2004; Looper, Wu, Barroso, Ulrich & Ulrich, 2006; Maki, 1997; Moe-Nilssen & Helbostad, 2004b; Nakamura, 1996; Niechwiej-Szwedo, Inness, Howe, Jaglal, McIlroy & Verrier, 2007; Owings and Grabiner, 2004; Owings and Grabiner, 2004b; Palliyath, 1998; Sekiya, Nagasaki, Ito & Furuna, 1997; Steinwender, et.al, 2000). It is a general consensus that increasing unsteadiness translates to a walking pattern with increased stride-to-stride variability. This formed the basis for the expectation that the motor impaired children would exhibit greater stride-to-stride variability, which was not confirmed by the data from the current study.

Although children with impaired motor function in the current study did not exhibit a clear trend towards increasing stride-to-stride variability this may have been because of the diversity of the nature of the impairments within this group. The MABC which was used to classify the children as motor impaired is comprised of three sub-scales (manual dexterity, ball skills and balance). Children accumulating error points on the manual dexterity sub-scale, for example, can be labeled 'motor impaired' in the same way as those scoring points on the balance tasks. Yet a child screened with manual dexterity impairment (fine motor skills) may walk with a typical pattern (within normal limits). In contrast, a child screened with balance impairment (gross motor skill) is more likely to have an altered gait pattern as a result of balance being an underlying feature in competent walking. A reconsideration of the validity of the criterion used in the classification process may be relevant in any further studies of this nature.

In addition, potential differences in gait pattern between the motor impaired and typically developing children may have been masked by the relatively low level of task demand. The children walked at their self-selected normal walking pace. Increasing the task difficulty, for example, by challenging the children to walk outside their comfortable walking pace, may require more attention and thus better discriminate between the two groups. Previous studies have identified a coexistence of attention problems for children with motor impairment (Kaplan, Wilson, Dewey & Crawford, 1998; Piek, Pitcher & Hay, 1999; Pitcher, Piek & Hay, 2003). Additionally, a recent study into the effect of walking speed on gait variability in adults showed that variability increased when walking both faster and slower then the preferred speed (Jordan, Challis & Newell, 2006). This supports the notion that the use of the preferred walking speed may allow for an enhanced stability that is not present in more demanding environments.

A number of implications were therefore drawn for the next study as a result of these findings:

(1) The high prevalence of motor impairment and the increased likelihood of children with high BMI being classified as motor impaired warranted further investigation in study 2.

(2) While some trends were noted in the parameters of gait between the motor impaired and the typically developing children none were significant. The addition of both slow and fast walking conditions might better discriminate between the two groups by increasing the task demands. Further, the criteria used for the classification of children as 'motor impaired' might need to be addressed.

(3) The current study, in common with others (Piek & Edwards, 1997; & Kaplan, Dewey, Crawford, Wilson, 2001), screened children according to their total impairment score which included their performance on three sub-scales (manual dexterity, ball skills & balance tasks). It was noted that poor performance in manual dexterity actually contributed the majority of overall points to the total impairment score yet conceivably children confronted with difficulty in fine motor tasks may indeed walk quite normally. That is, the nature of impairment may be more specific than implied in the MABC criteria. Should this be the case it would make more sense to use of the balance sub-scale as the criteria for motor impairment because of its clear contribution to successful locomotion consequently, the criteria may be revisited.

(4) Finally, the occurrence of the differences in the parameters of gait and the stride-to-stride variability in the developmental process requires further investigation. Significant differences were noted between age-bands 1 and 2 and no differences were found between age-bands 2 and 3 (however a limitation of the current study was that there were only six children allocated to age-band 3). Any follow up study needs to increase the range of children tested by including a more comprehensive sample of

age-bands 3 and 4. A sample of young adults might also be included to identify if the children in age-band 4 have similar or adult like parameters of gait.

CHAPTER VI

INTRODUCTION II

6.1 Development of Mature Walking

It was noted from the findings of the current preliminary study that both gait velocity and cadence decreased in variability with increasing age classification. However, no significant differences were noted for the other parameters measured. No significant differences were found between members of the second age-band (7 – 8 years) and those of the third (9 – 10 years). This finding could be interpreted as showing that the walking pattern of this sample was already 'adult like' in the age-band of 7 to 8 years. However, the small sample and relative ease of the task both require further investigation. It has been noted that increasing the task demands by walking at velocities both slower and faster than the normally self selected speed the variability of walking parameters increases (Sekiya, Nagasaki, Ito & Furuna, 1997). It is important therefore to further investigate walking under increased task demands before concluding about walking maturation.

The only study to comprehensively measure the variability in stride-to-stride gait parameters was conducted by Hausdorf et. al. (1999). It was evidenced from this study that the stride-to-stride variability in the timing of foot placement decreased between increasing age bands (3 – 4 yrs; 6 – 7 yrs & 11 – 12 yrs). This investigation did not include an investigation of the variability of spatial parameters and only measured walking at a normal self-selected walking pace. The current study therefore arises out of the need to examine the impact of increased task demands on the variability of spatial gait parameters such as step length and base of support. A sample of young adults will be included to provide a baseline indication of the parameters of mature walking. A child who exhibits a similar pattern to the young adult should, therefore, be classified as having a mature walking pattern.

The findings from study 1 provided initial evidence to suggest that a better understanding of the development of walking may be gleaned using stride-to-stride variability measurement. The advantage of using walking to measure motor development is the ability to accurately and objectively measure movement using current biomechanical techniques (GAITRite). At best, using the MABC developmental age could only be identified in discrete two year blocks corresponding to the age-bands. If a child was screened as motor impaired in the third age-band (9 – 10 years) it could only be assumed that they were performing at a level of the previous age-band (7 – 8 years) ± 2 years. Measurement of the parameters of gait, however, can provide a continuous record of the development of this fundamental motor skill.

6.2 Physical Activity Cycle

An additional motivation for the present study was to contribute to knowledge concerned with enabling children to have a healthy start to life. This has been identified as a major research priority in Australia (Department of Education, Science and Training, 2006). Being a healthy child largely centres on participating in and enjoying regular physical activity, and it is well documented that one of the outcomes of inactivity is increasing overweight and obesity levels (Spinks, Macpherson, Bain & McClure, 2007). Increasing obesity rates in children has been flagged as not only of concern due to the immediate health threats (diabetes, asthma and cardiovascular risk) to children, but also because of the rate at which it tracks into adolescence and adulthood. A study performed just over a decade ago reports that the probability of non-obese 6 year old children becoming obese adults was 10 %, but this increases to 50 % for obese 6 year olds (Whitaker, Wright, Pepe, Seidel & Dietz, 1997). Obesity does not have to track far into adulthood for it to become a major health concern. A BMI above 25 at the age of 18 has been related to significant increases in mortality within 20 years, after 32 years the mortality risk has been reported to double (Whitaker, Wright, Pepe, Seidel & Dietz, 1997).

It is recognised that prediction of physical activity participation in childhood is multi-faceted. Issues such as positive reinforcement (family, friends and teachers), enjoyment, personal demographics (age, gender, ethnicity & socio-economic status), fitness and environment all relate to either enable or confound regular participation in physical activity in childhood. This study focuses on the concepts of motor skills, body composition and self-efficacy (perceived competence) and their inter-relationship to physical activity. Interestingly, it may be that one of the consequences of lack of activity, obesity, may further contribute to continuing inactivity thus creating a 'vicious cycle' leading to still lower levels of fitness and decreasing health status (figure 6.1).

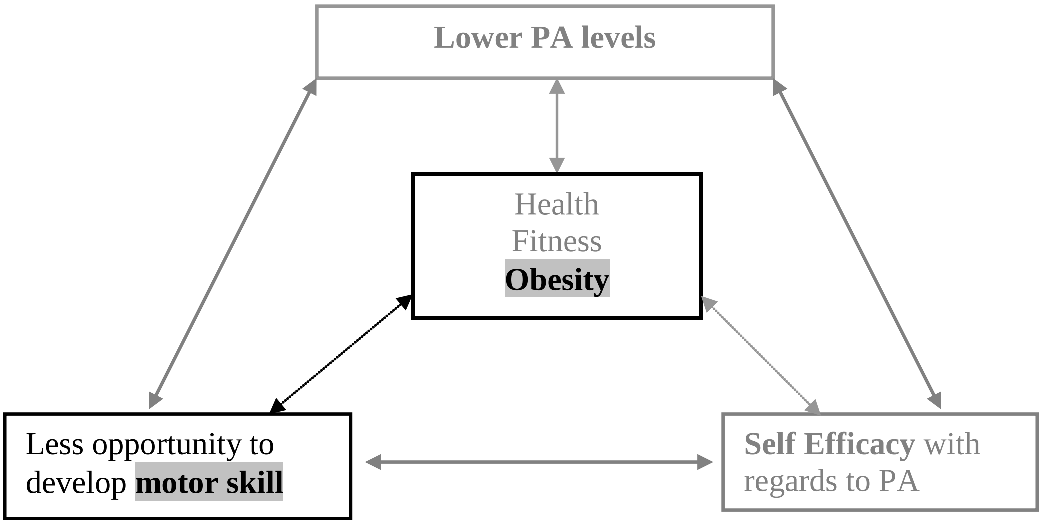


Figure 6.1 Self efficacy, physical activity & motor skill cycle

6.3 Prevalence of Motor Impairment

On the prediction of the conceptual framework seen in figure 6.1, the rate of motor impairment in Australia will be increasing in association with increasing levels of obesity and decreasing physical activity within the population. As identified in Chapter 2 the reporting of motor impairment prevalence within the population has been quite varied. In Australian samples alone the prevalence of impairment since 1975 has ranged from 4.1 – 35 % (Piek et al., 2004; Piek & Edwards, 1997; Revie & Larkin, 1995; Walkley, Holland, Treloar & Probyn-Smith, 1993). This in part can be attributed to the wide range of screening tools used. In some cases qualitative assessments of individual fundamental motor skills were used, in others motor skill batteries such as the MABC and the Bruininks-Ozeretsky Test of Motor Proficiency (BOTMP) were used. No clear trend has emerged in the literature with regards to an increase or decrease in the prevalence of motor impairment in recent years. Two current studies, however, have reported high prevalence of motor impairment within Australian samples using the MABC. Williams (2008) reports a prevalence of 37.6 %

of children classified as having DCD. Findings from the first study have replicated this finding suggesting that 28.7 % of children were classified as below the 15th percentile cut-off of the MABC. Both studies have relatively small samples n = 167 & 87 respectively, thus cannot be interpreted as representative of the Australian population. Nonetheless, this does provide some initial evidence to suggest that there may be an elevated rate of motor impairment in Australian primary aged children. Further population based studies will be needed to confirm these findings.

6.4 Body Mass Index and Motor Impairment

Evidence is emerging to confirm the notion that children with poor motor skills participate in less physical activity (Wrotniak, et al., 2006). This takes on greater significance in light of the previous evidence suggesting that prevalence of motor impairment could be as high as 30%. Several studies have investigated the link between physical activity and motor skills (Booth, et al., 1999; Booth & Patterson, 2001; Cairney, et al., 2005; Wrotniak, Epstien, Dorn, Jones & Kondilis, 2006; & Fisher et al., 2005). However, only weak relationships have been identified to date. The greatest amount of variance in physical activity habits explained by motor skills has been only 8.7 % (Wrotniak, et al., 2006). The most skilful children however, did spend more time in moderate to vigorous physical activity then the least skilled children. Cairney et al. (2005, 2006) found in a small sample that children with DCD were less likely to participate in physical activity, both organised and free play. Additionally it was noted that children with DCD had a lower self efficacy with regards to physical activity (Cairney et al. 2005, 2006).

A consequence of being less physically active is decreased fitness. Haga (2007) showed that motor impaired children performed significantly worse on all nine fitness tests administered. Of 67 children initially screened, the 12 children scoring the highest on the MABC (> 14.5 total impairment score, < 3rd percentile) were compared to the 12 children who scored the lowest (< 3.5 total impairment score, > 60th percentile). Strength, power and endurance were all assessed and found significantly different in the following tests: standing broad jump ($p = .015$), jumping on two feet ($p = .005$), jumping on one foot ($p = .035$), throwing a tennis ball ($p = .006$), pushing a medicine ball ($p < .001$), climbing wall bars ($p < .001$), shuttle run ($p = .05$), running 20 metres ($p = .003$) and the reduced Cooper test (6min walk/run) ($p < .001$).

The outcome of less physical activity and lower levels of fitness may be increased rates of overweight and obesity within this population. One study to date has directly reported increased adiposity and BMI for children with motor impairment (Cantell, Crawford & Doyle-Baker, 2008). Children, teenagers and adults with high and low motor competence were screened for a range of physical, fitness and health indices. The low motor competence group were shown to have a significantly higher BMI ($p = .001$) and were shown to have a higher prevalence of overweight and obesity, 52.1 % compared to 30 % in the high motor competence group (Cantell, Crawford & Doyle-Baker, 2008). A few studies have directly measured motor skill in overweight and obese children (Goulding, 2003; Graf, et.al., 2004; Kretschmann, et.al., 2001). Each of the three studies has found that the overweight and obese children performed worse on motor skill batteries (Bruininks-Oseretsky balance test & the KTK, a Dutch version of the MABC).

Findings from the first study (Chapter IV) also suggest a relationship between motor impairment and high BMI. It was noted that eight of the 87 children were classified as overweight and of the eight overweight children, 5 were also classified as motor impaired. Two of the remaining three neared the cut-off for motor impairment (<15th percentile) at the 18th and 22nd percentile. Upon initial inspection it seems as though the overweight children as a group were more likely to have underlying motor impairment affecting their movement. However, a second explanation that the overweight children simply had difficulty moving their larger mass around the MABC environment can also be entertained as this may have contributed to the poor performance on this particular screening tool.

The cause or effect question arises. Are children with poor motor skill more likely to withdraw from physical activity due to the poor self efficacy? Or is it that as poor fitness and higher BMI increases the task demands of being physically active this will inhibit regular participation?

Support for the latter assumption can be found in research conducted in an adult population of overweight participants with poor motor skills (Sartorio, et al., 2001). A weight reduction intervention was prescribed for overweight adults, and balance was measured pre and post. A 4.1 % reduction in BMI post intervention was related to a 20.5 % improvement in the balance score. It was concluded that this overweight sample exhibited difficulty moving their large bulk with the relatively small muscle mass, once perturbed. It may be that overweight children identified as having poor motor skills may benefit more from weight reduction interventions then motor skill improvement strategies.

6.5 Gait Variability, Motor Impairment and High BMI

Increased body mass has previously been shown to affect the walking patterns of children. The major differences in gait parameters noted have been: increased plantar pressure during the loading phase of stance; increased asymmetry of step length; slower velocity; increased stance time; increased stride time; slower cadence; smaller steps; increased step width; & greater energy expenditure (Dowling, Steele & Baur, 2004; Hills, Hennig, McDonald & Bar-Or, 2001; Hills & Parker, 1991a; Hills & Parker, 1991b; Hills & Parker, 1991c; Lelovics & Nagy, 2004; McGraw, McClenaghan, Williams, Dickerson & Ward, 2000; Plewa, Cieślinska-Swider, Bacik, Zahorska-Markiewicz, Markiewicz, & Blaszczyk, 2004; Volpe Ayub & Bar-Or, 2003).

While the outcome measures of walking have been widely shown to differ for overweight and obese children, the relative timing of muscle activation has been shown to be similar (Hills & Parker, 1993). The authors hypothesised that the coordination of limb movement did not differ between the two groups during a short walk (10m). Underlying differences in walking parameters between the two populations, in part, may be explained by the differing degree of balance control. McGraw McClenaghan, Williams, Dickerson and Ward (2000) found that obese children aged 8 – 10 years (n = 10) were significantly different to non-obese (n = 10) in a number of both anterior-posterior (AP) and medio-lateral (ML) balance tasks with larger discrepancies noted in the medio-lateral direction. This was attributed to greater degrees of freedom for control in the AP direction (ankle, knee and/or hip) in comparison to the ML direction which is mainly controlled with a hip strategy alone.

The variability of the centre of pressure vector was measured to indicate the regularity (stability) within the system, indicating underlying impairment to postural control. A more varied centre of pressure pattern relates to instability. No trends were found to differentiate the obese from the non-obese with regards to this underlying mechanism. The authors suggested that the gross differences in the parameters of gait were probably not caused by underlying impairments to the postural control system but more by the increased non-contributory mass (adipose tissue) added to the system. Further, they suggested that specific balance and stability interventions may not be of as much benefit as an adipose reduction intervention.

Hills and Parker (1991b) studied the effects of diet and exercise on gait parameters. Three groups were used, diet and exercise obese, control obese and normal weight reference of n = 7, 5 & 4 respectively. The results showed that the children in the experimental group had a more stable and symmetrical (step length L & R) gait pattern following the intervention, along with a decrease in body mass, body fat and sum of four skin fold measures. This study concludes similarly by advocating a weight reduction protocol as the most effective form of intervention.

Hills and Parker (1991a) have also shown that obese children have more difficulty adapting to gait speeds. They investigated the gait characteristics of obese children with an average age of 10.5 years. The children were classified obese if their body mass was above the 95^{th} percentile for their age and their BMI was above 25. The children walked at a slow <10%, normal and fast >30% speeds. Ten children in each of a control and experimental group were tested. The obese children adopted a safer, more tentative walking pattern by spending more time in stance phases of gait. The obese children displayed a decrease in hip flexion when asked to walk at the slow and faster speeds. An increase in toe-out was observed for the obese children along with a flat foot weight acceptance. This was thought to compensate for the decrease in foot clearance due to the limited hip flexion.

In a follow up study, Hills and Parker (1992) looked at the spatio-temporal gait patterns of obese children. The trials were over 3 walking speeds, slow (<10%), normal and fast (>30%). The obese participants displayed a greater double support time at each speed. The greatest double support time differences from normal gait for the obese participants were at the non-normal speeds, in particular the slow speed. It was noted that the improvement or maturation of gait parameters with increasing age may be delayed in obese children. As children grow larger with age (increasing adiposity) greater adaption of the gait pattern may be required to maintain stability (increase base of support & double support time) which may delay the attainment of a 'normal' 'mature' walking pattern. This may contribute to inactivity and lower self-confidence, further leading to lower participation in social or classroom physical activities.

Both children and adults generally adopt a walking speed, frequency and pattern that minimises physiological cost, asymmetry and variability (Holt, 1991; Holt, 1995; Jeng, Holt, Fetters & Certo, 1996; Jeng, Liao, Lai & Hou, 1997). Jeng et al. (1996) suggest that the physiological cost is a measure of function, while stability and symmetry are measures of neuromuscular coordination. Walking either faster or slower than the self-selected normal speed should increase the cost, asymmetry and variability of the pattern. The increased task demands of walking slower or faster than normal require the allocation of additional attention compared to normal walking speed (Woolacott & Shumway-Cook, 2002). The lack of differences in the gait parameters found in the initial study may partially be attributed to the protocol using only self-selected normal walking. It is proposed that by adding both a slow and fast condition the task demands will be increased and thus will provide a greater understanding of the level of skill development.

6.6 Impairment Classification Motor Impairment/DCD

A further limitation of the initial study was in the criteria used for identifying children as motor impaired. Increasingly in the literature researchers are reporting that children with DCD form a group that is not necessarily homogeneous (Hoare, 1994; & Wright & Sugden 1996a). Macnab, Miller and Polatajko (2001) have broken down the disorder into five sub-groups for analysis, by using cluster analysis techniques. Their cluster analysis was able to allocate children into each group providing a percentage of children who were categorised by each:

> (1) *Good Balance*: children with better gross skills than fine, both below normal levels. Standing balance and visual-perceptual skills both within normal ranges (13 %);
>
> (2) *Good Visual Motor*: high scoring on upper limb speed and dexterity, visuomotor integration, and visual perception skills, though were below normal on measures of kinaesthetic ability and balance (17%);
>
> (3) *General Perceptual-Motor*: difficulty with both kinaesthetic and visual skills (23 %);

(4) *Poor Fine Motor and Visual Motor*: poor performance on tasks requiring visual and dexterity skills (32 %); &

(5) *Poor Gross Motor*: poor performance for running speed and agility (15 %). (p. 63 - 64)

A classification using the MABC would identify at least three sub-groups of impairment, balance, ball skills and manual dexterity (Henderson & Sugden, 1996). It is most likely that children do not discretely exhibit impairment in individual sub-scales. It is possible that a child scores poorly on one, two or all three sub-scale categories. When the overlapping nature of impairment is taken into account a child could possibly be categorised into one of seven groups (Figure 6.2).

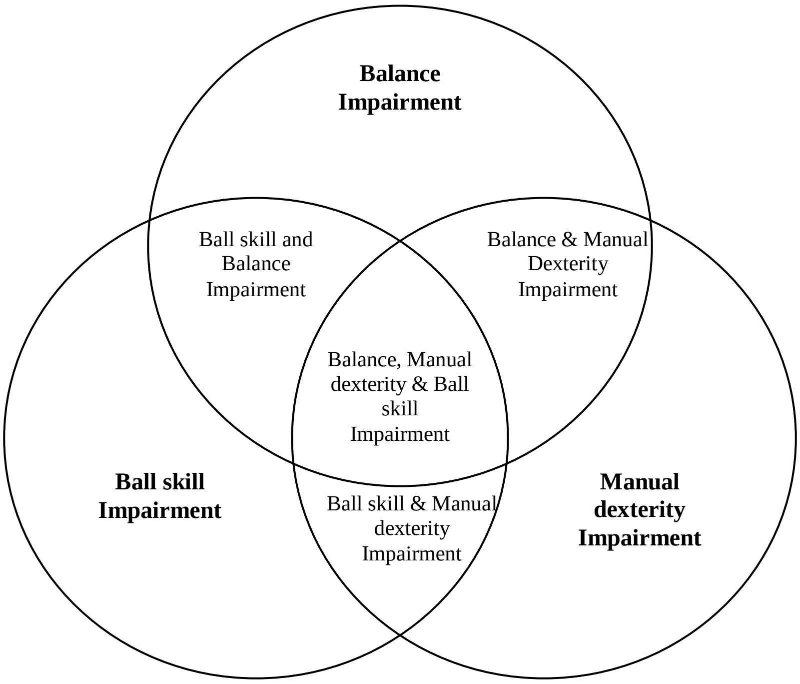


Figure 6.2 MABC sub-scale overlap.

The nature of motor impairment within children has been identified as a complex interaction of various systems. To simply screen a child as motor impaired or having developmental coordination disorder alone does not provide adequate information for clinicians, teachers or researchers alike. To appropriately intervene with strategies to assist children with impaired motor function requires a more detailed analysis of the nature of the underlying motor deficit or deficits.

General Aim

It was the aim of the current study to show that with the increasing availability of more sensitive equipment and procedures, children can be better diagnosed according their specific impairment, thus providing better opportunity for appropriate mediation.

6.7 Research Questions

Research Question 1.

What is the nature of the progression in the development of gait?

Research Question 2.

Can parameters of gait be used to discriminate between balance impaired children and non-balance impaired children?

Research Question 3.

Do overweight children have a greater incidence of impaired balance and coordination then their peers while walking?

CHAPTER VII

METHOD II

7.1 Participants

An information letter and request for participation was initially mailed to twenty metropolitan Catholic primary schools. From this group one school from the east and one from the west of Melbourne metropolitan area were recruited.

A total of 265 children from the two schools participated in this investigation. A breakdown of the male and female sample from each school can be seen below. In the region of School A, the most popular categories of employment were Professionals 16.2%, Managers and Administrators 10.8 % and Intermediate Clerical, Sales and Service Workers 9.4%. School B was located in a region where the most popular categories of employment were Professionals 18.6%, Intermediate Clerical, Sales and Service Workers 8.9% and Managers and Administrators 8.6 %. The median weekly income was $1000 - $1199 per household in both regions, which was slightly higher then the median household income in metropolitan Melbourne of $800 - $999 (Australian Bureau of Statistics, 2001).

Information letters and consent forms were sent home with all children from all grades prep to grade six (Appendix E). Approximately 70 % of pupils at School A and 40 % of pupils at School B returned the forms. A total of 265 (126 Male, 139 Female) children participated in this investigation.

The Movement Assessment Battery for Children (MABC) was administered to all of the 265 children participating in the study. Time constraints did not allow all of the children in School A to complete the GAITRite assessment. The total sample of children was included only to assess the prevalence of impairment within these children. The reduced sample of 218 was used for the rest of the analysis. A breakdown of the participants from each school by gender is presented below.

Table 7.1 Distribution of participants by gender and school

	MABC only		
	Male	Female	**Total**
School A	24	23	**47**
	MABC & GAITRite		
School A	64	68	**132**
School B	38	48	**86**
Total	**102**	**116**	**218**

In addition, twenty-four (7 male & 17 female) students were recruited from the three year levels of undergraduate population in Exercise Science at Australian Catholic University to provide a sample of young adults to complete the final part of the investigation. These participants comprised a sample of convenience.

Table 7.2 Basic Anthropometrics of Primary Children and Young Adults - Mean (SD)

Gender	**Measure**	**Age-band 1**	**Age-band 2**	**Age-band 3**	**Age-band 4**	**Young Adults**
Female	N	22	28	35	31	17
	Age (years)	6.14 (0.61)	7.98 (0.57)	9.98 (0.63)	11.69 (0.50)	19.09 (0.57)
	Stature (cm)	116.47 (5.07)	129.11 (6.48)	140.84 (7.42)	149.29 (7.74)	164.97 (6.36)
	Mass (kg)	21.93 (3.19)	27.80 (5.31)	36.75 (6.06)	41.27 (9.10)	59.56 (6.16)
Male	N	11	33	40	18	7
	Age (years)	6.30 (0.49)	7.93 (0.49)	10.08 (0.58)	11.89 (0.52)	21.86 (6.00)
	Stature (cm)	120.82 (4.41)	129.27 (5.70)	140.61 (7.16)	153.36 (8.15)	175.79 (5.34)
	Mass (kg)	24.11 (3.10)	28.92 (4.33)	38.35 (12.13)	45.40 (7.50)	71.84 (5.87)
Total	N	33	61	75	49	24
	Age (years)	6.19 (0.57)	7.95 (0.52)	10.04 (0.60)	11.76 (0.51)	19.9 (3.36)
	Stature (cm)	117.92 (5.22)	129.20 (6.02)	140.72 (7.23)	150.79 (8.05)	168.13 (7.8)
	Mass (kg)	22.66 (3.28)	28.41 (4.80)	37.60 (9.75)	42.78 (8.70)	63.14 (8.24)

Group Matching Processes

In order to compare the gait parameters of the balance impaired and overweight/obese children in each age-band two matching processes were followed. The first, was to age, gender and stature match the balance impaired children with their typically developing peers (Table 7.3).

Table 7.3 Age, stature and mass of balance impaired and typically developing matched groups.

	Balance Classification	Mean (SD)
Males (n = 12)		
Age (years)	BI	10.5 (1.8)
	Non-BI	10.2 (1.5)
Stature (cm)	BI	145.1 (12.4)
	Non-BI	144.0 (11.2)
Mass (kg)	BI	43.0 (18.0)
	Non-BI	39.6 (8.9)
Females (n = 15)	BI	
Age (years)	Non-BI	10.2 (2.7)
	BI	9.9 (2.5)
Stature (cm)	Non-BI	141.0 (16.3)
	BI	140.7 (16.8)
Mass (kg)	Non-BI	38.2 (11.6)
	BI	37.0 (12.4)

Of the 218 children in the sample, 51 (23.4 %) were classified as overweight using the BMI measurement. A matching process using the variables of gender, age and stature was also performed before comparing the parameters of gait of the overweight and normal weight children (Table 7.4).

Table 7.4 Age, stature and mass of overweight and normal matched groups.

	BMI Classification	Mean (SD)
Males (n = 25)		
Decimal age	Normal	9.7 (1.8)
	Overweight	9.6 (1.7)
Height	Normal	140.3 (12.0)
	Overweight	140.2 (12.0)
Weight	Normal	34.3 (7.8)
	Overweight	44.7 (14.3)
Females (n = 26)		
Decimal age	Normal	9.4 (1.8)
	Overweight	9.2 (1.9)
Height	Normal	137.7 (11.6)
	Overweight	137.6 (11.9)
Weight	Normal	32.4 (7.2)
	Overweight	40.1 (9.4)

7.2 Measures

There were four sources of data.

- Parent/Guardian questionnaire (screening only),
- Anthropometric measurements,
- Movement Assessment Battery for Children (MABC), &
- Spatio-temporal kinematics of gait measured from the GAITRite™ walkway. A detailed description of each instrument can be found in study 1 Method (Chapter 4).

7.3 Procedure

Approval from the Australian Catholic University human research ethics committee was gained (V2002.03.28), along with approval to conduct research in Catholic schools from the Catholic Education Office (GE/04/0009). The protocol for the GAITRite walkway testing required the children to walk at three speeds: their self selected (normal) walking speed; a slower than normal walking speed, and; a faster then normal walking speed. The continuous walking protocol administered for study one was again used in this study. On this occasion, however, the walking was completed wearing their ‘everyday’ school shoes to replicate the day-to-day conditions encountered by each child. Participants were screened out if inappropriate footwear was worn (eg. thongs/flip flops). Offinger, Brauch, Cranfill, Hisle, Wynn, Hicks and Augsburger (1999) compared the gait of children (n = 14) barefoot and wearing shoes using 3-D motion analysis. Increases in stride length from the barefoot condition 125.4±13.55 to the shod condition were observed (137.18±11.4) (p = .032). No significant differences were noted for velocity or cadence between the two. It was concluded that the statistical differences did not appear to be clinically significant. Due to the large proportion of time children spend with shoes on, the shod condition was adopted to improve ecological validity. The instruction for each walking condition remained constant. For the normal walking speed each child was instructed to “walk at your normal pace, as if you were walking to school”, for the slow walking speed each child was instructed to “walk slower than usual, as if you were dawdling” and for the fast walking speed each child was instructed to “walk faster than normal, as if you are hurrying to catch a bus”.

Table 7.5 shows that there was a noticeable increase in mean velocities from the slow to the fast.

Table 7.5 Comparison of velocities at slow, normal and fast walking.

	Slow Walking (cm/s)	Normal Walking (cm/s)	Fast Walking (cm/s)
Mean (sd)	111.6 (11.8)	137.5 (16.4)	173.4 (20.7)

A repeated measures ANOVA was performed to confirm differences between the three walking speeds. Because the assumption of Mauchly's Test of Sphericity could not be met the Greenhouse-Geisser transformation was used for the analysis ($F(1.56,338.72) = 1518.81$, $p < .001$, $\eta_p^2 = .875$). Between subjects contrasts were performed between the three groups, all three groups were significantly different from each other ($p < .001$).

7.4 Data Analysis

Independent Variables

The children tested were categorised as either motor impaired or not according to the MABC. A score below the 15^{th} percentile was used as the cut-off for motor impairment (Henderson & Sugden, 1996). For the purpose of this study the children classified below the 15^{th} percentile on only the balance subscales were identified. Each individual age-band was also used for comparison. The comparison of the children across age-bands was made using normalised gait data. The normalisation methods used by Hof (1996) were employed for this investigation as in study one.

Body mass index was used to identify children who were overweight and obese. The 'cut-off' values used were based on normal curves reported by Cole et al. (2000).

Dependent Variables

All gait variables used were exported from the GAITRite software in ASCII format and managed in Microsoft Excel spreadsheet software. The gait variables used for comparison between the various groups are listed in table 7.6

Table 7.6 Gait variables units and abbreviations

Gait Variable	Unit	Abbreviation
gait velocity	($cm.s^{-1}$)	vel
cadence	($steps.min^{-1}$)	cad
step length	(cm)	sl
base of support	(cm)	bos
step time	(sec)	st
double support time	(sec)	dst

Average velocity and cadence for each of the 10 trials at each of the 3 walking speeds was recorded. The individual footfall data for sl, bos, st and dst were also recorded. Mean, standard deviation (SD) and coefficient of variation (CV) for each of the three walking speeds was calculated for each child. The average of the gait parameters and the average of the variability for the gait parameters was then used as the basis for comparisons between the groups.

The CV for the individual footfall data for the ten trials was used as the stride-to-stride variability measurement. The CV could not be calculated for the base of support and double support time variables due to the effect of negative (or zero) values on the mean. As a consequence of this, standard deviation was used to assess stride-to-stride variability of participants' base of support and double support time. This therefore did not permit direct comparison to be made between the variability of these measures and the four remaining variables.

7.5 Descriptive Statistics

All statistical analyses were performed using the SPSS for Windows verson 15.0.0 software package (SPSS Inc, Chicago, Illinois). Mean and standard deviations were calculated for each gait variable and were presented as descriptive statistics.

Assumption Testing

Normality

To determine the statistics met the assumptions for the analyses performed a Shapiro-Wilk test was used. A significant value $p < .05$ indicated a non-normal sample (Field, 2005). Additionally, skewness and kurtosis values were observed. Both skewness and kurtosis values were divided by their associated standard error providing a z-score. In both cases a z-score within ± 1.96 was accepted as representing a normal sample. In cases where non-normality was observed $\log_n$ transformations were performed. Where the $\log_n$ transforms did not remove a violation, non-transformed data were used and the results were interpreted with caution.

Multivariate

The multivariate statistics required additional assumption testing. Initially each of the dependent variables were assessed for univariate normality as reported above. The Box's test was then used to account for covariance (multivariate) ($p > .05$) and Levene's test of homogeneity of variance (univariate) ($p > .05$) was used to check the homogeneity of covariance (Field, 2005).

7.6 Hypothesis Testing

Hypothesis 1.

There will be a significant difference between the variability of the stride-to-stride gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD), step time (CV) & double support time (SD) for children classified in each age-band 1, 2, 3, 4 and the young adult sample.

Multiple Analysis of Variance (MANOVA) was performed for each gait speed, slow, normal and fast. The mean gait parameters were dependent variables in the analysis with the age classification the independent variable.

Hypothesis 2.

The variability of stride-to-stride gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD), step time (CV) & double support time (SD) will discriminate between the balance impaired and non-balance impaired children.

Due to the work in related fields linking gait variability to balance deficiencies this concept was explored (Bauby & Kuo, 2000; Gabell & Nayak, 1984; Heiderscheit, 2000; Thies, Richardson & Ashton-Miller, 2004). Rather then identify the significant differences of individual dependent variable, gait variability, as a whole was assessed. In order to test the ability of the gait parameters to identify balance impairment three discrete discriminant analyses were performed, one for each walking speed. A stepwise enter method was adopted to identify the most useful dependent variables.

Hypothesis 3.

There will be a significant difference between the variability of the stride-to-stride gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD), step time (CV) & double support time (SD) for children classified as overweight and children with normal weight.

Multiple Analysis of Variance (MANOVA) was performed for each gait speed, slow normal and fast. The stride-to-stride variability parameters were the dependent variables in the analysis with overweight classification the independent variable.

CHAPTER VIII

RESULTS II

8.1 Participant Details

Age, stature and mass were recorded for all participants. These are reported in Table 8.1 sub-divided according to gender.

Table 8.1 Age, stature and mass according to gender

	Mean (SD)	Range
Males (n = 126)		
Age (yrs)	9.2 (1.8)	5.4 – 12.9
Stature (cm)	136.0 (11.8)	111.5 – 169.6
Mass (kg)	33.9 (10.6)	17.5 – 93.0
Females (n = 139)		
Age (yrs)	9.2 (2.0)	5.1 – 12.7
Stature (cm)	135.7 (13.6)	106.0 – 166.0
Mass (kg)	33.0 (9.6)	18.9 – 61.4

No anthropometrical differences were noted between the genders. The results from both genders were therefore combined for the remainder of the investigation and gender was not considered to be an intervening variable in this study. In the case of the young adult comparison a combined group was also used. It is recognised that stature and mass differences may introduce a gender bias to the results for the young adult and possibly the 11 – 12 year old sample (Öberg, Karznia & Oberg, 1993). However, to minimise the effect of size on the comparison of the gait parameters across the different age-bands and genders a normalisation process was undertaken (Hof, 1996). It was noted that males were significantly taller (M = 175.8 cm, F = 165.0 cm ($t(22) = -3.949$, $p = .001$) and heavier (M = 71.8 kg, F = 59.6 kg ($t(22) = -4.498$, $p < .001$) at the young adult level, and mass.

8.2 Research Questions Findings

Rather then reporting all the descriptives before the inferential statistics, the results will be reported on a research question by research question basis.

Research Question 1.

What is the nature of the progression in the development of gait?

Descriptive Statistics

Table 8.2 reports the age and physical characteristics of the four age-band groups and the young adult sample.

Table 8.2 Age, stature, mass and BMI measurements of participants across age-bands

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n =24)
Age (years)	6.189 (0.573)	7.955 (0.525)	10.038 (0.602)	11.763 (0.511)	19.898 (3.358)
Stature (cm)	117.9 (5.2)	129.2 (6.0)	140.7 (7.2)	150.8 (8.1)	168.3 (7.8)
Mass (kg)	22.66 (3.28)	28.41 (4.80)	37.60 (9.75)	42.78 (8.70)	63.14 (8.24)
BMI	16.24 (1.54)	16.93 (1.95)	18.80 (3.41)	18.67 (2.75)	22.27 (1.95)

Descriptive statistics are reported for both the mean normalised parameters of gait and the stride-to-stride variability gait parameters. The mean gait parameters were dependent variables in the analysis with age classification the independent variable. Although, to account for the effect of participant size on gait the normalised gait parameters were used in the analysis (Hof, 1996), for ease of interpretation the raw data have been presented here. The normalised values are presented in full in Appendix G. A comparison of the gait parameters at the normal walking speed can be seen in Table 8.3a).

Table 8.3a) Summary of parameters of gait across age-bands at normal walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n = 24)
Velocity ($cm.sec^{-1}$)	137.1 (14.4)	141.0 (18.1)	135.2 (15.1)	136.9 (17.0)	145.9 (12.6)
Cadence ($steps.min^{-1}$)	154.6 (14.1)	142.4 (13.1)	129.6 (9.9)	124.7 (9.8)	116.5 (6.8)
Step Length (cm)	53.1 (4.2)	59.2 (4.9)	62.4 (5.1)	65.4 (6.5)	75.1 (4.9)
Step Time (sec)	0.39 (0.03)	0.43 (0.04)	0.47 (0.04)	0.48 (0.04)	0.52 (0.03)
Base of Support (cm)	7.1 (1.5)	7.6 (1.7)	7.7 (2.3)	7.4 (2.3)	9.9 (2.1)
Double Support Time (sec)	0.09 (0.03)	0.10 (0.03)	0.12 (0.03)	0.13 (0.03)	0.23 (0.03)

MANOVA revealed significant differences were found between the parameters of gait across the age-bands ($F(24,940) = 12.696$, $p = .000$, $\eta_p^2 = .245$). Univariate analysis showed significant differences were found for all individual gait across age-bands, velocity ($p < .001$), cadence ($p < .001$), step length ($p < .001$), step time ($p < .001$), base of support ($p < .001$) and double support time ($p < .001$).

Table 8.3b) Summary of parameters of gait across age-bands at slow walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n =24)
Velocity ($cm.sec^{-1}$)	108.6 (8.7)	112.7 (12.1)	111.7 (12.4)	112.2 (12.3)	118.5 (10.1)
Cadence ($steps.min^{-1}$)	140.0 (14.3)	128.5 (9.9)	118.9 (8.7)	113.1 (8.3)	104.7 (5.6)
Step Length (cm)	46.5 (4.2)	52.4 (4.6)	56.2 (5.0)	59.2 (5.9)	67.9 (4.6)
Base of Support (cm)	7.2 (4.6)	7.8 (2.0)	8.1 (2.4)	7.7 (2.1)	10.0 (2.0)
Step Time (sec)	0.44 (0.05)	0.47 (0.04)	0.51 (0.04)	0.54 (0.04)	0.58 (0.03)
Double Support Time (sec)	0.12 (0.03)	0.12 (0.03)	0.15 (0.04)	0.16 (0.03)	0.28 (0.03)

Significant differences were found between the parameters of gait across the age-bands ($F(24,940) = 12.974$, $p = .000$, $\eta_p^2 = .249$) at the slow walking speed. Significant differences were found across the age-bands for all individual gait variables using univariate analyses, velocity ($p < .001$), cadence ($p < .001$), step length ($p = .001$), step time ($p < .001$), base of support ($p < .001$) and double support time ($p < .001$).

Table 8.3c) Summary of parameters of gait across age-bands at fast walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n = 24)
Velocity ($cm.sec^{-1}$)	169.7 (21.7)	176.6 (21.3)	176.1 (20.0)	167.7 (19.1)	183.2 (11.0)
Cadence ($steps.min^{-1}$)	181.7 (23.3)	169 (17.7)	156.1 (17.0)	139.9 (10.7)	130.1 (6.5)
Step Length (cm)	56.1 (4.8)	62.6 (4.4)	67.6 (5.5)	71.9 (7.1)	84.5 (5.0)
Base of Support (cm)	7.1 (1.3)	7.6 (1.9)	8.0 (2.2)	7.8 (2.0)	9.9 (1.8)
Step Time (sec)	0.34 (0.04)	0.36 (0.03)	0.39 (0.04)	0.43 (0.03)	0.46 (0.02)
Double Support Time (sec)	0.07 (0.02)	0.07 (0.02)	0.09 (0.03)	0.10 (0.02)	0.18 (0.02)

Significant differences were found between the parameters of gait ($F(24,940) = 11.999$, $p = .000$, $\eta_p^2 = .235$) at the fast walking speed. Significant differences were found across all gait parameters using univariate analyses, velocity ($p < .001$), cadence ($p < .001$), step length ($p < .001$), step time ($p < .001$), base of support ($p = .001$) and double support time ($p < .001$).

In most cases the cadence decreased and the step length, base of support, step time and double support time increased with increasing age across the three walking speeds.

Hypothesis 1.

Following the findings from study one the stride-to-stride variability of each of the gait parameters was the measure used to identify differences between the age-bands. The following hypothesis was therefore tested. *There will be a significant difference between the variability of the stride-to-stride gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD), step time (CV) & double support time (SD) for children classified in each age-band 1, 2, 3, 4 and young adults.*

Multiple Analysis of Variance (MANOVA) was performed for each gait speed, slow, normal and fast. The stride-to-stride variability of the gait parameters were the dependent variables in the analysis with age classification the independent variable.

Table 8.4a) Summary of the variability of stride-to-stride gait parameters across age-bands at normal walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n = 24)
vel (CV)	8.0 (2.2)	7.2 (3.1)	5.8 (2.9)	4.9 (1.7)	3.1 (1.4)
cad (CV)	5.0 (2.3)	4.8 (2.5)	3.5 (1.9)	2.8 (1.5)	1.5 (0.5)
sl (CV)	6.1 (1.6)	6.3 (1.9)	5.2 (1.7)	4.6 (1.4)	3.1 (1.0)
bos (SD)	2.5 (0.7)	2.5 (0.8)	2.4 (0.5)	2.3 (0.7)	1.9 (0.5)
st (CV)	6.4 (1.9)	6.0 (2.2)	4.8 (1.8)	4.1 (1.4)	3.10 (0.47)
dst (SD)	0.023 (0.005)	0.023 (0.007)	0.022 (0.006)	0.020 (0.005)	0.019 (0.006)

Significant differences were found for the variability of the stride-to-stride gait parameters between the age-bands (F(24,940) = 4.660, p = .000, η_p^2 = .106) at the normal walking speed. Significant differences were found using the univariate analysis for each of the parameters of velocity (p < .001), cadence (p < .001), step length (p = .001), base of support (p = .001) and step time (p < .001). Double support time was not significantly different (p > .05).

Table 8.4b) Summary of the variability of stride-to-stride gait parameters across age-bands at the slow walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n = 24)
vel (CV)	10.8 (4.1)	8.7 (3.4)	6.5 (2.2)	5.8 (1.9)	3.7 (2.0)
cad (CV)	5.8 (3.3)	4.9 (2.4)	4.0 (1.7)	3.6 (1.5)	2.0 (1.0)
sl (CV)	9.2 (2.9)	7.8 (2.3)	6.2 (1.7)	5.3 (1.4)	3.5 (1.2)
bos (SD)	2.2 (0.5)	2.4 (0.5)	2.4 (0.6)	2.5 (0.7)	1.8 (0.6)
st (CV)	7.7 (3.3)	6.6 (2.6)	5.3 (1.6)	5.1 (1.6)	3.66 (0.75)
dst (SD)	0.027 (0.005)	0.025 (0.007)	0.023 (0.005)	0.023 (0.008)	0.026 (0.013)

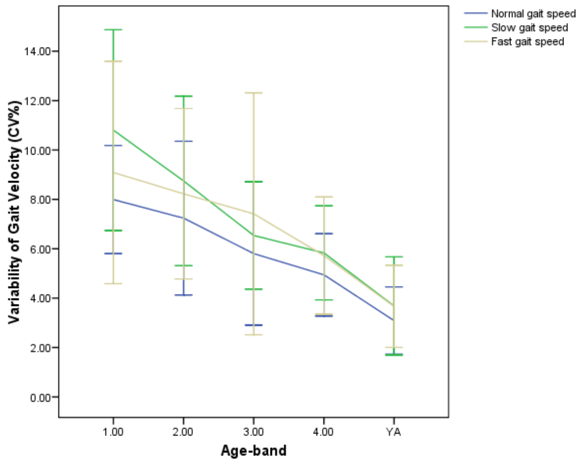
Significant differences were found between the variability of the stride-to-stride gait parameters across the age-bands (F(24,940) = 7.343, p = .000, η_p^2 = .158) at the slow walking speed. Significant differences were found using univariate analyses for all the individual parameters of velocity (p < .001), cadence (p < .001), step length (p = .001), base of support (p < .001), step time (p < .001) and double support time (p = .041).

Table 8.4c) Summary of the variability of stride-to-stride gait parameters across age-bands at the fast walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n = 24)
vel (CV)	9.1 (4.5)	8.2 (3.4)	7.4 (4.9)	5.7 (2.4)	3.7 (1.7)
cad (CV)	7.1 (4.2)	7.1 (4.0)	5.2 (3.4)	3.3 (2.2)	1.7 (0.9)
sl (CV)	6.2 (2.1)	5.7 (1.9)	5.0 (1.7)	4.6 (1.5)	3.2 (0.9)
bos (SD)	2.6 (0.9)	2.6 (0.9)	2.3 (0.7)	2.3 (0.6)	1.9 (0.4)
st (CV)	8.3 (4.4)	7.7 (3.1)	6.0 (2.5)	4.3 (1.5)	3.21 (0.71)
dst (SD)	0.026 (0.011)	0.022 (0.009)	0.019 (0.005)	0.018 (0.018)	0.016 (0.004)

Significant differences were found for the variability of the stride-to-stride gait parameters across the age-bands ($F(24,940) = 5.140$, $p = .000$, $\eta_p^2 = .116$) for the fast walking speed. Significant differences were found using univariate analyses for each of the individual parameters of velocity (p < .001), cadence (p < .001), step length (p = .001), base of support (p = .001), step time (p < .001) and double support time (p = .041).

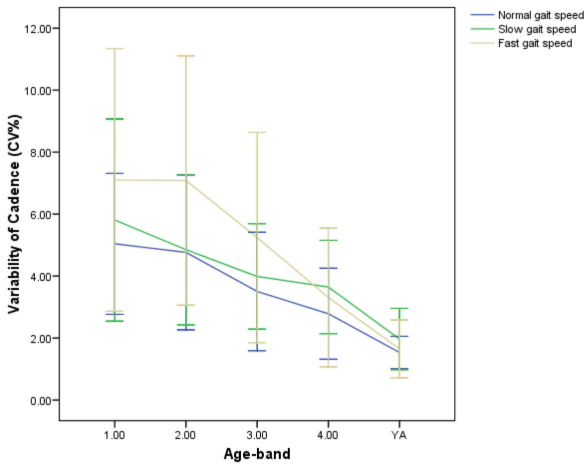
Following the identification of a significant difference across the age-bands for individual parameters pairwise comparisons between the adjacent age categories were undertaken in order to find the sources of the difference. The actual p-values for each comparison are reported in the accompanying tables. The results for each speed are combined to facilitate comparison.



		Pairwise Analysis p-values		
Age-Band	Vs	Normal	Slow	Fast
1	2	0.174	**0.001**	0.300
2	3	**0.001**	**0.000**	0.219
3	4	0.067	0.171	**0.017**
4	5	**0.004**	**0.002**	**0.032**

Figure 8.1 Comparison of the variability of gait velocity between age-bands

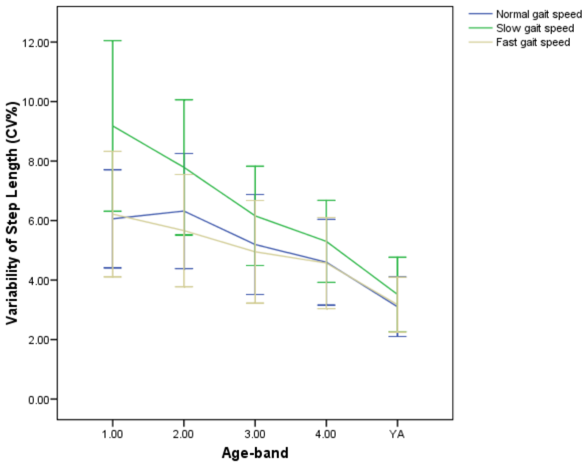
It can be seen from Figure 8.1 that there was a consistent trend of decreasing variability of gait velocity with increasing age. It can be noted from the pairwise comparisons that at each of the three walking speeds the young adults were significantly less variable then the oldest children in age-band 4.



		Pairwise Analysis p-values		
Age-Band	Vs	Normal	Slow	Fast
1	2	0.519	**0.036**	0.980
2	3	**0.000**	**0.017**	**0.002**
3	4	**0.048**	0.375	**0.002**
4	5	**0.011**	**0.001**	**0.048**

Figure 8.2 Comparison of the variability of cadence between age-bands

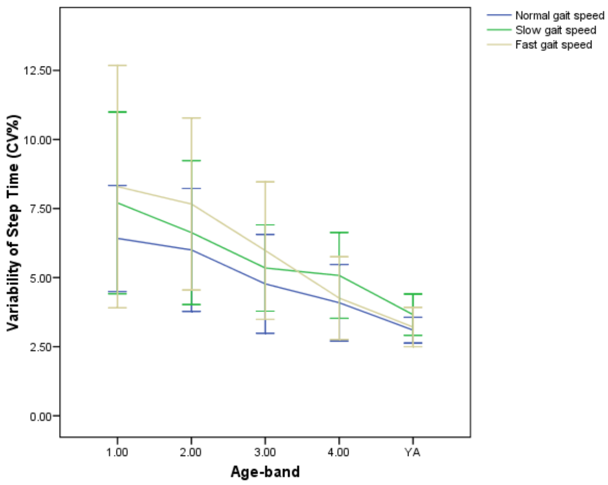
A similar downward trend was observed in the variability of cadence across age-bands in Figure 8.2. The young adult group was again significantly less variable then the children in age-band 4.



		Pairwise Analysis p-values		
Age-Band	Vs	Normal	Slow	Fast
1	2	0.466	**0.001**	0.138
2	3	**0.000**	**0.000**	**0.018**
3	4	0.051	**0.017**	0.235
4	5	**0.000**	**0.000**	**0.001**

Figure 8.3 Comparison of the stride-to-stride variability of step length between age-bands

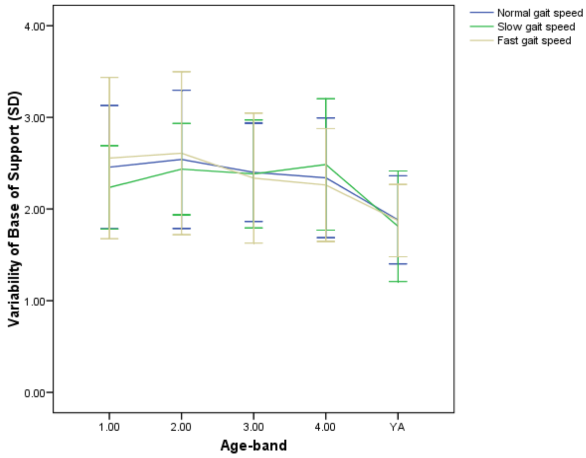
Step length variability decreased with increasing age as noted from Figure 8.3. The pairwise analysis reported a significant difference between the young adults and the oldest children in age-band 4 and between age-band 2 and 3 for all speeds and between all groups at the slow speed.



		Pairwise Analysis p-values		
Age-Band	Vs	Normal	Slow	Fast
1	2	0.282	**0.019**	0.289
2	3	**0.000**	**0.001**	**0.000**
3	4	**0.038**	0.490	**0.001**
4	5	**0.026**	**0.008**	0.125

Figure 8.4 Comparison of the stride-to-stride variability of step time between age-bands

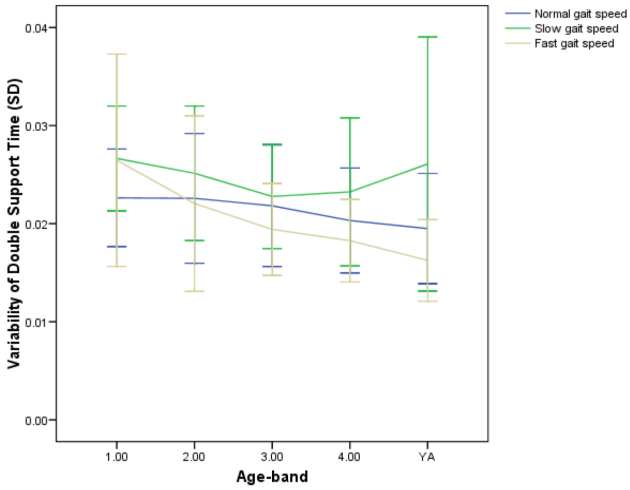
The downward trend of stride-to-stride variability was also noted for step time across the age-bands. However, while walking at the fast speed the young adults were not significantly different from the children in age-band 4.



Age-Band	Vs	Pairwise Analysis p-values Normal	Slow	Fast
1	2	0.540	0.114	0.741
2	3	0.199	0.606	**0.035**
3	4	0.613	0.338	0.585
4	5	**0.004**	**0.000**	**0.037**

Figure 8.5 Comparison of the stride-to-stride variability of base of support across age-bands

No clear downward trend was observed for the base of support variability. The young adult group were, however, significantly less variable then the children in age-band 4.



Age-Band	Vs	Pairwise Analysis p-values Normal	Slow	Fast
1	2	0.971	0.336	**0.004**
2	3	0.458	0.060	**0.029**
3	4	0.170	0.727	0.367
4	5	0.580	0.116	0.247

Figure 8.6 Comparison of the stride-to-stride variability of double support time across age-bands

Little difference was found between the age-bands for double support time variability. A slight downward trend was observed while walking fast from age-bands 1 to 2 and then from age-bands 2 to 3 upon analysis of the pairwise results.

The gait parameters in general continued to decrease beyond the commonly reported age of seven. In the majority of cases there were significant differences between the young adult group and the children from age-band 4. These results were therefore taken as providing general support for the acceptance of the first hypothesis.

Research Question 2.

Can parameters of gait be used to discriminate between balance impaired children and non-balance impaired children?

Eighty-two of the 265 children tested on the MABC scored below the 15th percentile (according to the Henderson & Sugden, 1996 cut-offs), thus, meeting the criterion for being classified as motor impaired. This equated to 30.9 % of this sample. It can be seen from Figure 8.7 that when the error points are analysed according to the three sub-scales it is their performance on manual dexterity that is the major reason for these participants being categorised as motor impaired. Manual dexterity does not, however, logically impact on the control of locomotion, consequently only those who were identified as balance impaired were used in this analysis.

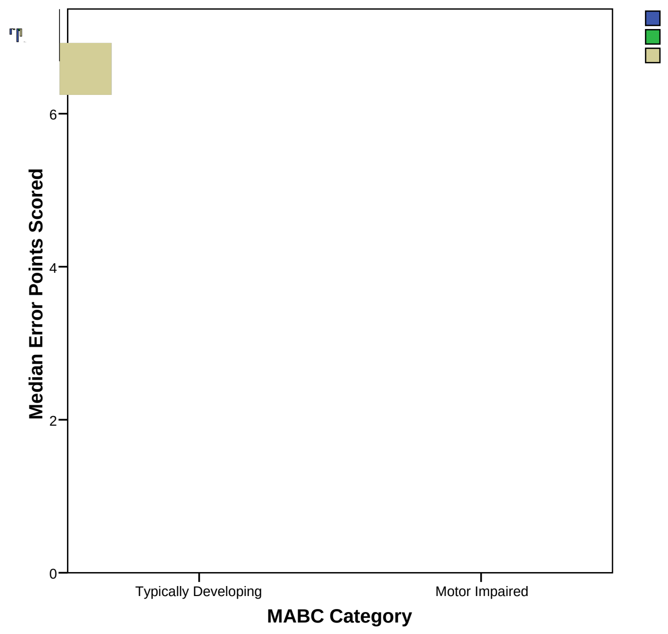


Figure 8.7 Breakdown in MABC sub-scale scores for the motor impaired and typically developing children.

Before performing the group gait comparisons children of similar gender, age and stature were matched with those identified as balance impaired and allocated to the typically developing group.

Descriptive statistics of gait parameters for balance impaired and non-balance impaired children

The following provides a comparison of the gait parameters of the balance impaired and non-impaired children across the three walking speeds. All data were normalised for the analysis however the non-normalised data are presented here for ease of understanding.

Table 8.5a) Comparison of parameters of gait at normal walking speed for children classified as balance impaired and non-impaired.

	BI	Non-BI
Velocity ($cm.sec^{-1}$)	136.24 (18.74)	139.51 (14.33)
Cadence ($steps.min^{-1}$)	130.96 (17.58)	132.17 (13.78)
Step Length (cm)	62.58 (6.92)	63.55 (6.95)
Base of Support (cm)	0.47 (0.06)	0.46 (0.05)
Step Time (sec)	7.83 (2.52)	7.34 (1.81)
Double Support Time (sec)	0.12 (0.04)	0.12 (0.03)

MANOVA showed that none of the normalised gait parameters were significantly different between the typically developing and the balance impaired children at the normal walking speed ($F(6,65) = 0.590$, $p = .737$, $\eta_p^2 = .052$).

Table 8.5b) Comparison of parameters of gait at slow walking speed for children classified as balance impaired and non-impaired.

	BI	Non-BI
Velocity ($cm.sec^{-1}$)	110.43 (12.15)	113.24 (10.91)
Cadence ($steps.min^{-1}$)	118.48 (14.25)	121.32 (12.51)
Step Length (cm)	56.21 (6.96)	56.26 (6.91)
Base of Support (cm)	0.51 (0.06)	0.50 (0.05)
Step Time (sec)	8.10 (2.65)	7.57 (1.77)
Double Support Time (sec)	0.15 (0.04)	0.14 (0.03)

Similarly, MANOVA showed that none of the normalised gait parameters were significantly different between the typically developing and the balance impaired children at the slow walking speed ($F(6,65) = 0.404$, $p = .874$, $\eta_p^2 = .036$).

Table 8.5c) Comparison of parameters of gait at fast walking speed for children classified as balance impaired and non-impaired.

	BI	Non-BI
Velocity ($cm.sec^{-1}$)	171.45 (23.58)	172.1 (20.75)
Cadence ($steps.min^{-1}$)	154.44 (27.76)	150.75 (18.55)
Step Length (cm)	67.20 (7.44)	68.93 (8.70)
Base of Support (cm)	0.40 (0.06)	0.40 (0.05)
Step Time (sec)	8.05 (2.16)	7.72 (1.79)
Double Support Time (sec)	0.09 (0.03)	0.09 (0.02)

Once again, MANOVA showed that none of the normalised gait parameters were significantly different between the typically developing and the balance impaired children at the fast walking speed ($F(6,65) = 1.525$, $p = .184$, $\eta_p^2 = .123$).

Hypothesis 2.

The variability of stride-to-stride gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD), step time (CV) & double support time (SD) will discriminate between the balance impaired and non-balance impaired children.

Descriptive statistics were calculated for the balance and non-balance impaired children's stride-to-stride variability gait parameters and are reported in Table 8.6.

Table 8.6 Comparison of stride-to-stride gait variability parameters for children classified as balance impaired and non-balance impaired at normal, slow and fast walking speed.

	Normal		Slow		Fast	
	BI	non-BI	BI	non-BI	BI	non-BI
Velocity (CV)	6.65 (3.26)	5.71 (1.83)	8.06 (3.76)	6.50 (2.83)	8.34 (4.45)	5.37 (1.92)
Cadence (CV)	4.42 (3.27)	3.17 (1.48)	5.19 (3.24)	3.49 (1.45)	5.76 (4.72)	3.90 (2.69)
Step Length (CV)	5.54 (1.97)	4.77 (1.13)	7.18 (3.01)	5.72 (1.85)	5.51 (2.02)	4.71 (1.99)
Step Time (CV)	5.62 (2.88)	4.34 (1.38)	6.64 (3.44)	4.91 (1.46)	6.80 (4.81)	4.75 (2.21)
Base of Support (SD)	2.58 (0.50)	2.43 (0.64)	2.69 (0.71)	2.28 (0.47)	2.57 (0.75)	2.26 (0.53)
Double Support Time (SD)	0.02 (0.01)	0.02 (0.00)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)	0.02 (0.01)

In order to test the ability of the gait parameters to discriminate between those with balance impairment and their peers three discrete discriminant analyses were performed, one for each walking speed. A stepwise enter method was adopted to identify the most useful dependent variables.

The first discriminant analysis was conducted to assess which of the six gait parameters at the normal speed, velocity (CV), Cadence (CV), Step length (CV), Step time (CV), Base of support (SD) and Double support time (SD) could distinguish those who were classified as balance impaired from those who were not. Wilks' lambda was significant, $\lambda = .924$, $\chi^2 = 5.506$, $p = .019$, which indicates that the model including only Step time (CV) was able to significantly discriminate between the two groups. The classification results however, showed that only a small percentage of cases were correctly predicted (58.3 %).

The second discriminant analysis was conducted to assess which of the same six gait parameters at the slow speed could distinguish those who were classified as balance impaired from those who were not. Wilks' lambda was significant, $\lambda = .819$, $\chi^2 = 13.742$, $p = .001$, which indicates that the model including the two variables, Base of Support (SD) and Cadence (CV) was able to significantly discriminate between the two groups. The classification results show that the model correctly predicted 72.2 % of cases.

Table 8.7 Classification results – Balance Impaired and Non-Impaired children at slow walking speed.

			Predicted Group Membership		Total
			Balance Impaired (<15%ile)	Not Impaired (>15%ile)	Balance Impaired (<15%ile)
Original	Count	Balance Impaired (<15%ile)	23	13	36
		Not Impaired (>15%ile)	7	29	36
	%	*Balance Impaired (<15%ile)*	*63.9*	*36.1*	*100*
		Not Impaired (>15%ile)	*19.4*	*80.6*	*100*

72.2% of original grouped cases correctly classified.

The third discriminant analysis was conducted to assess whether the same gait parameters walking at the fast speed could distinguish those who were classified as balance impaired from those who were not. Wilks' lambda was significant, $\lambda = .839$,

χ^2 = 12.299, p < .001, which indicated that the model including only Velocity (CV) was able to predict membership of the two groups. The classification results however, only reported a relatively small percentage of cases (63.9 %) which were correctly classified into the correct groups.

These results show some limited support for the second research hypothesis. The ability to discriminate between the balance impaired and typically developing children varied according to the walking speed. While walking at the slow speed, base of support variability and cadence variability together were able to correctly classify 72.2% of cases as either balance-impaired or non-impaired. At the normal and fast pace the variability in step time and velocity were the best discriminators but less effective and thus were less able to discriminate between the two groups.

Research Question 3.

Do overweight children have a greater incidence of impaired balance and coordination than their peers while walking?

Comparison of gait parameters of the overweight and normal BMI children

The outcome of the matching process is reported below.

Table 8.8 Comparison of age and stature in the overweight and normal groups

	Overweight	Normal
Age (years)	9.52 (1.81)	9.42 (1.80)
Stature (cm)	138.91 (11.93)	139.01 (11.75)

Table 8.9 reports the means of the anthropometric variables for the two groups.

Table 8.9 Comparison of anthropometric variables of the overweight and normal groups.

	Overweight	Normal
Mass (kg)	42.39 (12.16)	33.36 (7.46)
Leg Length (L & R mean)	74.92 (7.56)	74.94 (7.97)
BMI	21.5 (3.1)	17.0 (1.4)

The gait parameters of the overweight and normal BMI children were compared across each of the three walking speeds. The descriptive statistics are presented in the following tables.

Table 8.10a) Comparison of normal speed gait parameters for normal and overweight children.

	Normal	Overweight
Velocity ($cm.sec^{-1}$)	137.99 (17.03)	132.60 (16.10)
Cadence ($steps.min^{-1}$)	132.18 (13.49)	131.24 (13.32)
Step Length (cm)	62.70 (7.39)	60.64 (6.00)
Base of Support (cm)	7.62 (1.70)	8.58 (2.54)
Step Time (sec)	0.46 (0.04)	0.46 (0.05)
Double Support Time (sec)	0.11 (0.03)	0.13 (0.04)

MANOVA found that the overweight children displayed a significantly different walking pattern to that of the normal weight children ($F(6,95) = 4.086$, $p = .001$, $\eta_p^2 = .205$). Post hoc analysis showed the source of the differences were that base of support was significantly larger ($p = .027$) and double support time was significantly longer ($p = .002$).

Table 8.10b) Comparison of slow speed gait parameters for normal and overweight children.

	Normal	Overweight
Velocity ($cm.sec^{-1}$)	112.93 (12.76)	109.70 (12.56)
Cadence ($steps.min^{-1}$)	120.38 (10.62)	119.81 (13.32)
Step Length (cm)	56.36 (7.01)	54.94 (5.38)
Step Time (sec)	0.50 (0.04)	0.51 (0.06)
Base of Support (cm)	7.70 (1.99)	9.21 (2.44)
Double Support Time (sec)	0.14 (0.03)	0.16 (0.04)

MANOVA found the overweight children displayed a significantly different walking pattern to the normal weight children ($F(6,95) = 5.136$, $p = .000$, $\eta_p^2 = .245$). The univariate analyses results again showed that the base of support was significantly larger ($p = .001$) and double support time was significantly longer ($p = .002$).

Table 8.10c) Comparison of fast speed gait parameters for normal and overweight children.

	Normal	Overweight
Velocity (cm.sec^{-1})	176.32 (21.97)	169.22 (20.49)
Cadence (steps.min^{-1})	158.09 (20.28)	155.05 (19.29)
Step Length (cm)	67.21 (7.70)	65.71 (6.90)
Step Time (sec)	0.39 (0.05)	0.39 (0.05)
Base of Support (cm)	7.74 (1.81)	8.87 (2.33)
Double Support Time (sec)	0.08 (0.02)	0.09 (0.03)

MANOVA showed that the overweight children displayed a significantly different walking pattern to the normal weight children ($F(6,95) = 3.199$, $p = .007$, $\eta_p^2 = .168$). It was found upon univariate analyses that the source of the difference was again that the base of support was significantly larger ($p = .007$) and double support time was significantly longer ($p = .001$) for the balance impaired children.

Hypothesis 3.

There will be a significant difference between the variability of the stride-to-stride gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD), step time (CV) & double support time (SD) for children classified as overweight and children with normal weight.

Multiple Analysis of Variance (MANOVA) was performed for each gait speed, slow normal and fast. The stride-to-stride variability parameters were dependent variables in the analysis with weight classification the independent.

Table 8.11a) Comparison of normal speed stride-to-stride gait variability parameters for children classified according to BMI as normal and overweight.

	Normal	Overweight
Velocity (CV)	6.41 (3.12)	6.21 (2.62)
Cadence (CV)	4.02 (2.46)	3.80 (2.06)
Step Length (CV)	5.54 (1.78)	5.34 (1.96)
Step Time (CV)	5.22 (2.29)	5.15 (2.02)
Base of Support (SD)	2.37 (0.60)	2.50 (0.56)
Double Support Time (SD)	0.02 (0.01)	0.02 (0.01)

No significant differences were found between the overweight and normal children's parameters of stride-to-stride gait variability at their normal walking speed ($F(6,95) = 0.823$, $p = .555$, $\eta_p^2 = .049$).

Table 8.11b) Comparison of slow speed stride-to-stride gait variability parameters for children classified according to BMI as normal and overweight.

	Normal	Overweight
Velocity (CV)	7.38 (3.44)	7.70 (3.86)
Cadence (CV)	4.22 (1.77)	4.37 (2.57)
Step Length (CV)	6.49 (1.89)	6.93 (2.77)
Step Time (CV)	5.66 (1.70)	5.99 (2.88)
Base of Support (SD)	2.33 (0.53)	2.48 (0.51)
Double Support Time (SD)	0.02 (0.01)	0.02 (0.01)

No significant differences were found between the overweight and normal children's parameters of stride-to-stride gait variability at their slower then normal walking speed ($F(6,95) = 0.758$, $p = .604$, $\eta_p^2 = .046$).

Table 8.11c) Comparison of fast speed stride-to-stride gait variability parameters for children classified according to BMI as normal and overweight.

	Normal	Overweight
Velocity (CV)	6.77 (2.92)	7.53 (3.89)
Cadence (CV)	4.93 (3.34)	5.36 (3.42)
Step Length (CV)	5.39 (1.94)	5.13 (1.54)
Step Time (CV)	5.87 (2.51)	6.19 (2.84)
Base of Support (SD)	2.40 (0.73)	2.40 (0.71)
Double Support Time (SD)	0.02 (0.01)	0.02 (0.01)

No significant differences were found between the overweight and normal children's parameters of stride-to-stride gait variability at their faster then normal walking speed ($F(6,95) = 0.573$, $p = .751$, $\eta_p^2 = .035$).

The third research hypothesis was not supported. None of the stride-to-stride variability parameters of gait were found to be significantly different for children classified as overweight.

CHAPTER IX

DISCUSSION II

The motivation behind the current studies was to improve the screening and evaluation processes for children with poor motor skills. It was believed that the utilisation of an efficient, reliable and valid assessment tool would aid the early identification of at risk children. The value of early identification is highlighted in the context of the 'vicious cycle' of hypo-activity, poor skills > low self esteem > less activity > less opportunity to practice > and less skill development in which 'at risk' children can become entrapped. Once identified as 'at risk', intervention strategies can be developed and individualised to the specific needs of children in order to facilitate their participation in more physical activity. Participation in regular physical activity is emerging as a corner stone of a healthy start to life.

Five key issues from study one provided the line of inquiry which was pursued in study 2. They were as follows:

(1) Evidence of a developmental trend for selected gait parameters in the younger two age-bands which warranted further investigation with older children and young adults. Specifically, the variability of gait velocity and cadence measurements showed a decrease from age-band 1 to 2. A larger sample of children in the older age-bands of the MABC and a young adult sample were included in the second study in order to examine the gait variability across the age-bands and in comparison with a mature sample.

(2) Walking at the normal speed did not a provide any strong basis for discriminating between motor impaired and non-impaired children and there were no significant trends distinguishing the parameters of gait of the motor

impaired and those from the typically developing children. Perhaps due to the well learned/practised nature of walking at normal speed (self-selected), children classified as motor impaired have developed the same consistency as the non-impaired children. Following the assumption that the impaired children might not have the same degree of experience/practice when walking outside their 'comfortable' self-selected pace, they might, exhibit a less consistent pattern reflected in more variable stride-to-stride gait parameters, if this task was more varied. Increasing the task demands by the addition of both slow and fast walking conditions might therefore provide outcome measures that better discriminate between the two groups;

(3) If the above assumption holds true, the persistence of a higher degree of stride-to-stride variability than observed in same age peers may yet be a useful tool to identify maturation/development/delay or impairment of the fundamental motor skill of walking;

(4) The criteria used in this study for the classification of children as 'motor impaired' might need to be reviewed. Study one, in common with others (Kaplan, Dewey, Crawford, Wilson, 2001; Piek & Edwards, 1997), screened children according to their total MABC impairment score which included their performance on three sub-scales (manual dexterity, ball skills & balance tasks). It was noted that, for the sample as a whole, poor performance in manual dexterity actually contributed the majority of overall points to the total impairment score. Yet conceivably, children confronted with difficulty in fine motor tasks may still walk quite normally. The notion of DCD as a generic condition may no longer be useful. Thus, there may be more value now in identifying children within the more specific subgroup classifications. Should

this be the case it would make more sense to use the balance sub-scale as the criterion for identifying motor impairment in gross motor skills because of its clear conceptual relationship to successful locomotion;

(5) A high prevalence of motor impairment (28.7 %) was reported in the sample of participants from study one. This finding is at the high end of previously reported prevalence which ranged from 4.1 – 35 % (Piek & Edwards, 1997; Piek et al., 2004; Revie & Larkin, 1995; Walkley, Holland, Treloar & Probyn-Smith, 1993). From a population similar to that used in the current study, Williams (2008) reported that 37.6 % of his primary aged sample was classified as having DCD using the MABC 15th percentile cut-off as the criterion (Henderson & Sugden, 1996). These findings warrant further investigation within the Australian population. Further, the children identified as motor impaired, in the first study, were heavier (29.3 kg) and had a larger BMI (17.1) then their typically developing peers (27.0 kg) and (15.9). Consequently, an analysis of the children who were classified as overweight was performed. Eight of the total 87 children were categorised as overweight according to their BMI score. Of those eight, five were also identified as motor impaired. A chi-squared analysis revealed that the overweight children were 4.13 times more likely to be classified as motor impaired. Further investigation into the impact of body mass on motor impairment was required with a larger sample to confirm this finding.

The second study aimed to answer three research questions as a result of the refinement and development of these key issues.

9.1 Normal Development of Gait (Research Question 1.)

The first research question was: *What is the nature of the progression in the development of gait*? This was addressed by identifying the developmental trends for the stride-to-stride variability of the parameters of gait during the primary school years. If we are to use gait to identify children with balance impairment or developmental coordination disorder, it is clearly important to understand first the normative dimensions of the dynamics of gait throughout childhood. The fundamental motor skill of gait has been widely considered to be approaching maturity approximately around seven years of age (Gallahue & Ozmun, 2006). A number of studies investigating individual gait parameters have been cited in support of this notion. The muscle activity measured with EMG, kinematics (joint ranges of motion) and kinetics (joint moments and powers), gait efficiency, gait symmetry and variability have all been measured and assessed as being 'adult-like' by seven years (Ganley, 2004; Jeng et al., 1996; Jeng et al., 1997; McFadyen, 2001; Sutherland et al., 1988). Additionally, biarticluar joint power generation/absorption, at age six and step length, cadence, base of support and single support phase, have been shown to be adult like even earlier, at age five (Desloovere, 2004; Langerak, 2001). It is the contention of the current study, however, that the reporting of 'gait maturation' is largely dependent on the parameters being measured, each of which may reflect the 'maturation' of a number of different control systems, visual, kinaesthetic, neuromuscular etc. Gait as a whole may only be 'mature' when the last of these control systems is refined. For example, Lagerak et al. (2001) have suggested that cadence is mature by age 6 years, yet in this study when the intra-individual variability in cadence is measured from walking trial to trial it is clear that the control of cadence is yet to mature by age 12, as can be seen in the following figure. Therefore, when the measurement of the neuromuscular system's ability to apply a steady stable gait pattern is used as the dependent measure, different conclusions can be drawn than when measuring the gross outcome (mean cadence) of walking.

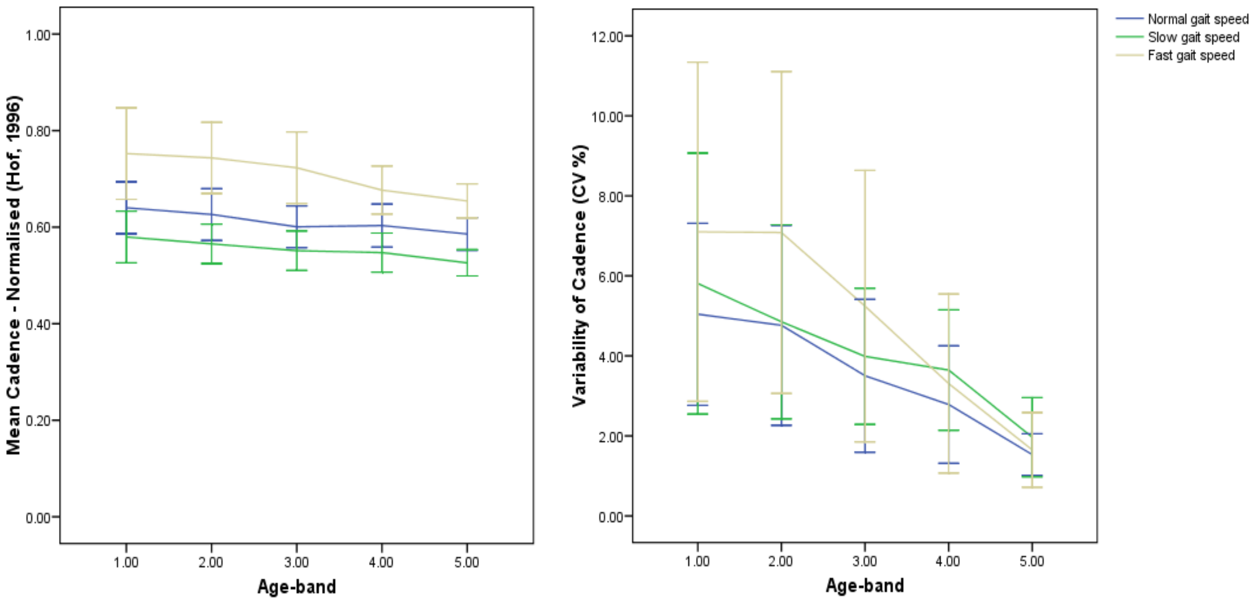


Figure 9.1 Comparison of cadence mean and intra-individual variability across age-bands.

Although the variability measures make this point most clearly, the mean descriptive measures in this study cast doubt on the notion of early maturation. In this study each parameter of gait was normalised in order to control for the differing sizes of the participants in each group. At each of the three walking speeds the double support time (longer), width of base of support (wider) and step lengths (longer) were all significantly different for the young adults when compared with those of the children. It is concluded from these findings that these primary aged children on the whole did not display 'adult-like' gait features by age seven, nor even by age 12. Analysis of the normalised values revealed that the 11 to 12 year old children walked with a narrower base of support, a shorter step length and a shorter double support time, for their size, compared to the young adults. This is taken as preliminary evidence that the gait parameters of this sample have not reached maturity even when mean descriptors are used as the dependent measure.

However, this study focussed on variability as the dependent measure. Few studies have investigated changes in the variability of stride-to-stride gait parameters measure during childhood. One of these, (Hausdorff et al., 1999) found that the stride-to-stride variability in stride time decreased with increasing age and that it had not yet reached maturity by seven years of age when compared to that of children aged 11 – 14 years. Findings from the current study support this notion and go even further, identifying that the process of the development of 'adult like' gait is continuing past age 12. Specifically velocity, cadence, step length and base of support all showed significantly greater variability for the 11 – 12 year old children then the measures found for the young adult sample. This provides support for the first hypothesis that: *There will be a significant difference between the variability of the stride-to-stride gait parameters of velocity (CV), cadence (CV), step length (CV), base of support (SD), step time (CV) & double support time (SD) for children classified in each age-band 1, 2, 3, 4 and young adults*. Further, as noted and going beyond the findings of Hausdorff et al. (1999), the data in this study show the dynamics of gait seem to still be maturing past 12 years of age and into early adulthood. The variability of gait pattern is said to be controlled by upper level neural activity (basal ganglia) (Hausdorff, Cudkowicz, Firtion, Wei & Goldberger, 1998), maturation of which still seems to be developing prior to young adulthood (Luna, Thulborn, Munoz, Merriam, Garver, Minshew, Keshavan, Genovese, Eddy & Sweeney, 2001). The significance of these findings is that change in stride-to-stride variability may be used as a measure of gait development and maturity well into the teenage years. This provides an improvement on current motor skill batteries which, on the whole, only test up to age 12. The usefulness of this measurement however is dependent on the development of a ‘normative’ database for comparison. This notion is picked up later in this chapter.

9.2 Balance Impairment (Research Question 2.)

Can parameters of gait be used to discriminate between balance impaired children and non-balance impaired children? Discriminant analyses were performed at each walking speed to determine the degree to which the variability of stride-to-stride gait parameters could correctly identify balance impaired and non impaired children.

The use of both slow and fast gait speed as a measure of increasing the task difficulty was a feature of this study. It has provided evidence that by increasing task demand, the measurement of stride-to-stride variability was able to identify differences between the balance impaired and non-impaired groups that would otherwise have remained ‘hidden’ at normal speeds.

Across all three walking speeds the average parameters of gait did not significantly differ between the balance impaired children and their non-impaired peers. It could be suggested that the balance impaired children walked at a similar pace with a similar cadence to the non-impaired children. It was noted, though, that as a group the balance impaired children had a wider standard deviation in many parameters. It may be that individual differences in selected parameters were masked by both the diverse nature of the group and the intra-individual variability. This possibly can be seen in the following figure.

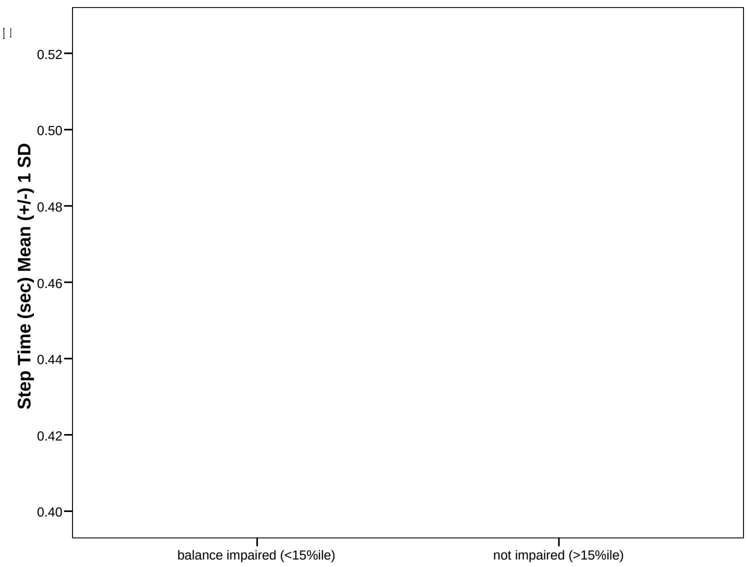


Figure 9.2 Mean step time (+/-) 1 Standard Deviation of Balance Impaired and non-impaired.

When variability in selected stride-to-stride gait parameters, however, was used as the dependent variable, differences emerged between the two groups. Further, significant differences were observed only in speeds/conditions with higher task demands both slow and fast. Cadence, step length, step time and base of support were all more variable for the balance impaired children while walking at a slower speed. Velocity, cadence and step time were all significantly more variable while walking at the faster speed. The effectiveness of these parameters in identifying motor impairment was tested by using three discriminant analyses, one for each walking speed. All six of the gait parameters (velocity, cadence, step length, base of support, step time and double support time) were included in each of the three analyses. Using a stepwise enter method, only the most significant discriminator variables were included in the final model. At the normal walking speed, step time (CV) was the only parameter to significantly discriminate between the balance impaired and non-impaired children and then only a relatively small percentage of cases were correctly predicted (58.3 %). MANOVA found none of the stride-to-stride variability parameters to be significantly different between the groups while walking at their normal self-selected pace.

The second discriminant analysis, using the six slow walking speed stride-to-stride variability gait parameters, was able to correctly predict a much higher percentage of cases (72.2%). Base of support variability (SD) and Cadence variability (CV) were identified as comprising the model that best discriminated between the two groups, using the stepwise method. MANOVA confirmed these as significantly different for the two groups of children (Base of support: $p = .005$; & Cadence: $p = .005$).

The third discriminant analysis conducted with the stride-to-stride variability parameters at the fast walking speed reported a smaller percentage of correctly classified cases (63.9 %). While this prediction is greater than that of chance alone, its use is limited. The best discriminator between the two groups was the variability in walking velocity (CV). None of the other parameters contributed significantly to the model in their own right.

A highly variable base of support is potentially a significant ‘problem’ in walking as it may easily perturb the child due to the nature of the lateral centre of mass movement. As shown in the following figure, the centre of mass sways from side to side during each step in a sinusoidal motion. This is inherently stable if the path stays within the base of support upon contact. However, if the base is small at foot contact the path of the centre of mass can sway outside this base reducing the lateral stability and thus requiring greater muscular effort and control to maintain stability. This may be due to the underlying processes that are assumed to control each. The variability in the placement of step width may be a result of a poor neuromuscular/kinaesthetic control (Hausdorf, 2005). This system therefore, serves as a rate limiting mechanism for gait maturation in this example.

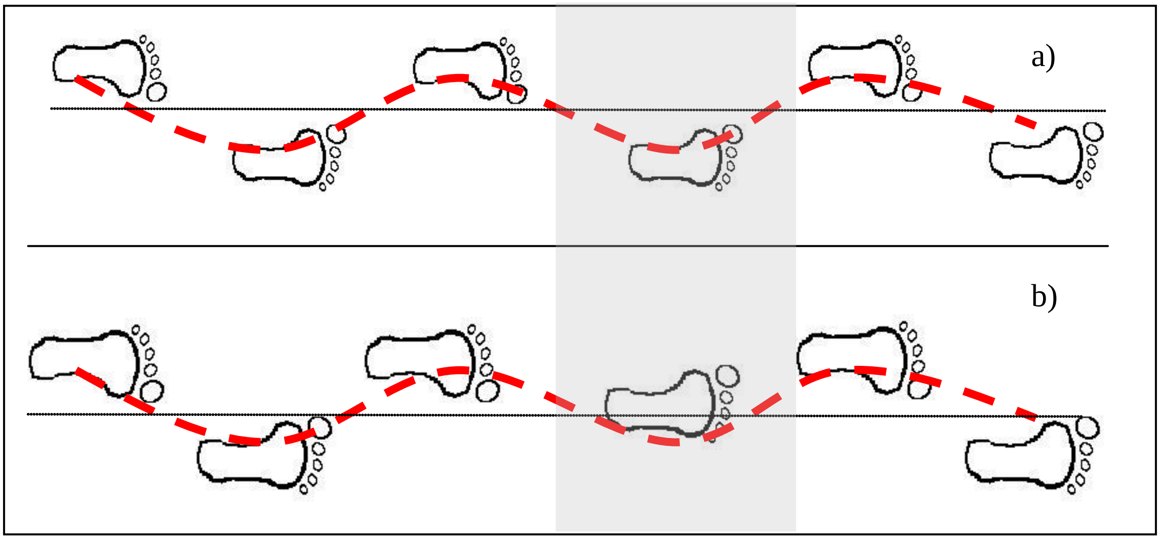


Figure 9.3 a) Centre of gravity path transposed over stable (low variability) base of support pattern. b) Centre of gravity path transposed over variable base of support.

It is also recognised that 'in accurate' placement of the foot in any one foot contact may result in an increased chance of hitting an obstacle (kerb or crack in pavement) again causing perturbation.

The increased variability in cadence may be a result of inefficiency in controlling the underlying pattern of stepping. As in patients with Parkinson's and Huntington's disease the more variable timing of the stepping pattern can either be a result of, or cause instability.

The finding that analysis of the variability of stride-to-stride parameters may provide a more sensitive objective measure of both balance impairment and balance development in primary aged children is consistent with previous research which has shown increased stride-to-stride variability in various pathologies (Dingwell & Cavanagh, 2001; Ebersbach, 1999; Gabell & Nayak, 1984; Hausdorff, 1994; Hausdorff, Cudkowicz, Firton, Wei & Goldberger, 1998; Hausdorff, Edelberg, Mitchell, Goldberger & Wei, 1997; Hausdorff, Rios & Edelberg, 2001; Maki, 1997; Nakamura, 1996; Herman, Giladi, Gurevich & Hausdorff, 2004; Palliyath, 1998; Steinwender, et.al, 2000). The underlying cause of a variable gait pattern is yet to be confirmed. However, greater variability in walking could be a result of an immature system, as outlined earlier, or as in the case of some of the above pathologies, more specific structural impairment in brain function. This notion will be explored with regards to the neural control of walking in a later section.

Although outside the scope of this study there is some evidence that specific areas of the brain controlling function may be common to the regulation of gait variability and motor impairment. Several areas of the brain have been suggested to be involved in DCD. Detailing each is also beyond the scope of this investigation, however, a brief description of each is provided:

> *The corpus callosum*: area of the brain connecting the left and right hemispheres, larger in musicians and left handed people (Visser, 2003);
>
> *The basal ganglia*: associated with functioning of motor control, cognition, emotion and learning (Lundy-Ekman, 1991). Of particular interest is its association with Attention Deficit Hyperactivity Disorder (ADHD) which is one of the co-morbidities of DCD (Martin, Piek & Hay, 2006); &

The cerebellum: associated with functioning of sensory perception, coordination and motor control. The cerebellum links to the cerebral motor cortex which sends information to the muscles causing movement. The cerebellum also integrates proprioceptive feedback providing information about the position of the body in space (Geuze & Kalverboer, 1987; Sigmundsson et al., 1997a; Sigmundsson et al., 1997b).

Similarly, brain function can be directly related to gait performance. It has been proposed that the basic human stepping pattern is firstly produced at the spinal level by Central Pattern Generators (CPG's) (Forssberg, 1999). The earliest emergence of this can be seen when a baby while lying on its back performs a cyclic stepping motion (Thelen Skala & Kelso, 1987). However, this spinal level activation seems only to provide a gross pattern. Higher level neural activity in concert with sensory information may shape and fine tune the gait pattern (Forssberg, 1999). Some evidence suggests that the basal ganglia interact with the brainstem system regulating automatic muscle tone and rhythmic limb movements (Takakusaki, Oohinata-Sugimoto, Saitoh & Habaguchi, 2004). Hausdorff, Cudkowicz, Firtion, Wei and Goldberger (1998) have suggested that this provides an important link between the gait variability and basal ganglia disorders which are a feature of Parkinson's and Huntington's disease. This is due to the role of the basal ganglia in regulating motor programs thus influencing gait fluidity and sequencing. Both PD and HD participants exhibited increased variability in gait parameters, two to three times higher than that of control participants. In another study, Rosano, Brach, Studenski, Longstreth and Newman (2007) used a Magnetic Resonance Imaging (MRI) technique to isolate areas of the brain of older adults with higher step length variability. It was found that higher levels of variability were associated with greater prevalence of infarcts (area of dead tissue due to loss of blood flow following a blockage) in the basal ganglia and white matter hyperintensities severity (affecting the transmission of neural signals). Children who are screened as motor impaired who also exhibit high levels of variability in their gait pattern may have a higher level deficit in brain function (either delayed maturation or impairment). Greater understanding of the underlying cause of the breakdown in these functions may provide not just better explanations – but alternatively, a means towards more effective rehabilitation. Further investigation is warranted to elucidate this relationship.

Problems of Classification

It is recognised that children classified as motor impaired according to MABC criteria may have altered or 'delayed' function in one or more of the three domains tested including manual dexterity, ball skills and balance and that these demands may act relatively independently. As a result, it might be expected that children experiencing difficulties solely with manual dexterity tasks, may have a gait pattern that could indeed be normal, or within normal limits. This issue was investigated using the data from this study. The following table displays the stride-to-stride variability parameters for the manual dexterity impaired group of children whose mean age (10.06 years), stature (140.9 cm) and mass (37.1 kg) were typical of children in age-band 3, age (10.04 years), stature (140.7 cm) and mass (37.6 kg). Of the 53 children identified with manual dexterity impairment 43 were members of age-band 3. This allowed for a direct comparison within the third age-band.

Table 9.1 Stride-to-stride variability at the normal walking speed for children screened with manual dexterity impairment and corresponding age-bands.

	Age-bands					
	1 (n = 33)	2 (n = 61)	Non MD Impaired 3 (n = 32)	MD Impaired 3 (n = 43)	4 (n = 49)	5 (n = 24)
vel (CV)	8.0 (2.2)	7.2 (3.1)	**5.7 (3.1)**	**5.9 (2.7)**	4.9 (1.7)	3.1 (1.4)
cad (CV)	5.0 (2.3)	4.8 (2.5)	**3.7 (2.1)**	**3.4 (1.8)**	2.8 (1.5)	1.5 (0.5)
sl (CV)	6.1 (1.6)	6.3 (1.9)	**5.3 (1.8)**	**5.1 (1.6)**	4.6 (1.4)	3.1 (1.0)
bos (SD)	2.5 (0.7)	2.5 (0.8)	**2.5 (0.4)**	**2.3 (0.6)**	2.3 (0.7)	1.9 (0.5)
st (CV)	6.4 (1.9)	6.0 (2.2)	**4.9 (2.0)**	**4.7 (1.6)**	4.1 (1.4)	3.10 (0.47)
dst (SD)	0.02 (0.005)	0.02 (0.007)	**0.02 (0.007)**	**0.02 (0.006)**	0.02 (0.005)	0.02 (0.006)

It can be seen that the group of children classified as impaired on the manual dexterity scale in age-band 3, exhibited a similar amount of variability in each of the gait parameters to that of the non-MD impaired children of the same age-range. It is suggested from this finding that the manual dexterity impaired children do walk with a normal pattern. This confirms one of the limitations of study one, and of the MABC. A child who is only screened as 'motor impaired' may have deficits in any of the three sub-scales tested, or in two or all three of the scales. This becomes problematic for clinicians who may require further insight into the underlying mechanisms of the specific deficit to provide the appropriate intervention. It may be necessary to develop more objective tests for deficits in, at least, each of the three MABC domains. The use of gait assessment is provided here as an objective measurement of dynamic balance performance.

9.3 Motor Impairment and Developmental Delay.

To determine the degree of impairment related to the increased stride-to-stride variability in the children classified as balance impaired a comparison was made with the children in various age-bands. The majority of balance impaired children were from age-band 4 (20 of 49). This age-band was split according to balance impairment and compared to the other age-bands.

Table 9.2 Comparison of gait parameters for the balance impaired children in age-band 4 and the corresponding age-bands at the slow walking speed.

	Age-bands					
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 Balance Impaired (n = 29)	4 Non-Impaired (n = 20)	5 (n = 24)
vel (CV)	8.0 (2.2)	**7.2 (3.1)**	**5.8 (2.9)**	**6.1 (1.8)**	5.6 (2.0)	3.1 (1.4)
cad (CV)	5.0 (2.3)	**4.8 (2.5)**	**3.5 (1.9)**	**3.8 (1.6)**	3.5 (1.5)	1.5 (0.5)
sl (CV)	6.1 (1.6)	**6.3 (1.9)**	**5.2 (1.7)**	**5.5 (1.5)**	5.1 (1.3)	3.1 (1.0)
bos (SD)	**2.5 (0.7)**	**2.5 (0.8)**	**2.4 (0.5)**	**2.7 (0.9)**	2.3 (0.5)	1.9 (0.5)
st (CV)	6.4 (1.9)	6.0 (2.2)	4.8 (1.8)	5.2 (1.7)	5.0 (1.5)	3.1 (0.5)
dst (SD)	0.027 (0.005)	0.025 (0.007)	0.023 (0.005)	0.022 (0.007)	0.024 (0.008)	0.026 (0.013)

It can be observed in Table 9.2 that the stride-to-stride variability of selected gait parameters at the slow walking speed were comparable to those of children in an age-band below and possibly two to three in the case of base of support variability. This suggests that the children screened as balance impaired by the MABC have greater variability of gait than their peers, which may be a result of impaired neural control of this fundamental motor skill. This is also consistent with the notion of developmental delay. Importantly, the development of a normative database for comparison will allow researchers, clinicians and educators to quantify the degree of this delay. The MABC itself is limited in its application as a screening tool for motor impairment. The Likert based scoring system and the relatively few performance tests in each sub-scale, limit its diagnostic potential. The current study classified children according to both overall impairment and balance impairment scales for a comparison of gait parameters. Inferences made from the gait analyses performed here are limited to the accuracy of the MABC age classifications. A longitudinal monitoring approach is required to further explain the developmental process in children using at least yearly data. It is recommended, therefore, that both large-scale cross-sectional studies providing normative data together with longitudinal studies documenting 'normal' development of walking are required to develop a database for baseline developmental comparison.

9.4 Motor Impairment and Overweight Children (Research Question 3.)

Do overweight children have a greater incidence of impaired balance and coordination during walking? It was identified in study one firstly that the children classified as motor impaired had a higher body mass and BMI as a group then the typically developing children. Previous studies have also identified that overweight children perform poorly on motor skill batteries (Graf, et al., 2004; Kretschmann, et.al., 2001 & Goulding, 2003). A comparison was made between children classified as overweight and children of normal weight status to clarify the relationship of weight with the performance of motor skills. This relationship was not reproduced in the second study. There was only a slightly greater percentage of motor impairment (34.4%) within the overweight children as opposed to that within the children of normal weight status (29.9%) (Table 9.4).

Table 9.3 Frequency of typically developing and motor impaired children who were overweight and of normal weight

	TD	**MI**	**Total**
Normal Weight	143	61	204
% of Normal Weight	70.10%	29.90%	100.00%
Overweight	40	21	61
% of Overweight	65.60%	34.40%	100.00%
Total	183	82	265
	69.10%	30.90%	100.00%

A comparison was also made between both the mean descriptive and stride-to-stride variability parameters of the overweight children and those of children classified as being of normal weight. As with the groups of children classified as balance impaired, it was believed an underlying problem with the motor pattern would be manifest in a more varied stride-to-stride gait pattern.

The overweight children did not, however, walk with increased stride-to-stride variability when compared to children of normal weight. No significant differences were found across the three gait speeds between the three groups. The hypothesis, therefore, was not supported. However, when considering mean scores for the gait parameters across all three gait speeds the overweight children were found to walk with a wider base of support and spend a greater amount of time in double support. Both these findings support previous research (Hills & Parker, 1991). It is thought that the increased mass for stature creates greater potential instability in the system. To compensate for this the base of support is widened and the time in double support is increased.

While the overweight children have overt differences to children of normal weight, with the increased base of support and double support time, they do not appear to exhibit the underlying motor pattern variability of those identified as motor impaired. The significance of this finding lies with the application of appropriate intervention programs. It is contended here that the over-representation of overweight children amongst those classified as motor impaired may purely be a result of carrying a larger mass around the environment rather than suffering from any underlying motor impairment. A weight reduction intervention therefore, rather then a motor skill specific program may be more beneficial to the function of overweight children. This effect has been observed in a small sample of adults in which a weight reduction protocol improved balance performance (Sartorio, et al. 2001).

9.5 Limitations

- The resolution of the GAITRite walkway system prevents meaningful interpretation of the smaller spatial measurements. The mat is made up of a grid of 1cm sensors, centred at 1.27 centimetres away from each other. The base of support measurements at the fast walking pace ranged from 7.1 – 9.9 cm across the five age-groups tested. This corresponds to a possible measurement error of 12.3 %.

- The sample of participants was recruited from just two schools in metropolitan Melbourne. The findings may not be generalised to the broader Australian population. Further, only a percentage of children from each school were tested. It is not known whether the children tested at the time were representative of the school population as whole.

- The first version of the MABC was used to classify children with motor impairment. Since the time of testing a second version has been developed with improved age-range, validation and task age-band overlap (Henderson & Sugden, 2007).

- The MABC itself was limited in its application as a screening tool for motor impairment. The likert based scoring system and the relatively few performance tests in each sub-scale limit its application. The current study classified children according to both overall impairment and balance impairment scales for a comparison of gait parameters. Inferences made from the gait analyses performed here are limited to the accuracy of the MABC classification.

- Inferences regarding the development of children in this study are limited due to the cross-sectional design. Longitudinal testing is required to further explain the developmental process children.

- It is recognised that children with DCD have a high degree of co-morbidity with children classified as ADHD. Differences noted here regarding the non-normal gait speeds may be in part due to the inability of children suffering from both disorders to adequately concentrate on walking at the required gait speed for the entirety of the test.

- The BMI measurement was used to identify children as overweight. To improve the accuracy of this measurement either a Dual X-Ray Absorptiometry (DEXA) or Magnetic Resonance Imaging (MRI) techniques may be used.

9.6 Conclusion

This study confirmed that as children increase in age they exhibit decreased stride-to-stride variability. It was noted that even at age twelve children's gait did not yet exhibit an 'adult like' pattern. This suggests that the neural control of walking is still immature at the age of twelve. Children classified as balance impaired displayed gait patterns which resembled those of younger children. Future identification of normative measures in association with the use of the rate of maturation of these parameters can assist researchers, clinicians and educators alike to more accurately measure the *degree* of an individual's motor impairment or delay. Findings from the current study suggest that the balance impaired children as a group walked with a pattern that resembled that of children two age-bands younger at the slow speed. The stride-to-stride variability measurements walking at the slow speed were also able to correctly classify 72.2 % of balance impaired children. This was taken as preliminary support for the use of gait as a screening tool for early identification of balance impairment.

The use of gait analysis by practitioners can also be used to provide a more detailed description of individual impairment. These findings have pointed to three underlying processes that need to be addressed if compensations are to be achieved. Deficiencies in sequencing can be identified (high stride-to-stride variability) and also deficits in stability (base of support and double support time) and propulsion (step length and velocity). Some implications of identifying impairment in each of these three categories, propulsion, stability or sequencing are identified below:

- *Propulsion*: Gait velocity and mean step length both relate to the ability to produce the required strength for propulsion. It is recognised from the current findings however, that neither the younger, balance impaired or overweight children exhibit deficiencies with regards to propulsion. As a consequence of this finding, strength training is unlikely to be a relevant intervention within these populations.
- *Stability*: Base of support and double support time measures are both related to stability. A wide-base is often used as a compensatory mechanism to

provide greater lateral support for unstable walkers. Double support time can also be increased, thus, increasing the proportion of time with both feet on the ground. During this time the centre of mass is most likely within the base of support, improving stability. These two measurements were found to significantly differ for the overweight children. Manoeuvring a larger mass requires greater stability hence they appeared to adopt a specific strategy to enhance the stability of their gait. However, the balance impaired children did not overtly change either of these parameters to adopt a more stable platform for walking. Upon investigation of the maturation of walking, both base of support and double support time increased with age across the three walking speeds indicating improved stability with age. Greater variability in both of these parameters can also cause instability. As identified in Figure 9.3, the centre of mass can translate close to the base of support when the step pattern varies. The more varied the foot placement the more chance that the centre of mass will move outside the base of support, causing instability. Enhanced participation in physical activity and play may be appropriate for children with these symptoms along with the known DCD approaches, sensory integration and perceptual motor tasks (Pless & Carlsson, 2000). These methods require the participant to integrate the sensation, perception and movement to promote the correct processing of the sensory input. Challenging the vestibular system to overcome balance perturbation by balancing on beams and swinging in hammocks has been regularly used to stimulate this process (Dempsey & Foreman, 2001).

- *Sequencing* – High variability in the timing of foot placement (step time) may be a result of a system working under higher than normal task constraints, or with larger than normal individual constraints. Individual constraints that have been shown to increase the stride-to-stride variability include conditions such as Parkinson's and Huntington's disease, along with the general deterioration of the aging process. A child with poor motor skill may have difficulty reproducing an invariant stepping pattern when the task constraints are increased. Divided attention and walking at non-normal speeds both increase task demands and have been shown to impact upon the outcome of the movement sequence (stride-to-stride variability). As previously identified, a variable foot placement pattern may also be a result of structural damage/delay to specific portions of the brain controlling movement. To date, the value of targeted interventions to reduce gait variability for children has not been reported and is worthy of further investigation. Intervention strategies based around the emergence of 'anchoring theory' may be a useful tool to combat poor gait rhythm within this population (Di Fabio, Zampieri & Greany, 2003). The aim of anchoring 'therapy' is to synchronise the stepping rhythm to an external visual or auditory rhythm. Acoustic pacing has been used to synchronise the stepping pattern of stroke patients during 'online' real-time practice (Roerdink, Lamoth, Kwakkel, van Wieringen & Beek, 2007). This process may be used to assist children with a gait that exhibits high stride-to-stride variability.

It is recognised that children may encounter each of the above mentioned intervention strategies within an enriched day to day play environment. This facilitates not only physical development, but, the necessary social, environmental and cognitive factors that are essential for well rounded development.

9.7 Further Research

The findings of these studies have pointed the way forward to ongoing areas for further research. First and foremost there is a clear need for increased 'normative' understanding of the development of the processes underlying the development of stride-to-stride variability. The future inclusion of older children from the early teen years to young adulthood in studies of this nature along with the development of some longitudinal testing protocols will improve our current understanding. Further, the current study has been constrained by its use of the MABC age-bands for developmental comparison. This provides quite gross categories potentially at times when changes may be occurring. In future studies a chronological year-by-year breakdown in gait variability reporting may better serve developmental researchers and practitioners.

Gait parameters may be used in future studies to not only identify a general stage of development or 'maturation', but also for identifying specific balance and/or timing/sequencing deficits for the developmentally delayed child. Specifically, a propulsion, stability and sequencing model may be used for diagnosis and remediation. A developmental scale outlining the yearly rate of change in these gait parameters is not expected to plateau until well into the teenage years. Further investigation is recommended to track the development and maturation of gait into the teenage years bridging the gap between late childhood and young adult reference data.

The development of walking as one of the fundamental motor skills provides an important 'prerequisites' for successful interaction with the immediate environment. Being able to successfully ambulate in conditions with varying task demands may even be a core requirement for any meaningful environmental interaction. This study has highlighted that some children are yet to master this, once thought of, automatic motor skill by the age of twelve. If we are to provide all children with a healthy start to life it is critical that we can help all children to equip themselves with the necessary building blocks for effective exploration and mastery of their physical environment. Increased understanding of the fundamental motor skills and how they develop in children is an essential contribution to this important goal.

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APPENDICES

APPENDIX A

PRINCIPAL LETTER

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

INFORMATION LETTER TO PRINCIPAL

TITLE OF PROJECT: The Movement Signatures of Primary School Aged Children: Variance, Symmetry and Motor Proficiency.

NAMES OF SUPERVISOR: Assoc. Prof. John Saunders

NAME OF STUDENT RESEARCHER: Mr. Cameron Wilson

NAME OF PROGRAMME IN WHICH ENROLLED: PhD

Your school is invited to participate in a study investigating motor performance of primary school aged children. The testing will require your students to perform the Movement Assessment Battery for Children (MABC), have a their walking analysed completing 10 walkthroughs over a carpeted walkway (5m) that records the stepping pattern (GAITRite).

The MABC testing is made up of:
- Balance tests such as standing on one leg or hopping.
- Manual dexterity tests such as threading nuts on a bolt, and
- Ball skills tests such as one hand catching.

The GAITRite walkway is an electronic roll-up mat that collects information on individuals' walking patterns. If your students participate in this study, they will be required to walk across the GAITRite 10 times at their preferred walking pace. Each child will be supervised at all times and escorted to and from class by a research assistant.

The risks associated with this study are minimal, no more than any normal P.E. class. The information that will be recorded will be kept confidential. Only the participating researchers will have access to the data being collected. If you have further queries on this issue, it should be directed to Asoc. Prof. John Saunders or Mr. Cameron Wilson as listed below.

Your students will be required to wear a pair of his/her own flat-soled shoes (school shoes). Upon arrival each child's body weight and leg length measurements will be recorded. Each child will then be instructed to complete 10 walks across the mat at his/her normal pace. In the same session the children will be performing the MABC test assisted by a researcher. In all, this should take approximately 30-40 minutes.

The potential benefits of this study include the general group results being made available to the P.E. staff of the school to assist in the development of a program that includes all motor performance levels. If you so wish, individual results can be made available assist in specific areas of the P.E. classes.

It is important to understand that you are free to refuse consent altogether without having to justify that decision, or to withdraw consent and discontinue participation of your students in the study at any time without giving a reason. If during the project any of your students feel uncomfortable in any way and no longer wish to continue he/she is free to withdraw at any time without any unfavourable consequences. Upon completion of the study tasks, or if you choose to withdraw your students from the study, you will be given the opportunity to ask questions regarding the project.

At all times the information that will be collected will remain confidential. A coding system will be used to identify your students and this will be destroyed at the conclusion of the study.

Any questions regarding this project should be directed to the Principal Investigators.

Assoc. Prof. John Saunders
on 9953 3038
in the School of Exercise Science
115 Victoria Parade Fitzroy,
Victoria 3065

(or) Mr Cameron Wilson
on 9953 3419
in the School of Exercise Science
115 Victoria Parade Fitzroy,
Victoria 3065

At the conclusion of the study an information session will be held where group results will be produced. You are cordially invited to attend that session and ask questions about the study.

Please be advised that this study has been presented to and approved by the Human Research Ethics Committee at Australian Catholic University. If at anytime you have a query or complaint about the way that you have been treated in this study, you may write care of the Office of Research.

Chair, HREC
C/o Research Services
Australian Catholic University
Locked Bag 4115
FITZROY VIC 3065
Tel: 03 9953 3157
Fax: 03 9953 3305

Any complaint made will be treated in confidence, investigated fully and the participant informed of the outcome.

Thank you for your cooperation with this important research.

Yours sincerely,

Mr. Cameron Wilson
STUDENT RESEARCHER

APPENDIX B

PARENT GUARDIAN INFORMATION

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

INFORMATION LETTER TO PARENT/GUARDIAN

TITLE OF PROJECT: The Movement Signatures of Primary School Aged Children: Variance, Symmetry and Motor Proficiency.

NAMES OF STAFF SUPERVISORS: Ass. Prof. John Saunders

NAME OF STUDENT RESEARCHERS: Mr. Cameron Wilson (Ph.D. Candidate)

Your child is invited to be a participant in a study investigating motor performance of primary school aged children. The testing will require your child to perform the Movement Assessment Battery for Children (MABC) and have a their walking analysed by completing 15 walkthroughs over a carpeted walkway (5m) that records the stepping pattern (GAITRite).

The MABC testing is made up of:
- Balance tests such as standing on one leg or hopping.
- Manual dexterity tests such as threading nuts on a bolt, and
- Ball skills tests such as one hand catching.

The GAITRite walkway is an electronic roll-up mat that collects information on individuals' walking patterns. If your child participates in this study, he/she will be required to walk across the GAITRite 10 times at his/her preferred walking pace. Each child will be supervised at all times and escorted to and from class by a research assistant.

The risks associated with this study are minimal. The information that will be recorded will be kept confidential. Only the participating researchers will have access to the data being collected. If you have further queries on this issue, it should be directed to Ass. Prof. John Saunders or Mr. Cameron Wilson as listed below.

Your child will be required to wear a pair of his/her own flat-soled shoes (school shoes). Upon arrival each child's body weight and leg length measurements will be recorded. He/she will then be instructed to complete 10 walks across the mat at his/her normal walking pace. In the same session your child will be performing the MABC test assisted by a researcher. In all, this should take approximately 30-40 minutes.

The potential benefits of this study include the general group results being made available to the P.E. staff of the school to assist in the development of a program that includes all motor performance levels. If you so wish, individual results can be made available to the P.E. staff to assist in specific areas of the P.E. classes.

It is important to understand that you are free to refuse consent altogether without having to justify that decision, or to withdraw consent and discontinue participation of your child in the study at any time without giving a reason. If during the project your child feels uncomfortable in any way and no longer wishes to continue he/she is free to withdraw at any time without any unfavourable consequences. Upon completion of the study tasks, or if you choose to withdraw your child from the study, you will be given the opportunity to ask questions regarding the project.

At all times the information that will be collected will remain confidential. A coding system will be used to identify your child and this will be destroyed at the conclusion of the study.

Any questions regarding this project should be directed to the Principal Investigators.

Ass. Prof. John Saunders

on 9953 3038

in the School of Exercise Science

115 Victoria Parade Fitzroy Victoria 3065

or

Mr Cameron Wilson

on 9953 3419

in the School of Exercise Science

115 Victoria Parade Fitzroy Victoria 3065

At the conclusion of the study an information session will be held where group results will be produced. You are cordially invited to attend that session and ask questions about the study.

Please be advised that this study has been presented to and approved by the Human Research Ethics Committee at Australian Catholic University. If at anytime you have a query or complaint about the way that you have been treated in this study, you may write care of the Office of Research.

Chair, HREC
C/o Research Services
Australian Catholic University
Locked Bag 4115
FITZROY VIC 3065
Tel: 03 9953 3157
Fax: 03 9953 3305

Any complaint made will be treated in confidence, investigated fully and the participant informed of the outcome.

If you agree for your child to participate in this study please complete the details on both the attached consent forms and sign them. Please retain one copy for your records and the other copy will be filed by the Principal Investigator at Australian Catholic University Campus in a securely locked filing cabinet.

Thank you for your cooperation with this important research.

Yours sincerely,

Mr. Cameron Wilson
STUDENT RESEARCHER

Ass. Prof. John Saunders
SUPERVISOR

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

PARENT/GUARDIAN CONSENT FORM

TITLE OF PROJECT: The Movement Signatures of Primary School Aged Children: Variance, Symmetry and Motor Proficiency.

NAMES OF STAFF SUPERVISORS: Asoc. Prof. John Saunders

NAME OF STUDENT RESEARCHERS: Mr. Cameron Wilson (Ph.D. Candidate)

I .... (*the parent/guardian*) have read and understood the information provided in the Letter to the Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may participate in this activity, realising that I can withdraw my consent at any time. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify my child in any way.

NAME OF PARENT/GUARDIAN: ....
(block letters)

SIGNATURE ....…… DATE......................................…

NAME OF CHILD ....
(block letters)

SIGNATURE OF SUPERVISOR:

……………………………………………………… DATE:…………………………………….

SIGNATURE OF STUDENT RESEARCHER:

……………………………………………… DATE:…………………………………

APPENDIX C

SCREENING QUESTIONNAIRE

PARENT/GUARDIAN QUESTIONNAIRE

(Responses on behalf of child)

Date of Birth: ……./……../……..

Was your child born pre or post term? **Y / N** If Yes, how many weeks **pre** or **post** term? ……….../………

At what age did your child begin to walk (unassisted)?……………………….. (months)

Does your child suffer from any neurological or neuromuscular disorders (eg. Cerebral Palsy, Attention Deficit Hyperactivity Disorder (ADHD))?
……………………………………………………………………

Which foot would your child kick a ball with? **L / R**

Which hand does your child use to write? **L / R**

Does your child exhibit any difficulties in the following areas:

Handwriting: **Y / N**

Balance: **Y / N**

Hand eye coordination (catching a ball): **Y / N**

If 'Yes' what specific problems has your child had?

………………………………………………………………………………………………
………………………………………………………………………………………………
………………………………………………………………………………………

Circle the most appropriate response on the rating scale of 1-5:

Does your child participate in any sporting activities outside of the school PE curriculum? **Y / N**

If Yes, how often? (1 – once a week, 2 – twice a week, 3 – every second day, 4 – everyday, & 5 – twice a day)

1 2 3 4 5

Does your child unusually trip, fall or bump into objects during everyday activity? (**1** - not at all, **3** - sometimes, **5** - often)

1 2 3 4 5

APPENDIX D

MABC RECORD FORMS

MOVEMENT ABC

RECORD FORM

Movement Assessment Battery for Children

Compiled by Sheila E. Henderson and David A. Sugden

AGE BAND 1 — 4–6 years

Name.. Gender ....

Home address .... Date of test ....

.... Date of birth ....

.... Age ....

School .... Grade/class ....

....

Assessed by ....

Preferred hand (defined as the hand used to write with) ....

Other information ....

....

Published by The Psychological Corporation Limited, 32 Jamestown Road, London NW1 7BY.

Printed in the United Kingdom
ISBN 0 7491 0132 6

POSTING COINS — MANUAL DEXTERITY

Quantitative data

Record time taken (secs); F for failure; R for refusal; I for inappropriate

Preferred hand
Trial 1 ....
Trial 2 ....

Nonpreferred hand
Trial 1 ....
Trial 2 ....

age 4	age 5	age 6	score	age 4	age 5	age 6
0–23	0–20	0–17	0 / 0	0–27	0–23	0–20
24–25	21	18–19	1 / 1	28–30	24–25	21–22
26–27	22	20	2 / 2	31–33	26	23
28–32	23–24	21–24	3 / 3	34–47	27	24–25
33–49	25–29	25–28	4 / 4	48–55	28–32	26–29
50+	30+	29+	5 / 5	56+	33+	30+

* Item score

* Item score = (Preferred hand + Nonpreferred hand) ÷ 2

Qualitative observations

Body control/posture

- Does not look at slot while inserting coins ☐
- Holds face too close to task ☐
- Holds head at an odd angle ☐

- Does not use pincer grip to pick up coins ☐
- Exaggerates finger movements in releasing coins ☐
- Does not use the supporting hand to hold box steady ☐
- Does *extremely* poorly with one hand (asymmetry striking) ☐
- Changes hands or uses both hands during a trial ☐
- Hand movements are jerky ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Misaligns coins with respect to slot ☐
- Uses excessive force when inserting coins ☐
- Is *exceptionally* slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐

Other

....

....

THREADING BEADS — MANUAL DEXTERITY

Quantitative data

Record time taken (secs); F for failure; R for refusal; I for inappropriate

Trial 1 ....
Trial 2 ....

score	age 4*	age 5	age 6
0	0–38	0–55	0–47
1	39–46	56–60	48–53
2	47–51	61–66	54–55
3	52–57	67–76	56–61
4	58–64	77–103	62–100
5	65+	104+	101+

Item score

* 4 year olds thread 6 beads only

Qualitative observations

Body control/posture

- Does not look at bead while inserting tip of lace ☐
- Holds materials too close to face ☐
- Holds head at an odd angle ☐

- Does not use pincer grip when picking up beads ☐
- Holds lace too far from tip ☐
- Holds lace too near tip ☐
- Finds it difficult to push tip with one hand and pull it through with the other ☐
- Changes threading hand during a trial ☐
- Hand movements are jerky ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Sometimes misses hole with tip of lace ☐
- Picks up beads the wrong way round ☐
- Is *exceptionally* slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐

Other

....

....

BICYCLE TRAIL — MANUAL DEXTERITY

Quantitative data

Record number of deviations; F for failure; R for refusal; I for inappropriate

Trial 1 ....
Trial 2 ....
Hand used ....

score	age 4	age 5	age 6
0	0–4	0–1	0
1	5	2	1
2	6–7	3	–
3	8–9	4–5	2
4	10–11	6–7	3
5	12+	8+	4+

Item score

Qualitative observations

Body control/posture
- Does not look at trail ☐
- Holds face too near paper ☐
- Holds head at an odd angle ☐

- Holds pen with an odd/immature grip ☐
- Holds pen too far from point ☐
- Holds pen too close to point ☐
- Does not hold paper still ☐
- Changes hands during a trial ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements
- Progresses in short jerky movements ☐
- Uses excessive force, presses very hard on paper ☐
- Is *exceptionally* slow ☐
- Goes too fast for accuracy ☐

Other
....
....

CATCHING BEAN BAG — BALL SKILLS

Quantitative data

Record number of catches; R for refusal; I for inappropriate

....

score	age 4*	age 5	age 6
0	6–10	7–10	9–10
1	5	6	8
2	4	5	7
3	2–3	3–4	6
4	1	1–2	5
5	0	0	0–4

Item score

* 4 year olds may trap the bean bag against the body

Qualitative observations

Body control/posture
- Does not follow trajectory of bean bag with eyes ☐
- Turns away or closes eyes as bean bag approaches ☐

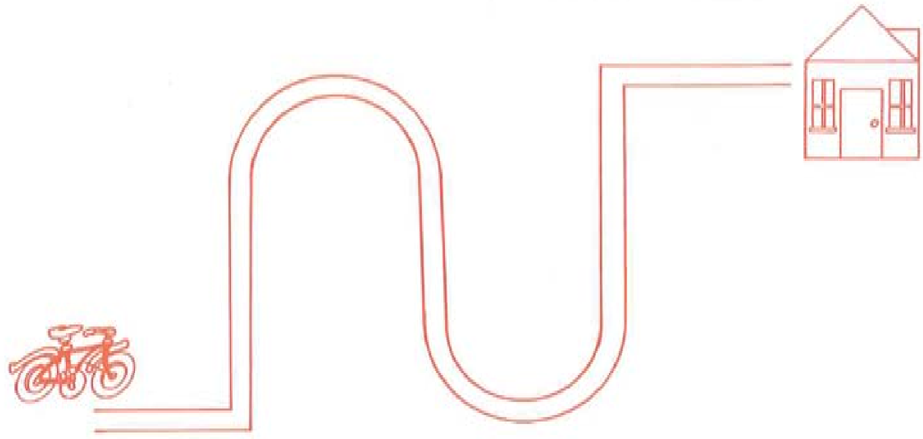
- Arms are not raised symmetrically for catching ☐
- Holds hands out flat with fingers stiff as the bean bag approaches ☐
- Hands and arms held wide apart, fingers extended ☐
- Arms and hands do not 'give' to meet impact of bean bag ☐
- Fingers close too early or too late ☐

- Does not move until bean bag strikes body ☐
- Body appears rigid/tense ☐

Adjustments to task requirements
- Does not adjust to height of throw ☐
- Does not adjust to direction of throw ☐
- Does not adjust to force of throw ☐
- Movements lack fluency ☐

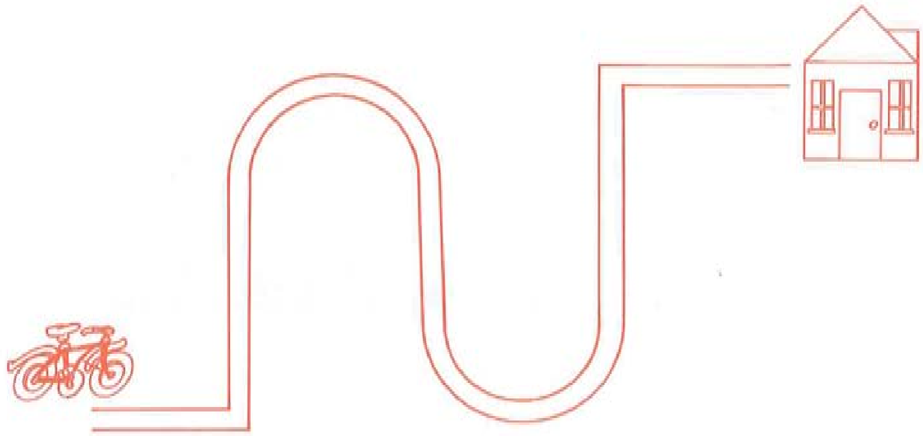
Other
....
....

BICYCLE TRAIL



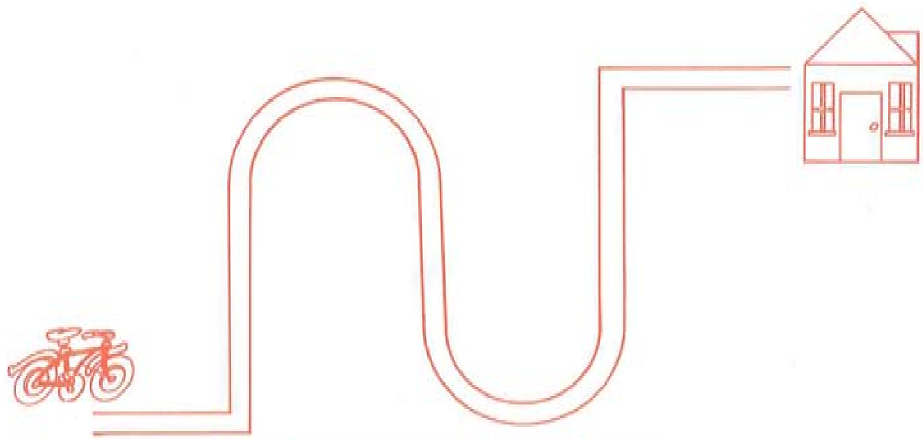
Name ....

BICYCLE TRAIL



Name ....

BICYCLE TRAIL



Name ....

ROLLING BALL INTO GOAL — BALL SKILLS

Quantitative data

Record number of goals; R for refusal; I for inappropriate

....

Hand used ....

score	age 4	age 5	age 6
0	5–10	6–10	8–10
1	4	5	7
2	3	4	6
3	2	3	5
4	1	2	4
5	0	0–1	0–3

Item score

Qualitative observations

Body control/posture

- Does not keep eyes on target ☐
- Does not use a pendular swing of the arm ☐
- Does not follow through with the rolling arm ☐
- Releases ball too early or too late ☐
- Changes hands from trial to trial ☐
- Cannot maintain balance while rolling ball ☐

Adjustments to task requirements

- Errors are consistently to one side of goal (asymmetry striking) ☐
- Control of direction variable ☐
- Judges force of roll poorly (too much or too little) ☐
- Control of force is variable ☐
- Movements lack fluency ☐

Other

....

....

ONE-LEG BALANCE — STATIC BALANCE

Quantitative data

Record time balanced (secs); R for refusal; I for inappropriate

Preferred leg	Nonpreferred leg
Trial 1	Trial 1 ....
Trial 2	Trial 2 ....

Preferred leg: age 4	age 5	age 6	score	Nonpreferred leg: age 4	age 5	age 6
5–20	11–20	15–20	0 / 0	5–20	9–20	15–20
4	8–10	11–14	1 / 1	4	6–8	11–14
3	7	9–10	2 / 2	3	5	8–10
2	5–6	7–8	3 / 3	2	4	6–7
1	3–4	5–6	4 / 4	1	3	4–5
0	0–2	0–4	5 / 5	0	0–2	0–3

* Item score

* Item score = (Preferred leg + Nonpreferred leg) ÷ 2

Qualitative observations

Body control/posture

- Does not hold head and eyes steady ☐
- Looks down at feet ☐
- Makes no or few compensatory arm movements to help maintain balance ☐
- Exaggerated movements of arms and trunk disrupt balance ☐
- Body is held rigid ☐
- Sways wildly to try to maintain balance ☐
- Does *extremely* poorly on one leg (asymmetry striking) ☐

Other

....

....

JUMPING OVER CORD — DYNAMIC BALANCE

Quantitative data

Record **P** for success; **F** for failure; **R** for refusal; **I** for inappropriate

Trial 1 ....
Trial 2 ....
Trial 3 ....

score	age 4*	age 5	age 6
0	pass on Trial 1		
1	–	–	–
2	pass on Trial 2		
3	pass on Trial 3		
4	–	–	–
5	fails all 3 trials		

Item score

* 4 year olds need not land with feet together

Qualitative observations

Body control/posture

- Does not use arms to assist jump ☐
- Arms swing out of phase with legs ☐
- Arm movements are exaggerated ☐

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐

- Makes no preparatory crouch ☐
- Lacks springiness/no push-off from feet ☐
- Uneven take-off and loss of symmetry in flight and landing ☐
- Lands with stiff legs/on flat feet ☐
- Stumbles on landing ☐

Adjustments to task requirements

- Does not combine upward and forward movements effectively ☐
- Uses too much effort ☐
- Movements are jerky ☐

Other

....

....

WALKING HEELS RAISED — DYNAMIC BALANCE

Quantitative data

Record **number of correct steps**; **F** for failure; **R** for refusal; **I** for inappropriate

Trial 1 ....
Trial 2 ....
Trial 3 ....

score	age 4	age 5	age 6
0	9–15	12–15	15
1	7–8	9–11	14
2	5–6	8	13
3	4	6–7	10–12
4	3	5	8–9
5	0–2	0–4	0–7

Item score

Qualitative observations

Body control/posture

- Does not look ahead ☐
- Does not keep head steady ☐

- Does not compensate with arms to maintain balance ☐
- Exaggerated arm movements disrupt balance ☐

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐

- Is very wobbly when placing feet on line ☐
- Sways wildly to try to maintain balance ☐

Adjustments to task requirements

- Goes too fast for accuracy ☐
- Individual movements lack smoothness and fluency ☐
- Sequencing of steps is not smooth/pauses frequently ☐

Other

....

....

RECORD FORM

MOVEMENT ABC

Movement Assessment Battery for Children

Compiled by Sheila E. Henderson and David A. Sugden

AGE BAND 2 **7–8 years**

Name .... Gender ....

Home address .... Date of test ....

.... Date of birth ....

.... Age ....

School .... Grade/class ....

....

Assessed by ....

Preferred hand (defined as the hand used to write with) ....

Other information ....

....

Published by The Psychological Corporation Limited, 24-28 Oval Road, London NW1 7DX.

Printed in the United Kingdom
ISBN 0 7491 0133 4

FLOWER TRAIL — MANUAL DEXTERITY

Quantitative data

Record **number of deviations**; **F** for failure; **R** for refusal; **I** for inappropriate

Trial 1 ....
Trial 2 ....
Hand used ....

score	age 7	age 8
0	0–2	0
1	3	1
2	4	2
3	5–6	3–6
4	7–10	7–9
5	11+	10+

Item score

Qualitative observations

Body control/posture

- Does not look at trail ☐
- Holds face too near paper ☐
- Holds head at an odd angle ☐

- Holds pen with an odd/immature grip ☐
- Holds pen too far from point ☐
- Holds pen too close to point ☐
- Does not hold paper still ☐
- Changes hands during a trial ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Progresses in short jerky movements ☐
- Uses excessive force, presses very hard on paper ☐
- Is *exceptionally* slow ☐
- Goes too fast for accuracy ☐

Other

....

....

ONE-HAND BOUNCE AND CATCH — BALL SKILLS

Quantitative data

Record **number of catches**; **R** for refusal; **I** for inappropriate

Preferred hand	Nonpreferred hand
....	....

age 7	age 8	score	age 7	age 8
9–10	10	0 / 0	8–10	9–10
8	9	1 / 1	7	8
7	8	2 / 2	6	7
6	7	3 / 3	5	6
4–5	5–6	4 / 4	4	5
0–3	0–4	5 / 5	0–3	0–4

*Item score

* Item score = (Preferred hand + Nonpreferred hand) ÷ 2

Qualitative observations

Body control/posture

- Does not follow trajectory of ball with eyes ☐
- Turns away or closes eyes as ball approaches ☐

- Holds hand out flat with fingers stiff as the ball rebounds ☐
- Tries to catch ball with hand facing downwards ☐
- Arm and hand do not 'give' to meet impact of ball ☐
- Fingers close too early or too late ☐
- Does *extremely* poorly with one hand (asymmetry striking) ☐

- Body appears tense/rigid throughout ☐

Adjustments to task requirements

- Bounces ball too close to feet or too far away ☐
- Does not adjust body position for catching ☐
- Judges force of bounce poorly (too much or too little) ☐
- Does not adjust position of feet as necessary ☐
- Movements lack fluency ☐

Other

....

....

THROWING BEAN BAG INTO BOX — BALL SKILLS

Quantitative data

Record number of goals; R for refusal; I for inappropriate

....

Hand used ....

score	age 7	age 8
0	6–10	6–10
1	5	5
2	4	4
3	3	3
4	2	2
5	0–1	0–1

Item score: ☐

Qualitative observations

Body control/posture

- Does not keep eyes on target ☐
- Does not use a pendular swing of the arm ☐
- Does not follow through with throwing arm ☐
- Releases bean bag too early or too late ☐
- Changes hands from trial to trial ☐
- Trunk and hips do not rotate as throwing arm comes forward ☐
- Over-rotates and loses balance ☐

Adjustments to task requirements

- Errors are consistently to one side of the box (asymmetry striking) ☐
- Judges force of throw poorly (too much or too little) ☐
- Control of force is variable ☐
- Movements lack fluency ☐

Other

....

....

STORK BALANCE — STATIC BALANCE

Quantitative data

Record time balanced (secs); R for refusal; I for inappropriate

Preferred leg	Nonpreferred leg
Trial 1	Trial 1 ....
Trial 2	Trial 2 ....

Preferred leg age 7	Preferred leg age 8	score	Nonpreferred leg age 7	Nonpreferred leg age 8
12–20	20	0 / 0	11–20	19–20
9–11	13–19	1 / 1	8–10	11–18
7–8	9–12	2 / 2	5–7	9–10
6	6–8	3 / 3	4	6–8
4–5	4–5	4 / 4	3	4–5
0–3	0–3	5 / 5	0–2	0–3

* Item score: ☐

* Item score = (Preferred leg + Nonpreferred leg) ÷ 2

Qualitative observations

Body control/posture

- Does not hold head and eyes steady ☐
- Looks down at feet ☐
- Makes no or few compensatory arm movements to help maintain balance ☐
- Exaggerated movements of arms and trunk disrupt balance ☐
- Body is held rigid ☐
- Sways wildly to try to maintain balance ☐
- Does *extremely* poorly on one leg (asymmetry striking) ☐

Other

....

....

JUMPING IN SQUARES — DYNAMIC BALANCE

Quantitative data

Record number of correct jumps; F for failure; R for refusal; I for inappropriate.

Trial 1 ....

Trial 2 ....

Trial 3 ....

score	age 7	age 8
0	5	5
1	–	–
2	4	4
3	3	3
4	2	2
5	0–1	0–1

Item score

Qualitative observations

Body control/posture

- Does not use arms to assist jump ☐
- Arms swing out of phase with legs ☐
- Arm movements are exaggerated ☐

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐

- Makes no preparatory crouch ☐
- Lacks springiness/no push-off from feet ☐
- Uneven take-off and loss of symmetry in flight and landing ☐
- Jumps with stiff legs/on flat feet ☐
- Stumbles on landing ☐

Adjustments to task requirements

- Does not combine upward and forward movements effectively ☐
- Uses too much effort ☐
- Movements are jerky ☐

Other

....

....

HEEL-TO-TOE WALKING — DYNAMIC BALANCE

Quantitative data

Record number of correct steps; R for refusal; I for inappropriate

Trial 1 ....

Trial 2 ....

Trial 3 ....

score	age 7	age 8
0	13–15	15
1	8–12	14
2	7	13
3	5–6	10–12
4	3–4	7–9
5	0–2	0–6

Item score

Qualitative observations

Body control/posture

- Does not look ahead ☐
- Does not keep head and eyes steady ☐

- Does not compensate with arms to maintain balance ☐
- Exaggerated arm movements disrupt balance ☐

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐

- Is very wobbly when placing feet on line ☐
- Sways wildly to try to maintain balance ☐

Adjustments to task requirements

- Goes too fast for accuracy ☐
- Individual movements lack smoothness and fluency ☐
- Sequencing of steps is not smooth/pauses frequently ☐

Other

....

....

MOVEMENT ABC

RECORD FORM

Movement Assessment Battery for Children

Compiled by Sheila E. Henderson and David A. Sugden

AGE BAND 3 — **9–10 years**

Name .... Gender ....

Home address .... Date of test ....

.... Date of birth ....

.... Age ....

School .... Grade/class ....

....

Assessed by ....

Preferred hand (defined as the hand used to write with) ....

Other information ....

....

Published by The Psychological Corporation Limited, 24-28 Oval Road, London NW1 7DX.

Printed in the United Kingdom
ISBN 0 7491 0134 2

SHIFTING PEGS BY ROWS — MANUAL DEXTERITY

Quantitative data

Record **time taken** (secs); **F** for failure; **R** for refusal; **I** for inappropriate

Preferred hand	Nonpreferred hand
Trial 1	Trial 1 ....
Trial 2	Trial 2 ....

age 9	age 10	score	age 9	age 10
0–12	0–12	0 / 0	0–14	0–13
13	13	1 / 1	15	14
14	–	2 / 2	16	15
15	14	3 / 3	17	16
16–17	15–16	4 / 4	18–19	17
18+	17+	5 / 5	20+	18+

Item score*

* Item score = (Preferred hand + Nonpreferred hand) ÷ 2

Qualitative observations

Body control/posture

- ☐ Does not look at board while inserting pegs
- ☐ Holds face too close to task
- ☐ Holds head at an odd angle

- ☐ Does not use pincer grip to pick up pegs
- ☐ Exaggerates finger movements in releasing pegs
- ☐ Does not use the supporting hand to hold board steady
- ☐ Does *extremely* poorly with one hand (asymmetry striking)
- ☐ Changes hands or uses both hands during a trial
- ☐ Hand movements are jerky

- ☐ Sitting posture is poor
- ☐ Moves constantly/fidgets

Adjustments to task requirements

- ☐ Misaligns pegs with respect to holes
- ☐ Uses excessive force when inserting pegs
- ☐ Is *exceptionally* slow/does not change speed from trial to trial
- ☐ Goes too fast for accuracy

Other

....

....

THREADING NUTS ON BOLT — MANUAL DEXTERITY

Quantitative data

Record **time taken** (secs); **F** for failure; **R** for refusal; **I** for inappropriate

Trial 1 ....
Trial 2 ....

score	age 9	age 10
0	0–20	0–17
1	21–23	18–19
2	24	20–21
3	25–28	22
4	29–33	23–24
5	34+	25+

Item score

Qualitative observations

Body control/posture

- ☐ Does not look at nuts and bolt while threading
- ☐ Holds materials too close to face
- ☐ Holds head at an odd angle

- ☐ Does not use pincer grip to pick up nuts
- ☐ Does not hold the bolt steady to receive nuts
- ☐ Finds it difficult to coordinate hand movements
- ☐ Changes threading hand during a trial
- ☐ Hand movements are jerky

- ☐ Sitting posture is poor
- ☐ Moves constantly/ fidgets

Adjustments to task requirements

- ☐ Does not align the nuts correctly on bolt
- ☐ Tries to force nut when misaligned
- ☐ Is *exceptionally* slow/does not change speed from trial to trial
- ☐ Goes too fast for accuracy

Other

....

....

SHIFTING PEGS BY ROWS — MANUAL DEXTERITY

Quantitative data

Record time taken (secs); F for failure; R for refusal; I for inappropriate

Preferred hand	Nonpreferred hand
Trial 1	Trial 1 ....
Trial 2	Trial 2 ....

age 9	age 10	score	age 9	age 10
0–12	0–12	0 / 0	0–14	0–13
13	13	1 / 1	15	14
14	–	2 / 2	16	15
15	14	3 / 3	17	16
16–17	15–16	4 / 4	18–19	17
18+	17+	5 / 5	20+	18+

Item score*

* Item score = (Preferred hand + Nonpreferred hand) ÷ 2

Qualitative observations

Body control/posture

- Does not look at board while inserting pegs ☐
- Holds face too close to task ☐
- Holds head at an odd angle ☐

- Does not use pincer grip to pick up pegs ☐
- Exaggerates finger movements in releasing pegs ☐
- Does not use the supporting hand to hold board steady ☐
- Does *extremely* poorly with one hand (asymmetry striking) ☐
- Changes hands or uses both hands during a trial ☐
- Hand movements are jerky ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Misaligns pegs with respect to holes ☐
- Uses excessive force when inserting pegs ☐
- Is *exceptionally* slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐

Other

....

....

THREADING NUTS ON BOLT — MANUAL DEXTERITY

Quantitative data

Record time taken (secs); F for failure; R for refusal; I for inappropriate

Trial 1 ....
Trial 2 ....

score	age 9	age 10
0	0–20	0–17
1	21–23	18–19
2	24	20–21
3	25–28	22
4	29–33	23–24
5	34+	25+

Item score

Qualitative observations

Body control/posture

- Does not look at nuts and bolt while threading ☐
- Holds materials too close to face ☐
- Holds head at an odd angle ☐

- Does not use pincer grip to pick up nuts ☐
- Does not hold the bolt steady to receive nuts ☐
- Finds it difficult to coordinate hand movements ☐
- Changes threading hand during a trial ☐
- Hand movements are jerky ☐

- Sitting posture is poor ☐
- Moves constantly/ fidgets ☐

Adjustments to task requirements

- Does not align the nuts correctly on bolt ☐
- Tries to force nut when misaligned ☐
- Is *exceptionally* slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐

Other

....

....

FLOWER TRAIL — MANUAL DEXTERITY

Quantitative data

Record number of deviations; F for failure; R for refusal; I for inappropriate

Trial 1 ....

Trial 2 ....

Hand used ....

score	age 9	age 10
0	0	0
1	1	1
2	–	–
3	2	2
4	3	–
5	4+	3+

Item score

Qualitative observations

Body control/posture

- Does not look at trail ☐
- Holds face too near paper ☐
- Holds head at an odd angle ☐

- Holds pen with an odd/immature grip ☐
- Holds pen too far from point ☐
- Holds pen too close to point ☐
- Does not hold paper still ☐
- Changes hands during a trial ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Progresses in short jerky movements ☐
- Uses excessive force, presses very hard on paper ☐
- Is *exceptionally* slow ☐
- Goes too fast for accuracy ☐

Other

....

....

TWO-HAND CATCH — BALL SKILLS

Quantitative data

Record number of correct catches; R for refusal; I for inappropriate

....

score	age 9	age 10
0	6–10	8–10
1	5	7
2	4	6
3	3	4–5
4	1–2	1–3
5	0	0

Item score

Qualitative observations

Body control/posture

- Does not follow trajectory of ball with eyes ☐
- Turns away or closes eyes as ball approaches ☐

- Arms are not raised symmetrically for catching ☐
- Holds hands out flat with fingers stiff as the ball approaches ☐
- Arms and hands do not 'give' to meet impact of ball ☐
- Fingers close too early or too late ☐

- Body appears rigid/tense throughout ☐

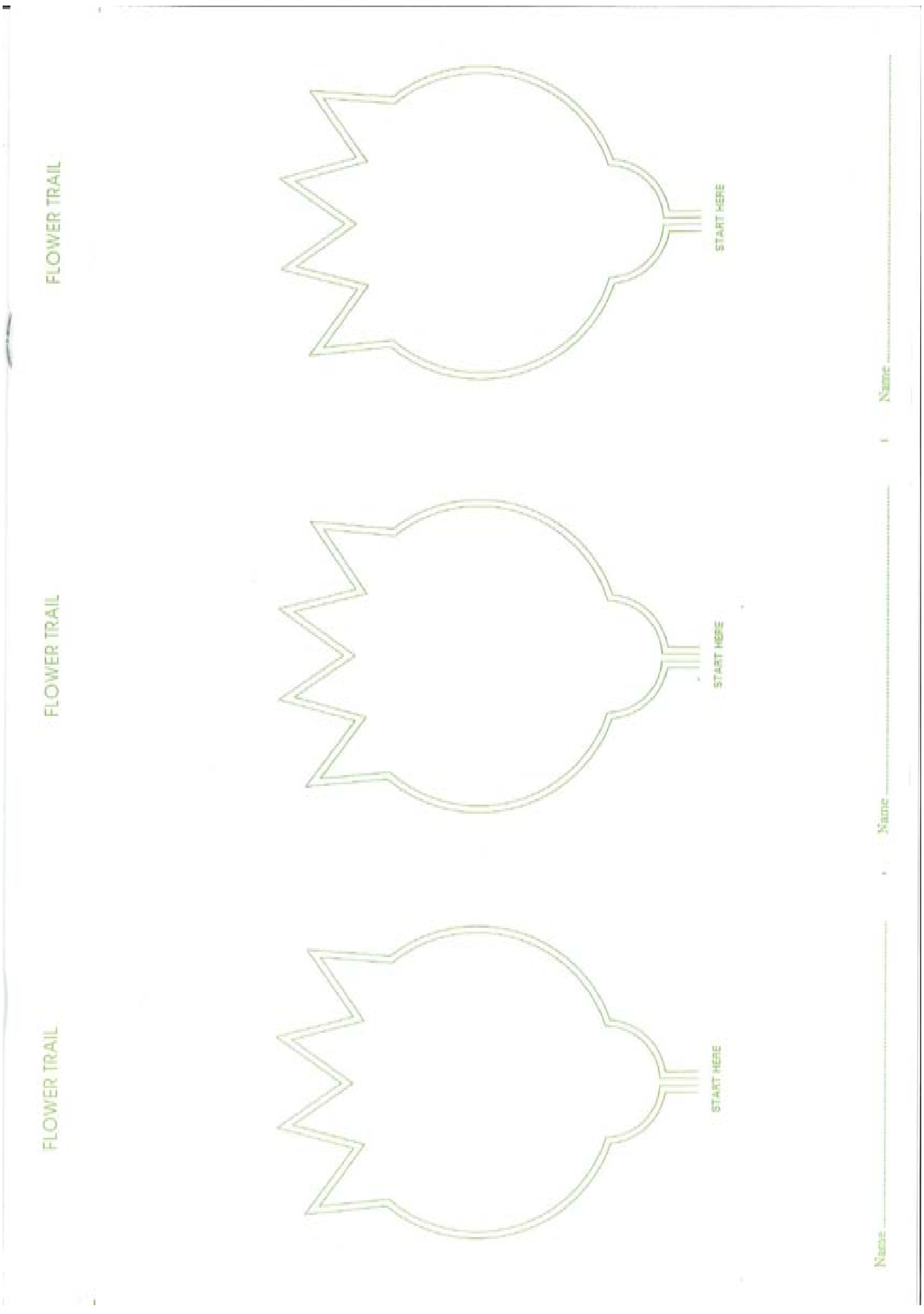
Adjustments to task requirements

- Does not adjust body position for catching ☐
- Does not adjust position of feet as necessary ☐
- Judges force of throw poorly (too much or too little) ☐
- Movements lack fluency ☐

Other

....

....


FLOWER TRAIL
START HERE
Name
FLOWER TRAIL
START HERE
Name
FLOWER TRAIL
START HERE
Name

THROWING BEAN BAG INTO BOX — BALL SKILLS

Quantitative data

Record number of goals; R for refusal; I for inappropriate

....

Hand used ....

score	age 9	age 10
0	5–10	6–10
1	4	5
2	3	–
3	2	4
4	–	3
5	0–1	0–2

Item score

Qualitative observations

Body control/posture

- Does not keep eyes on target ☐
- Does not use a pendular swing of the arm ☐
- Does not follow through with throwing arm ☐
- Releases bean bag too early or too late ☐
- Changes hands from trial to trial ☐
- Trunk and hips do not rotate as throwing arm comes forward ☐
- Over-rotates and loses balance ☐

Adjustments to task requirements

- Errors are consistently to one side of the box (asymmetry striking) ☐
- Judges force of throw poorly (too much or too little) ☐
- Control of force is variable ☐
- Movements lack fluency ☐

Other

....

....

ONE-BOARD BALANCE — STATIC BALANCE

Quantitative data

Record time balanced (secs); R for refusal; I for inappropriate

Preferred leg	Nonpreferred leg
Trial 1	Trial 1 ....
Trial 2	Trial 2 ....

age 9	age 10	score	age 9	age 10
6–20	9–20	0 / 0	6–20	8–20
5	6–8	1 / 1	5	6–7
4	5	2 / 2	4	5
3	4	3 / 3	3	4
2	3	4 / 4	2	3
0–1	0–2	5 / 5	0–1	0–2

* Item score

* Item score = (Preferred leg + Nonpreferred leg) ÷ 2

Qualitative observations

Body control/posture

- Does not hold head and eyes steady ☐
- Looks down at feet ☐
- Makes no or few compensatory arm movements to help maintain balance ☐
- Exaggerated movements of arms and trunk disrupt balance ☐
- Body is held rigid ☐
- Sways wildly to try to maintain balance ☐
- Does *extremely* poorly on one leg (asymmetry striking) ☐

Other

....

....

HOPPING IN SQUARES — DYNAMIC BALANCE

Quantitative data

Record number of correct hops; F for failure; R for refusal; I for inappropriate.

Preferred leg	Nonpreferred leg
Trial 1	Trial 1 ....
Trial 2	Trial 2 ....
Trial 3	Trial 3 ....

age 9	age 10	score	age 9	age 10
5	5	0 / 0	5	5
–	–	1 / 1	–	–
–	–	2 / 2	4	4
4	4	3 / 3	3	3
1–3	3	4 / 4	1–2	2
0	0–2	5 / 5	0	0–1

* Item score

* Item score = (Preferred leg + Nonpreferred leg) ÷ 2

Qualitative observations

Body control/posture

- Does not use arms to assist hop ☐
- Arms swing out of phase with legs ☐
- Arm movements are exaggerated ☐

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐

- Nonsupporting leg held up in front of body ☐
- Lacks springiness/no push-off from feet ☐
- Noticeably poorer on one foot than the other ☐
- Hops with stiff legs/on flat feet ☐
- Stumbles on landing ☐

Adjustments to task requirements

- Does not combine upward and forward movements effectively ☐
- Uses too much effort ☐
- Movements are jerky ☐

Other

....

....

BALL BALANCE — DYNAMIC BALANCE

Quantitative data

Record number of drops; F for failure; R for refusal; I for inappropriate

Trial 1	Hand used ....
Trial 2	
Trial 3	

score	age 9	age 10
0	0	0
1	–	–
2	1	1
3	2	2
4	3–4	3–4
5	5+	5+

Item score

Qualitative observations

Body control/posture

- Does not look ahead ☐
- Does not keep head steady ☐

- Does not compensate with free arm to maintain balance ☐
- Exaggerated arm movements disrupt balance ☐

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐
- Shuffles forward, does not lift feet off floor ☐

Adjustments to task requirements

- Goes too fast to control ball ☐
- Individual movements lack smoothness and fluency ☐
- Sequencing of steps is not smooth/pauses frequently ☐

Other

....

....

MOVEMENT ABC

RECORD FORM

Movement Assessment Battery for Children

Compiled by Sheila E. Henderson and David A. Sugden

AGE BAND 4 11–12 years

Name .... Gender ....

Home address .... Date of test ....

.... Date of birth ....

.... Age ....

School .... Grade/class ....

....

Assessed by ....

Preferred hand (defined as the hand used to write with) ....

Other information ....

....

Published by The Psychological Corporation Limited, 24-28 Oval Road, London NW1 7DX.

Printed in the United Kingdom
ISBN 0 7491 0135 0

TURNING PEGS — MANUAL DEXTERITY

Quantitative data

Record time taken (secs); F for failure; R for refusal; I for inappropriate

Preferred hand	Nonpreferred hand
Trial 1	Trial 1 ....
Trial 2	Trial 2 ....

Preferred hand: age 11	Preferred hand: age 12	score	Nonpreferred hand: age 11	Nonpreferred hand: age 12
0–20	0–19	0 / 0	0–23	0–23
21–22	20–21	1 / 1	24–25	24–25
23	22	2 / 2	26	26
24	23	3 / 3	–	–
25–26	24	4 / 4	27	27
27+	25+	5 / 5	28+	28+

Item score*

* Item score = (Preferred hand + Nonpreferred hand) ÷ 2

Qualitative observations

Body control/posture

- Does not look at board while inserting pegs ☐
- Holds face too close to task ☐
- Holds head at an odd angle ☐

- Does not use pincer grip to pick up pegs ☐
- Exaggerates finger movements in releasing pegs ☐
- Does not use the supporting hand to hold board steady ☐
- Does *extremely* poorly with one hand (asymmetry striking) ☐
- Changes hands or uses both hands during a trial ☐
- Hand movements are jerky ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Misaligns pegs with respect to holes ☐
- Uses excessive force when inserting pegs ☐
- Is *exceptionally* slow/does not change speed from trial to trial ☐
- Goes too fast for accuracy ☐

Other

....

....

CUTTING–OUT ELEPHANT — MANUAL DEXTERITY

Quantitative data

Record number of faults; F for failure; R for refusal; I for inappropriate

Trial 1 ....

Trial 2 ....

Hand used ....

score	age 11	age 12
0	0–1	0–1
1	2–3	2–3
2	4–6	4
3	7–9	5–6
4	10–16	7–9
5	17+	10+

Item score

Qualitative observations

Body control/posture

- Does not look at shape while cutting ☐
- Holds materials too close to face ☐
- Holds head at an odd angle ☐

- Grips scissors awkwardly ☐
- Grip on scissors is correct but twists them while cutting ☐
- Holds paper too far from cutting hand ☐
- Finds it difficult to coordinate movements ☐
- Changes cutting hand during a trial ☐
- Hand movements are jerky ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Is unprepared for changes of direction ☐
- Cuts with short jerky movements ☐
- Is *exceptionally* slow ☐
- Goes too fast for accuracy ☐

Other

....

....

FLOWER TRAIL — MANUAL DEXTERITY

Quantitative data

Record number of deviations; F for failure; R for refusal; I for inappropriate

Trial 1 ....

Trial 2 ....

Hand used ....

score	age 11	age 12
0	0–1	0–1
1	2	2
2	3	3
3	4	4
4	5–7	5–7
5	8+	8+

Item score

Qualitative observations

Body control/posture

- Does not look at trail ☐
- Holds face too near paper ☐
- Holds head at an odd angle ☐

- Holds pen with an odd/immature grip ☐
- Holds pen too far from point ☐
- Holds pen too close to point ☐
- Does not hold paper still ☐
- Changes hands during a trial ☐

- Sitting posture is poor ☐
- Moves constantly/fidgets ☐

Adjustments to task requirements

- Progresses in short jerky movements ☐
- Uses excessive force, presses very hard on paper ☐
- Is *exceptionally* slow ☐
- Goes too fast for accuracy ☐

Other

....

....

ONE-HAND CATCH — BALL SKILLS

Quantitative data

Record number of correct catches; R for refusal; I for inappropriate

Preferred hand	Nonpreferred hand
....	....

age 11	age 12	score	age 11	age 12
6–10	8–10	0 / 0	6–10	8–10
5	7	1 / 1	5	7
4	6	2 / 2	4	5–6
3	5	3 / 3	2–3	4
2	4	4 / 4	1	3
0–1	0–3	5 / 5	0	0–2

Item score

* Item score = (Preferred hand + Nonpreferred hand) ÷ 2

Qualitative observations

Body control/posture

- Does not follow trajectory of ball with eyes ☐
- Turns away or closes eyes as ball approaches ☐

- Holds hand out flat with fingers stiff as the ball rebounds ☐
- Arm and hand do not 'give' to meet impact of ball ☐
- Fingers close too early or too late ☐
- Does *extremely* poorly with one hand (asymmetry striking) ☐

- Body appears tense/rigid throughout ☐

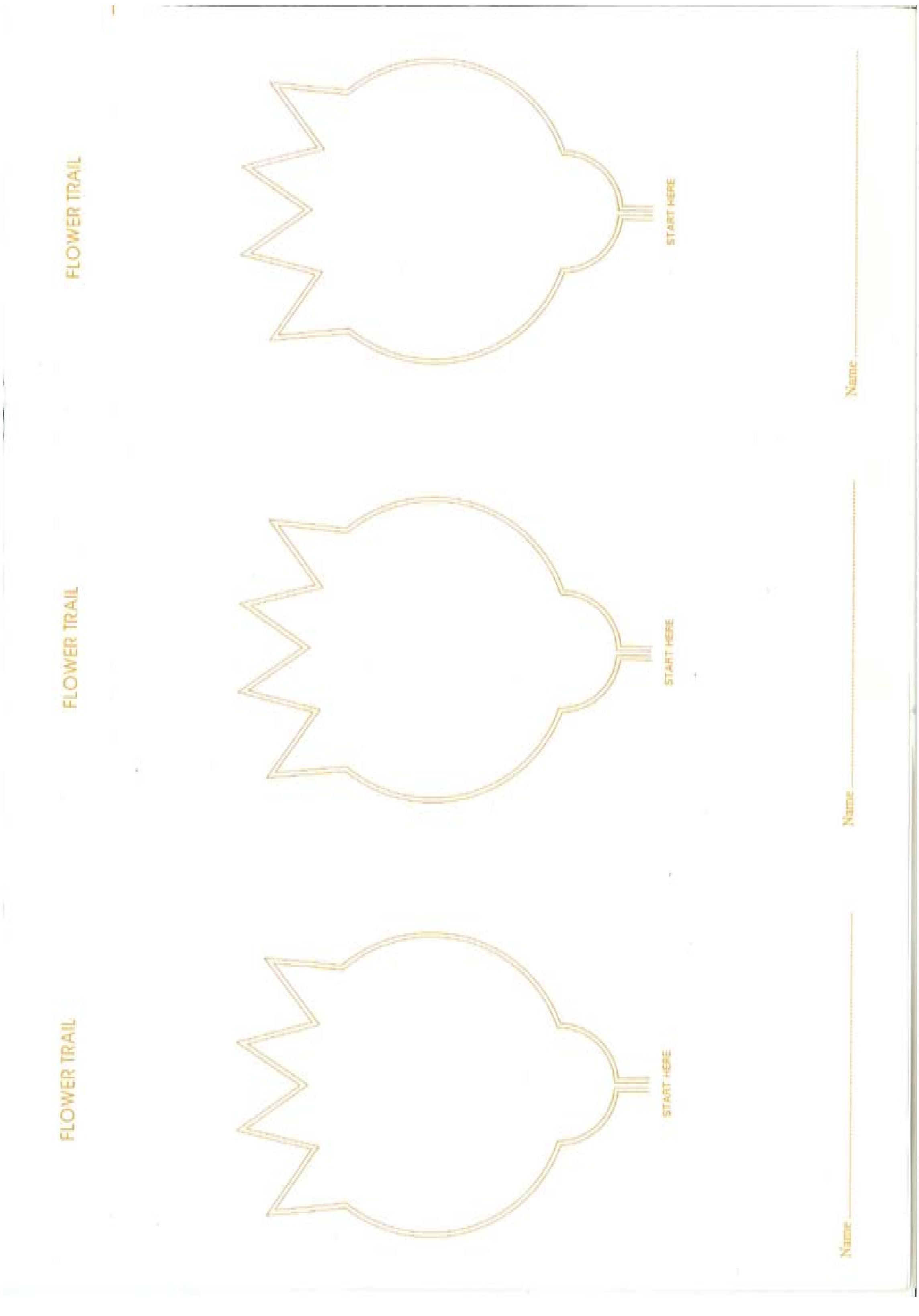
Adjustments to task requirements

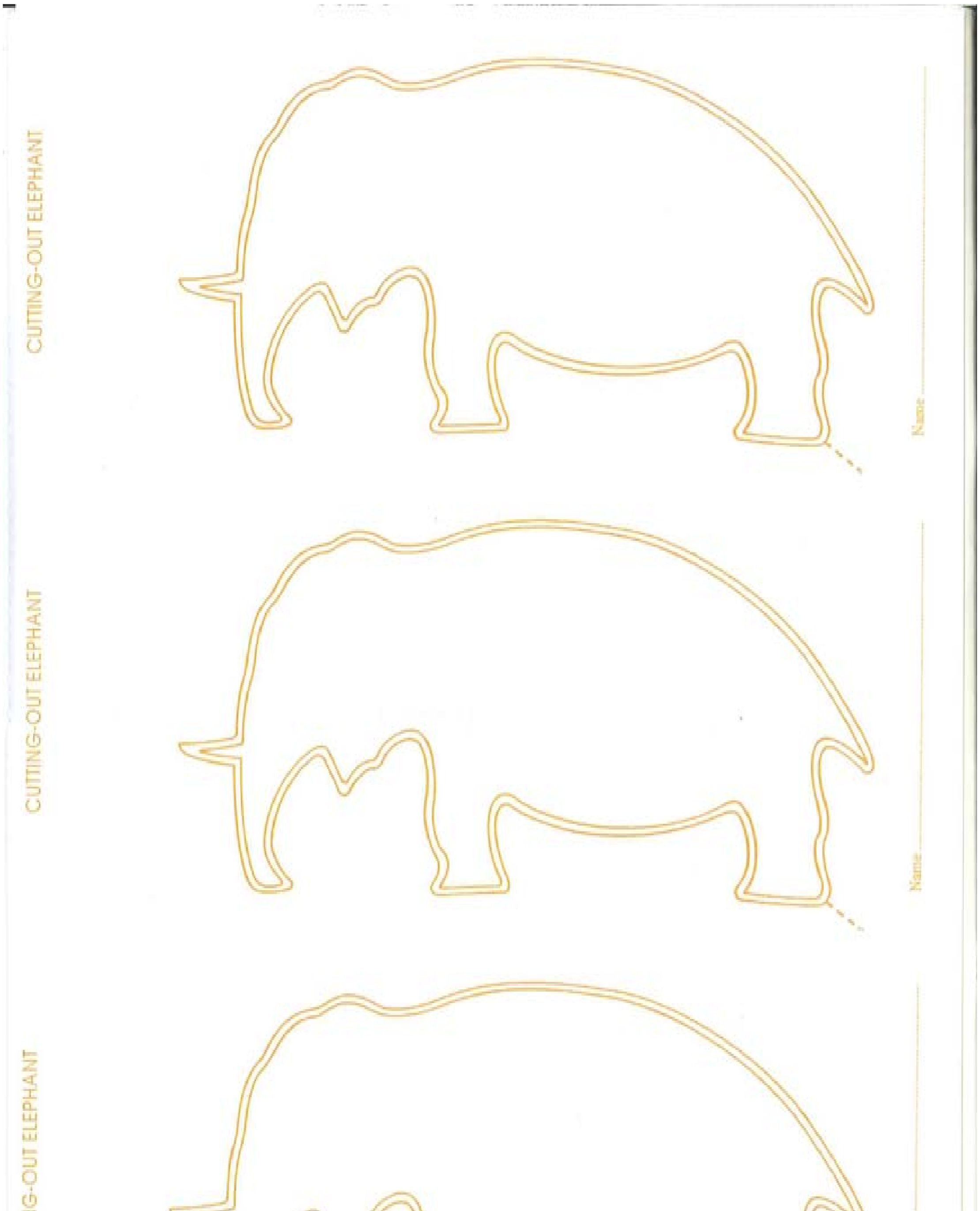
- Does not adjust body position for catching ☐
- Does not adjust position of feet as necessary ☐
- Judges force of throw poorly (too much or too little) ☐
- Movements lack fluency ☐

Other

....

....


FLOWER TRAIL
START HERE
Name
FLOWER TRAIL
START HERE
Name
FLOWER TRAIL
START HERE
Name


CUTTING-OUT ELEPHANT
Name
CUTTING-OUT ELEPHANT
Name
CUTTING-OUT ELEPHANT
Name

THROWING AT WALL TARGET — BALL SKILLS

Quantitative data

Record number of goals; R for refusal; I for inappropriate

....
Hand used ....

score	age 11	age 12
0	6–10	6–10
1	5	5
2	4	4
3	3	3
4	2	2
5	0–1	0–1

Item score

Qualitative observations

Body control/posture

- Does not keep eyes on target ☐
- Does not use a pendular swing of the arm ☐
- Does not follow through with throwing arm ☐
- Releases ball too early or too late ☐
- Changes hands from trial to trial ☐
- Trunk and hips do not rotate as throwing arm comes forward ☐
- Over-rotates and loses balance ☐

Adjustments to task requirements

- Errors are consistently to one side of the target (asymmetry striking) ☐
- Judges force of throw poorly (too much or too little) ☐
- Control of force is variable ☐
- Movements lack fluency ☐

Other

....

....

TWO-BOARD BALANCE — STATIC BALANCE

Quantitative data

Record time balanced (secs); R for refusal; I for inappropriate

Trial 1 ....
Trial 2 ....

score	age 11	age 12
0	10–20	11–20
1	8–9	9–10
2	7	7–8
3	5–6	6
4	4	5
5	0–3	0–4

Item score

Qualitative observations

Body control/posture

- Does not hold head and eyes steady ☐
- Looks down at feet ☐
- Makes no or few compensatory arm movements to help maintain balance ☐
- Exaggerated movements of arms and trunk disrupt balance ☐
- Body is held rigid ☐
- Sways wildly to try to maintain balance ☐
- Cannot hold feet in a straight line ☐

Other

....

....

JUMPING AND CLAPPING — DYNAMIC BALANCE

Quantitative data

Record number of claps; F for failure; R for refusal; I for inappropriate

Trial 1 ....

Trial 2 ....

Trial 3 ....

score	age 11	age 12
0	4+	4+
1	–	–
2	3	3
3	–	–
4	2	2
5	0–1	0–1

Item score

Qualitative observations

Body control/posture

- Does not use arms to assist jump ☐
- Does not raise arms symmetrically to clap ☐

- Body appears tense ☐
- Body appears limp/floppy ☐

- Makes no preparatory crouch ☐
- Lacks springiness/no push-off from feet ☐
- Uneven take-off/loss of symmetry in flight and landing ☐
- Lands with stiff legs/on flat feet ☐
- Stumbles on landing ☐

Adjustments to task requirements

- Does not combine upward and forward movements effectively ☐
- Does not coordinate timing of jump and clap ☐
- Uses too much effort ☐
- Movements are jerky ☐

Other

....

....

WALKING BACKWARDS — DYNAMIC BALANCE

Quantitative data

Record number of steps; F for failure; R for refusal; I for inappropriate

Trial 1 ....

Trial 2 ....

Trial 3 ....

score	age 11	age 12
0	15	15
1	11–14	14
2	10	10–13
3	8–9	8–9
4	6–7	6–7
5	0–5	0–5

Item score

Qualitative observations

Body control/posture

- Does not look behind to check position on track ☐
- Does not keep head steady ☐

- Does not compensate with arms to maintain balance ☐
- Exaggerated arm movements disrupt balance ☐

- Body appears rigid/tense ☐
- Body appears limp/floppy ☐
- Does not rotate trunk and shoulders when stepping backwards ☐

- Is very wobbly when placing feet on line ☐
- Sways wildly to try to maintain balance ☐

Adjustments to task requirements

- Goes too fast for accuracy ☐
- Individual movements lack smoothness and fluency ☐
- Sequencing of steps is not smooth/pauses frequently ☐

Other

....

....

APPENDIX E

PARENT GUARDIAN INFORMATION

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

INFORMATION LETTER TO PARENT/GUARDIAN

TITLE OF PROJECT: Body mass index, motor impairment and gait in primary aged children

NAMES OF SUPERVISOR: Assoc. Prof. John Saunders

NAME OF STUDENT RESEARCHER: Mr. Cameron Wilson

NAME OF PROGRAMME IN WHICH ENROLLED: PhD

Your child is invited to be a participant in a study investigating motor performance of primary school aged children. The testing will require your child to perform the Movement Assessment Battery for Children (MABC), have a their walking analysed by completing three lots of 10 walkthroughs over a carpeted walkway (5m) that records the stepping pattern (GAITRite).

The MABC testing is made up of:
- Balance tests such as standing on one leg or hopping.
- Manual dexterity tests such as threading nuts on a bolt, and
- Ball skills tests such as one hand catching.

The GAITRite walkway is an electronic roll-up mat that collects information on individuals' walking patterns. If your child participates in this study, he/she will be required to walk across the GAITRite 10 times at his/her preferred walking pace and a further 10 at a slow and 10 at a fast walking pace. Each child will be supervised at all times and escorted to and from class by a research assistant.

The risks associated with this study are minimal, no more than any normal P.E. class. The information that will be recorded will be kept confidential. Only the participating researchers will have access to the data being collected. If you have further queries on this issue, it should be directed to Dr. Noel Lythgo or Mr. Cameron Wilson as listed below.

Your child will be required to wear a pair of his/her own flat-soled shoes (school shoes). Upon arrival each child's body weight and leg length measurements will be recorded. He/she will then be instructed to complete three lots of 10 walks across the mat at his/her normal, fast and slow walking pace. In the same session your child will be performing the MABC test assisted by a researcher. In all, this should take approximately 30-40 minutes.

The potential benefits of this study include the general group results being made available to the P.E. staff of the school to assist in the development of a program that includes all motor performance levels. If you so wish, individual results can be made available to the P.E. staff to assist in specific areas of the P.E. classes.

It is important to understand that you are free to refuse consent altogether without having to justify that decision, or to withdraw consent and discontinue participation of your child in the study at any time without giving a reason. If during the project your child feels uncomfortable in any way and no longer wishes to continue he/she is free to withdraw at any time without any unfavourable consequences. Upon completion of the study tasks, or if you choose to withdraw your child from the study, you will be given the opportunity to ask questions regarding the project.

At all times the information that will be collected will remain confidential. A coding system will be used to identify your child and this will be destroyed at the conclusion of the study.

Any questions regarding this project should be directed to the Principal Investigators.

Assoc. Prof. John Saunders
on 9953 3038
in the School of Exercise Science
115 Victoria Parade Fitzroy,
Victoria 3065

(or) Mr Cameron Wilson
on 9953 3419
in the School of Exercise Science
115 Victoria Parade Fitzroy,
Victoria 3065

At the conclusion of the study an information session will be held where group results will be produced. You are cordially invited to attend that session and ask questions about the study.

Please be advised that this study has been presented to and approved by the Human Research Ethics Committee at Australian Catholic University. If at anytime you have a query or complaint about the way that you have been treated in this study, you may write care of the Office of Research.

Chair, HREC
C/o Research Services
Australian Catholic University
Locked Bag 4115
FITZROY VIC 3065
Tel: 03 9953 3157
Fax: 03 9953 3305

Any complaint made will be treated in confidence, investigated fully and the participant informed of the outcome.

If you agree for your child to participate in this study please complete the details on both the attached consent forms and sign them. Please retain one copy for your records and the other copy will be filed by the Principal Investigator at Australian Catholic University Campus in a securely locked filing cabinet.

Thank you for your cooperation with this important research.

Yours sincerely,

Mr. Cameron Wilson
STUDENT RESEARCHER

Australian Catholic University
Brisbane Sydney Canberra Ballarat Melbourne

ACU National

PARENT/GUARDIAN CONSENT FORM

TITLE OF PROJECT: Body mass index, motor impairment and gait in primary aged children

NAME OF SUPERVISOR: Dr. Noel Lythgo

NAME OF STUDENT RESEARCHER: Mr. Cameron Wilson

I .... (*the parent/guardian*) have read (*or, where appropriate*, have had read to me) and understood the information provided in the Letter to the Participants. Any questions I have asked have been answered to my satisfaction. I agree that my child, nominated below, may participate in this activity, realising that I can withdraw my consent at any time. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify my child in any way.

NAME OF PARENT/GUARDIAN: ....
(block letters)

SIGNATURE .... DATE......................................

NAME OF CHILD ....
(block letters)

SIGNATURE OF PRINCIPAL SUPERVISOR:

………………………………………………… DATE:…………………………………….

SIGNATURE OF STUDENT RESEARCHER:

………………………………………………… DATE: ……………………………………

APPENDIX F

GENDER, AGE & STATURE MATCHING

Table F.1 Comparison of motor impairment groups on matched variables of age and stature

	MI	TD
Age (years)	9.81 (1.72)	9.86 (1.79)
Stature (cm)	139.35 (11.95)	139.26 (11.35)

Table F.2 reports the means of the anthropometric variables for the two groups.

Table F.2 Related anthropometric variables for motor impaired and typically developing children.

	MI	TD
Mass (kg)	36.73 (11.45)	36.17 (9.47)
Leg Length (L & R mean)	74.91 (7.7)	75.28 (8.0)
BMI	18.6 (3.4)	18.3 (2.8)

The gait parameters of the motor impaired and typically developing children were compared across the three walking speeds.

Table F.3 Comparison of balance impairment groups on matched variables of age and stature

	BI	Non-BI
Age (years)	10.33 (2.12)	10.22 (2.03)
Stature (cm)	142.68 (13.76)	141.25 (13.40)

Table F.4 reports the means of the anthropometric variables for the two groups.

Table F.4 Related anthropometric variables for balance impaired and typically developing children.

	BI	Non-BI
Mass (kg)	39.36 (13.51)	36.98 (10.30)
Leg Length (L & R mean)	76.71 (8.9)	76.82 (9.1)
BMI	18.9 (4.1)	18.1 (2.6)

APPENDIX G

SUMMARY OF NORMALISED VALUES

Table G.1a) Summary of normalised parameters of gait across age-bands at normal walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n = 24)
Velocity	0.56 (0.06)	0.54 (0.07)	0.50 (0.06)	0.48 (0.06)	0.49 (0.04)
Cadence	0.64 (0.054)	0.626 (0.054)	0.601 (0.043)	0.603 (0.045)	0.586 (0.034)
Step Length	0.88 (0.05)	0.86 (0.07)	0.82 (0.06)	0.80 (0.08)	0.84 (0.05)
Step Time	1.579 (0.134)	1.613 (0.142)	1.676 (0.124)	1.668 (0.177)	1.713 (0.096)
Base of Support	0.12 (0.02)	0.11 (0.03)	0.1 (0.03)	0.09 (0.03)	0.11 (0.02)
Double Support Time	0.356 (0.113)	0.357 (0.092)	0.437 (0.166)	0.439 (0.092)	0.752 (0.096)

Table G.1b) Summary of normalised parameters of gait across age-bands at slow walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n =24)
Velocity	0.45 (0.04)	0.44 (0.05)	0.41 (0.04)	0.39 (0.04)	0.40 (0.03)
Cadence	0.58 (0.054)	0.565 (0.041)	0.551 (0.041)	0.547 (0.04)	0.526 (0.027)
Step Length	0.77 (0.05)	0.77 (0.07)	0.74 (0.06)	0.72 (0.07)	0.76 (0.05)
Step Time	1.749 (0.178)	1.786 (0.128)	1.827 (0.139)	1.844 (0.138)	1.907 (0.095)
Base of Support	0.12 (0.02)	0.11 (0.03)	0.11 (0.03)	0.09 (0.03)	0.11 (0.02)
Double Support Time	0.465 (0.116)	0.458 (0.109)	0.537 (0.124)	0.54 (0.101)	0.935 (0.103)

Table G.1c) Summary of normalised parameters of gait across age-bands at fast walking speed.

	Age-bands				Young Adults
	1 (n = 33)	2 (n = 61)	3 (n = 75)	4 (n = 49)	(n = 24)
Velocity	0.70 (0.09)	0.68 (0.09)	0.65 (0.08)	0.59 (0.07)	0.62 (0.04)
Cadence	0.752 (0.095)	0.743 (0.074)	0.723 (0.074)	0.677 (0.05)	0.654 (0.035)
Step Length	0.92 (0.06)	0.92 (0.07)	0.89 (0.06)	0.87 (0.08)	0.95 (0.06)
Step Time	1.356 (0.143)	1.365 (0.125)	1.400 (0.131)	1.487 (0.106)	1.534 (0.08)
Base of Support	0.12 (0.02)	0.11 (0.03)	0.11 (0.03)	0.09 (0.02)	0.11 (0.02)
Double Support Time	0.283 (0.095)	0.263 (0.074)	0.310 (0.089)	0.336 (0.076)	0.580 (0.068)