Motor Skill Acquisition in Children with Poor Motor Coordination

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Thesis submitted as a partial fulfilment of the requirements for the degree:

Master of Philosophy

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Abstract

Physical Activity is essential for growth, development and wellbeing. Children with poor motor coordination are known to have lower levels of participation in physical activity and exercise in comparison to their typically developing peers, at least partly due to the difficulty in acquiring the motor skills they need for participation. Reduced participation in physical activity in childhood increases the risk of developing obesity, cardiovascular disease and psychosocial problems which persist throughout adolescence and adulthood. Poor motor coordination in these children has been largely attributed to their difficulty in acquiring and performing motor skills. However, motor skill acquisition is not yet well understood in this group, in particular whether these children are able to improve the quality of their movement and the pattern of motor skill acquisition.

The following thesis aims to investigate the motor skill acquisition in a group of children with motor coordination difficulties and is comprised of two main studies. The first one aims at creating a simple and easy tool for screening coordination in large cohorts of children in mainstream schools in order to identify children with poor motor coordination.
The second study is a pilot/feasibility study aimed at informing the implementation of a fully powered follow-up motor learning intervention trial. It involved detection of a sample of children with poor motor coordination using the designed screening tool in 3 mainstream schools and recruiting them into a physical training intervention with an embedded practice of a novel rhythmic stepping task. The characteristics of their performance throughout the training program were investigated by instrumenting the stepping ask and comparing the performance with a group of children with normal motor coordination.

Applying a reduction analysis on a large set of motor screening data (which included test items from The Bruininks-Oseretsky Test of Motor Proficiency-Short Form (BOT-SF) as well as Fundamental Movement Skill), we successfully designed a test which has face validity for detection of children with poor coordination. Using this test, we screened a total of 571 students (273 females and 298 males) from 3 main stream schools in Oxfordshire and invited students who scored below the 25th percentile on our screening test (117; 53 girls and 64 boys) to an 11 week training intervention. Thirty-three students attended the intervention (21 girls and 12 boys) with a great difference in recruitment and retention rates between the schools.

The learning of the novel motor skill was measured by analysis of the participants' performance on a novel stepping task, in which they stepped rhythmically in accordance to a sequence of visual stimuli presented on a computer screen. The performance (movement time), measured using accelerometry, was significantly worse in children with coordination

problems (*p*<.001) mean±SD= 1.193±.036. Importantly, children with poor motor coordination were able to improve their performance on the task with no significant differences between the groups. However, we observed a tendency for difference in the pattern of improvement over time (*p*=.06).

Given the nature of the conducted studies, i.e. as feasibility studies, our findings don't allow of a straightforward generalisation. Still, they entail important implications in clinical and school-based training interventions, directed towards children with poor motor coordination, and it is recommended that a follow-up trial take place which takes into account the suggestions mentioned in this thesis with regards to the involvement of schools, importance of applying successful recruitment strategy and the requirements of successful intervention.

Acknowledgement

I dedicate this piece of work to my soulmate and beloved, Patrick Duerr, whose love, care and faith kept me on my feet all along.

I would like to thank my supervisors Helen Dawes and Anne Delextrat for their help and guidance throughout the project. Many thanks to all current and previous members of the Movement Science Group who volunteered to run the screening and the training sessions, especially Francesca Lui (my Chiquita), Daan Meester the great inspiration, Ruben Zijlstra my great companion who designed both data collection and analysis programmes, Julian Rudisch for all the useful conversations and Tom Derikx and Judith Kunft for working on NIRS.

Many thanks to my dear colleagues Catherine Wheatley, Leisle Ezekiel, Yetunde Dairo and Ben Weedon for their help and support and to Andy Meaney for training the children and keeping them happy.

Thank you to my dear Bence for all the library times and great friendship, and to Majd Jarrar for the prolonged online study sessions and unlimited support.

I am also infinitely grateful to my family and especially my sisters Heba and Noor for being there for me every day.

Thesis Map

This thesis aims to investigate the motor skill acquisition in a group of children with motor coordination problems. The main study is a feasibility study which precedes and informs the design of a fully powered intervention trial. The thesis is comprised of five chapters. The first chapter is an introduction to the topic accompanied by the review of the relevant literature. It explains the importance of participation in physical activity and exercise for the health and wellbeing of children and draws the connection between poor motor coordination and physical activity participation, which is explained by the difficulty that children with poor motor coordination have in acquiring the motor skills they need for effective participation.

In this chapter, the available literature on motor learning deficiency in this group is discussed and criticised, so are the motor assessment tools available for categorisation. The gaps in the literature are identified including: 1- the need for developing a motor assessment tool which has utility for detection of children with poor coordination from mainstream schools 2- the need for investigating the ability of children with motor coordination to acquire functional sport related motor tasks; especially tasks which involve lower limb and multi joint coordination. The chapter ends by stating the objectives, aims and hypotheses of the different parts of the study.

Chapter 2 describes the study in which we designed a motor assessment tool for detection of children with motor coordination problems in main stream schools. This assessment tool is quick, easy and has utility for the purpose it was created for. The design of the test was based on a reduction analysis performed on multiple test items from standardised assessment tools.

Chapter 3 describes a small study which aimed to validate the methods intended for use in the main intervention study. The Inertial Measurement Unit (IMU) is used to detect movement events during the rhythmic stepping task and since this task is novel, the use of the IMU needed to be validated against the golden standard of motion analysis, namely the Optical Camera Motion System (OCMS).

Chapter 4 describes the main intervention trial with an initial focus on the methods including; participants (screening, selection, inclusion criteria, and recruitment), ethics and consent, and a detailed description of the intervention including the physical training intervention and the rhythmic stepping intervention i.e. the motor learning task. The outcome measures are then listed and defined. After that, the data analysis and statistical analysis methods are described and results are reported for both the feasibility aspect of the study and the motor learning intervention (in terms of group difference in motor performance and learning).

Chapter 5 discusses the finding of the three different studies in light of the available literature and provides detailed commentary on how the main trial should be run in order to achieve the best results in answering the clinical question.

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List of Abbreviations

Abbreviation	Stands for
AR (1)	First Order Autoregressive
BOTMP	The Bruininks-Oseretsky Test of Motor Proficiency
BOT-SF	The Bruininks-Oseretsky Test of Motor Proficiency-Short Form
CLEAR	Clinical Exercise and Rehabilitation Unit
CMO	Chief Medical Officer
COM	Centre of Motion
CONSORT	Consolidated Standards for the Reporting of Trials
CO-OP	Cognitive Orientation to daily Occupational Performance
CST	Chester Step Test
DCD	Developmental Coordination Disorder
DSM	American Psychiatric Association Diagnostic and Statistical Manual
EPIC	Engagement Participation Inclusion and Confidence in sport
EUROFIT	European test of Physical Fitness
FMS	Fundamental Movement Skills
GCSE	General Certificate of Secondary Education
HR_{max}	maximum Heart Rate
ICC	Intraclass Correlation Coefficient
ID	Identity
IMU	Inertial Measurement Unit
KMO	The Kaiser-Meyer-Olkin
KTK	The Body Coordination Test for Children (Körperkoordinationstest Für Kinder)
Lft-Lft-Rt	Left-Left-Right
LPMS-B	Life Performance Motion Sensor-B
MABC	Movement Assessment Battery for Children
MAND	The McCarron Assessment of Neuromuscular Development
MEMS	Micro-Electro Mechanical Systems
OCMS	Optical Camera Motion System
PE	Physical Education
PI	Participant Information

REML	Restricted Maximum Likelihood method
RPE	Rate of Perceived Exertion
Rt-Lft	Right-Left
Rt-Rt-Lft	Right-Right-Left
Rt-Rt-Lft-Lft	Right-Right-Left-Left
SPSS	Statistical Package For Social Sciences
SRT	Serial Reaction Time
SVMg	Sum of Vector Magnitude corrected for gravity
TD	Typically Developing
TGMD	The Test of Gross Motor Development
TOMI	Test of Motor Impairment
UREC	University Research Ethics Committee
VO2 max	Maximum Volume of O_2 consumption
WHO	World Health Organisation

Chapter (1): Introduction

1.1 Motor Development and Physical Activity

Movement is the only way by which humans are able to explore and manipulate the world around them. Accordingly, one of the most important functions of the human nervous system is the production of adaptable and complex movements (Wolpert, Diedrichsen et al. 2011). Motor development in infants and children, from the point of view of the Ecological Theory of Motor Development (Bronfenbrenner and Morris 1998; Haywood and Getchell 2014), is mainly facilitated by the interaction between the subject, the task and the environment. The constraints the task and the environment impose provide the challenges which necessitate the acquisition of motor skills to help adapt to these constraints (Haywood and Getchell 2009). Thus, the more opportunities children are given to interact with their environment, the more tuned and versatile their motor abilities are likely to become.

Development of appropriate motor control and coordination skills is crucial for providing children with opportunities to interact with their environment, perform activities of daily living (Hill and Barnett 2011) and participate in different types of physical activity (King, Stokols et al. 2002). Less exposure to environmental stimulation, which may be the result of less developed motor control, has detrimental effects on overall development and wellbeing. It also feeds a vicious circle of lack of participation in physical activity and group play and lack of motivation, in turn creating less opportunity for improving motor proficiency and a subsequent reduction in confidence (Green, Richard et al. 1996).

Regular participation in exercise is necessary for the optimisation of body performance and overall wellbeing (Penedo and Dahn 2005; Warburton, Nicol et al. 2006). Exerciseduring childhood and adolescence is of particular importance as is needed to improve strength (Lloyd, Faigenbaum et al. 2013) cardiorespiratory fitness (Armstrong and van Mechelen 2008) and body composition (Ruiz, Rizzo et al. 2006; Spolidoro, Pitrez Filho et al. 2013), which in turn decreases the likelihood of developing cardiovascular and metabolic conditions (Chaput, Saunders et al. 2013; Nelson, Horowitz et al. 2013). Moreover, exercise levels in adolescence are correlated with activity levels and lifestyle in adulthood (Hancox, Milne et al. 2004). But the benefits of physical activity and exercise extend well beyond the physical health to cognitive and psychological wellbeing including alleviating depression and anxiety and improving self-esteem (Norris, Carroll et al. 1992; Kirkcaldy, Shephard et al. 2002). As evident from brain imaging studies, physical activity is also associated with the structure and function of the adolescent brain (Chaddock, Erickson et al. 2010; Chaddock-Heyman, Erickson et al. 2014) and induces both higher cognitive performance and better academic achievement (Hillman, Erickson et al. 2008; Biddle and Asare 2011).

Notwithstanding the widespread awareness of the empirically well-confirmed relationship between physical activity and health (Warburton, Nicol et al. 2006), worldwide levels of participation in physical activity have been very low (Hallal, Andersen et al. 2012). In fact, physical inactivity is considered to be the fourth leading risk factor for mortality causing 35 million deaths worldwide (WHO 2004). This finding encouraged multiple UK and international health organisations to produce guidelines of age-specific physical activity recommendations for health (Sallis, Patrick et al. 1994; Twisk 2001; WHO 2010).

Current UK guidelines (GOV.UK 2011), which also find international agreement, recommend that children and adolescents aged 5-18 years participate in moderate-to-vigorous intensity physical activity for 60 min and up to several hours each day and should incorporate vigorous activities including those that strengthen muscle and bone three or more times per week (Andersen, Harro et al. 2006; Janssen and LeBlanc 2010; Carson, Hunter et al. 2016). Despite these recommendations, a global percentage of 81% of children between 11-17 years old fail to achieve sufficient levels of physical activity (WHO 2010), while increasingly engaging in sedentary activities 50% of the time (Colley, Wong et al. 2012; Carson, Hunter et al. 2016).

Research has shown that physical activity participation is directly associated with the level of gross motor coordination during childhood (Barnett, Van Beurden et al. 2009). In the model described and elaborated by Stodden et al (2008), it is contended that "the development of motor skill competence is a primary underlying mechanism that promotes engagement in physical activity" (Stodden, Goodway et al. 2008) with a reciprocal and developmentally dynamic relationship between motor skill competence and physical activity being central to their model. They thus suggest that the relationship between motor skill competence and physical activity becomes ever stronger as a function of time over the developmental period (Stodden, Langendorfer et al. 2009).

In the period of middle and later childhood, higher levels of motor skill competence offer a greater motor repertoire to engage in various physical activities, sports, and games (Stodden, Goodway et al. 2008). It is expected, accordingly, that moderately to highly skilled children will naturally self-select higher levels of physical activity, whereas children with less-proficient levels of motor skill competence will engage in lower levels of physical activity. It follows that , children with low coordination abilities who exhibit difficulties in acquiring age-appropriate motor skills are particularly at risk of decreased levels of physical activity (Cairney, Hay et al. 2005; Cairney, Hay et al. 2010)

Additionally, positive correlation between fitness, movement proficiency and coordination has been established (Haga 2009; Rivilis, Hay et al. 2011). Both Cantel & Crawford et al (2008) and Morris & Dawes et al (2013) showed that the degree of coordination deficiency is negatively correlated with fitness. Young people with low motor coordination abilities demonstrate lower levels of fitness and participation in physical activity when compared to their peers (Cantell, Crawford et al. 2008; Haga 2009; Kolehmainen, Francis et al. 2011). A recent research in our group had shown not only that coordination and fitness are correlated, but also that the relationship between them is linear (Weedon et al. forthcoming).

Approximately 5-6% of school-aged children and adolescents in the UK experience significant motor control and coordination difficulties which affect their performance of activities of daily living, leisure activities, sports and academic performance (Cairney, Hay et al. 2005; Cantell, Crawford et al. 2008; Lopes 2013). When exploring the leisure time and physical activity patterns of children with coordination problems, Raz-Silbiger, Lifshitz et al (2015) have illustrated a worrying risk profile for metabolic syndrome (Cantell, Crawford et al. 2008; Morris, Dawes et al. 2013) and cardiovascular disease (Faught, Hay et al. 2005; Rivilis, Hay et al. 2011) due to a higher percentage of body fat (Cairney, Hay et al. 2005; Joshi, Missiuna et al. 2015).

This reduction in levels of physical activity and participation in children with low coordination is likely attributed to poor competence in basic physical skills (Cairney, Hay et al. 2005; Barnett, Van Beurden et al. 2009). As children grow older, the requirements for participation in general play and organised sports become greater, with the need for more complicated movements, exacerbating the problem and feeding the vicious circle of poor fitness and inactivity which continues and even increases in severity through adolescence and adulthood (Hands, Larkin et al. 2009; Stodden, Langendorfer et al. 2009) compromising overall health and well-being (Fisher, Reilly et al. 2005; Green, Lingam et al. 2011) and increasing the susceptibility for developing psychological problems, such as anxiety and depression (Cairney, Rigoli et al. 2013).

The Sport Council in the UK has realised the importance of directing national efforts of inducing physical activity towards groups who are more typically less active (UK Sport Council 2016), including children with coordination and neurodevelopmental problems (Fisher, Reilly et al. 2005). Therefore, the UK's Chief Medical Officer (CMO 2011) has called for school-based intervention to prevent exclusion of the more susceptible groups (All-Party-Commission-on-Physical-Activity 2014). This would help these children to achieve good physical skills in school, raising their confidence to participate in a number of activities including social and school activities (Barnett, Dawes et al. 2013).

1.2 Poor Motor Coordination

The detrimental effects of poor motor proficiency and coordination on health and wellbeing have attracted a lot of attention in the last couple of decades, which made research in this domain prominent in paediatric healthcare (Magalhães, Missiuna et al. 2006; Barnett 2008; Wilson, Ruddock et al. 2013). Children with low motor coordination are generally characterised by poor performance in daily activities which require coordination and difficulty acquiring age-appropriate motor skills (APA 2013). The impairment is known to be incongruent with their overall cognitive abilities are cannot be attributed to a profound neurological disorder, such as cerebral palsy or muscular dystrophy pathology (Hadders-Algra 2003). The coordination problems manifest themselves in slow and imprecise performance of motor tasks (Schoemaker and Smits-Engelsman 2015), comprising activities of daily living, play and participation in sport. Importantly, these children struggle with learning complicated tasks needed for everyday life that typically developing children seem to learn smoothly, without any added effort (Bo and Lee 2013; Schoemaker and Smits-Engelsman 2015).

1.2.1 Implications

The difficulty children with poor motor coordination experience in acquiring fundamental functional and sport skills impedes their ability to take part in sports or social activities that require practice of these skills. In a study by Smyth& Anderson (2000), observation of the amount of motor activity during school breaks showed that children with poor motor coordination spent their time merely watching the active play of other children; during Physical Education classes, they frequently engaged in off-task behaviours, such as going to the toilet (Schoemaker and Smits-Engelsman 2015). These results have been confirmed using accelerometry in a study by Green et al, 2011.

A series of interviews with adolescents with motor coordination problems revealed multiple obstacles which limit the adolescents' ability to fully engage in ordinary activities, especially when participation requires particular motor skills, such as running fast or handling a ball~~,~~. In addition, they reported a decreased sense of enjoyment (Barnett, Dawes et al. 2013; Kwan, Cairney et al. 2013). Decreased tolerance to physical activity has been attributed to low energy levels, muscle fatigue and poor physical tolerance in this population (Morris, Dawes et al. 2013). The recurrent experiences of failure, as well as negative feedback from parents, peers, and others raises children's awareness of their lack of competence in motor skills, which negatively influences their self-perception and leads them to generally eschew failure experiences by showing little motivation for becoming physically active (Schoemaker and Smits-Engelsman 2015).

Because physical activity and play are crucial for children's psychological and social development, lack of participation has remarkable social implications which can lead to social isolation (Poulsen, Ziviani et al. 2008). Children with poor motor coordination have reported lower scores of perceived physical self and competence, implying that they are aware of their motor incompetence (Yu, Sit et al. 2016) - in itself a crucial determinant of involvement in physical activity (Barnett, Dawes et al. 2013). Children with poor motor coordination can suffer substantial secondary emotional and mental problems including behavioural problems, decreased sense of self-worth, anxiety and depression (Cairney, Rigoli et al. 2013). Children with movement difficulty have reported to be less happy than other children, and 41% of them are less popular amongst their peers. At school, and particularly during Physical Education (PE) classes, the main site for these children to get an opportunity for participating in physical activity, they reported lack of support, bullying and even being "mocked" by their peers and PE teachers because of their inefficient and inept movement during team sports (Barnett, Dawes et al. 2013).

1.2.2 Categorisation

There have been multiple attempts in the literature to classify this group of children. The earliest report in the literature dates from 1900s study, with Bagley who recognized that children show different levels of motor performance which he categorized as "very clever, clever, awkward and very awkward"(Bagley 1901). In 1926 Lippitt drew attention to what he called "poor muscular coordination in children" (Cermak and Larkin 2002). Orton, in 1937 was the first to identify a case of "unusual difficulties in learning complex movements, which could involve speech (Orton 1937)" and he called it "clumsiness". Since then, different labels and categorical criteria have been applied to the children who have developmental motor difficulties affecting their daily life. Among the terms used to describe this condition are: "clumsiness", "physical awkwardness", "sensory integrative dysfunction", "perceptual motor dysfunction", "low motor competency/proficiency" and "developmental dyspraxia" (Magalhães, Missiuna et al. 2006; Zwicker, Missiuna et al. 2012). Labelling of the condition has varied between different countries and professions to a certain degree dyspraxia (Geuze, Jongmans et al. 2001; Polatajko and Cantin 2005).

Because having a uniform label for the condition improves the efficiency of communication between researchers and clinicians (Geuze, Schoemaker et al. 2015), an interdisciplinary consensus meeting convened in London, Ontario, in 1994 where researchers and practitioners came together from different parts of the world and agreed on adopting the term "Developmental Coordination Disorder" (DCD) (Polatajko, Fox et al. 1995). Since then, the term DCD has gained popularity, with most subsequent publications referring to the condition as DCD (Zwicker, Missiuna et al. 2012). The word "developmental" here indicates that the children have difficulties in learning the motor skills required for their daily activities - as opposed to acquired disorders where the learned skill can be suddenly lost. "Coordination", here, denotes "balanced and effective interaction of movement (Henderson and Henderson 2002).

DCD is a provisional term still awaiting a precise definition (Cermak and Larkin 2002). It encompasses a wide spectrum of mild motor difficulties researchers and practitioners are trying to understand. Until a better understanding of this complicated condition has been attained, the definition of DCD must remain flexible (Polatajko, Fox et al. 1995).

The above efforts of categorisation set out to define a distinct pathological group the severity of whose symptoms calls for labelling and special treatment. Our data, however, (Weedon et al. in press) shows that coordination abilities in children are rather spread over a continuum, and in large samples they are both normally distributed and linearly correlated with to fitness parameters. Throughout this thesis, we shall refer to our population as "children with low motor coordination". The term DCD will be avoided, as we did not intend to diagnose the participants of the study; rather, we aimed at approaching a wide spectrum of children who performed poorly at motor skill tests, whether or not they satisfy all above mentioned diagnostic criteria. However, we do hope that the findings of the study will be conducive to informing the future research in DCD, and developmental conditions in general.

Children with poor motor coordination form a heterogeneous group with a vast array of different types and levels of motor performance dysfunction, with some children having difficulty only with fine skills that require finger and hand dexterity, others with motor skills that require inter-limb coordination. Some children have balance problems, and others may have been delayed in reaching milestone (Polatajko and Cantin 2005; Zwicker, Missiuna et al. 2012). It is safe to say, though, that there is some degree of consistency amongst manifestations of motor difficulties these children present with. That is, they perform motor tasks with less speed, less accuracy, and more variability (de Castelnau, Albaret et al. 2008). The children described here do not have a problem with basic motor abilities, such as standing and walking; rather, they struggle with more complicated every-day and school-related activities, such as handwriting, and completing tasks on time, all of which may have a significant negative impact on school performance (Cantell, Smyth et al. 1994; Missiuna, Rivard et al. 2004). As high as 87% of these children are known not to overcome their difficulties with age (Cousins and Smyth 2003) and without suitable intervention, these deficiencies may last well into adolescence and adulthood (Kirby, Edwards et al. 2010).

1.2.3 Prevalence

Prevalence of poor motor coordination in children varies across the literature due to lack of consensus on the definition and classification of the condition (Zwicker, Missiuna et al. 2012). The most frequently reported prevalence is 5-6% (APA 2013), which also varies between countries (ranging from 1.4% - 19.0%), depending on the sensitivity of the measures used and the cut-offs chosen for categorization (Gillberg 2003). The different cut-offs used in every country are also influenced by the general norm, expectation and the type of activities the children do at school in each country. Boys seem to have higher levels of poor coordination than girls (Lao, Sahota et al. 2011). However, some recent studies showed equal prevalence between genders. This discrepancy might result from different social expectation levels (Cermak and Larkin 2002), as well as the fact that DCD has been directly linked to preterm birth, known to affect boys more than girls (Lao, Sahota et al. 2011). In addition, a higher incidence of coordination disorders are found among children with a history of prenatal or perinatal difficulties i.e. low-birth weight (Van Baar, Van Wassenaer et al. 2005; Marlow, Hennessy et al. 2007).

1.3 Identification and motor proficiency assessment

In order to provide support and special attention to children with poor coordination, clinicians and researchers need a uniform classification system. The reference classification system used for DCD diagnosis is the criterion-based American Psychiatric Association Diagnostic and Statistical Manual DSM-IV and DSM-V, which offers qualitative criteria primarily serving clinical purposes. In the most recent version (DSM-5)(APA 2013) the criteria for diagnosis are:

A- "The acquisition and execution of coordinated motor skills is substantially below the expected given the individual chronological age and opportunity for skill learning and use. Difficulties are manifested as clumsiness (dropping or bumping into obstacles) and Slowness and inaccuracy of performance of motor skills (catching an object, using cutlery, handwriting, cycling or participating in sports).

B- Motor skill deficit significantly and persistently interfere with activities of daily living (appropriate to chronological age) and impacts school productivity leisure and play.

C- Onset is in the early developmental period

D- Motor deficits are not better explained by intellectual disability or visual impairment and are not attributable to a neurological disorder affecting movement (cerebral palsy, muscular dystrophy, and degenerative disorder)".

These diagnostic criteria have served a great purpose of clinical diagnosis of children in need of clinical intervention. However, in school or sport settings the need is not so much for classification but for description and detection. A deviation from this criterion-based approach has been deemed permissible in the literature for the benefit of the children involved (Geuze, Jongmans et al. 2001) e.g. when delivering intervention programs which benefit the children (Geuze, Schoemaker et al. 2015). Thus, there is a need for tools which enable teachers, clinicians and researcher to detect these children. Children with poor motor coordination might display an awkward or a non-fluent style of movement, easy to be identified visually. Orton, 1937 described it to be similar to a "right-handed person trying to write with the left hand". Nonetheless, it remains challenging to objectively assess motor skill performance in children with poor coordination

1.3.1 Motor Assessment for diagnostic purposes

The motor proficiency criterion in DSM (criterion-A) refers to the motor ability as being significantly lower than expected for the child's age. The first step to measure this discrepancy of age-specific motor proficiency is achieved using a norm-referenced motor proficiency test. Many standardized motor competence tests have been developed to assess both gross and fine motor coordination in children (Cairney, Hay et al. 2009; Cools, De Martelaer et al. 2009). The most commonly used tests include the Movement Assessment Battery for Children (MABC or MABC-2) (Henderson, Sugden et al. 1992; Henderson, Sugden et al. 2007) and its predecessor, Test of Motor Impairment (TOMI) , the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP and BOTMP-2) (Bruininks 1978; Bruininks and Bruininks 2005), the McCarron Assessment of Neuromuscular Development (MAND) (McCarron 1997) (Geuze, Jongmans et al. 2001), the Body Coordination Test for Children (Körperkoordinationstest Für Kinder – KTK (Kiphard and Schilling 2007) and the Test of Gross Motor Development, Second Edition (TGMD-2) (Ulrich 2000).

A-Test of Gross Motor Development, Second Edition (TGMD-2)

TGDM-2 is a process and product-oriented which is both criterion and norm based (Cools, Martelaer et al. 2009). It measures gross motor performance based on qualitative aspects of movement skills, which enables it to identify those children whose performance is significantly worse than their peers in gross movements. It covers the age range between 3-10 years, within which the most substantial changes in the child's motor development take place (Ulrich, 2000). The test includes locomotion and object control skills. The summation of the two sub-scores comprises the total score. The test requires 15 to 20 minutes for administration and is commonly used during PE.

A great advantage of the TGDM-2 is the incorporation of qualitative aspects in the assessment but the test may not be inappropriate to use cross culturally as a standard for object control assessment since its highly affected by the popular sports in the specific nation (Cools, Martelaer et al. 2009).

B-Körperkoordinationtest für Kinder (KTK)

The KTK is used to assess gross body control and coordination, particularly dynamic balance skills. It is appropriate for typically developing children as well as children with neurological, behavioural and learning problems ages 5 to 14. The advantages of the test include being widely standardized and highly reliable (Valaey and Vandroemme, 1999). It is also easy to set up and the administration time is short (20 min) with a low possibility of learning the test items, which makes it useful for evaluation of skill development and intervention. The disadvantage of this test is its limitation to one aspect of gross movement, namely the balance function. Object control and locomotion performance are not assessed in the test.

C-The Movement Assessment Battery for Children (MABC)

MABC is the most commonly cited motor test in the literature (Venetsanou, Kambas et al. 2011) and is recognised as the most reliable and valid (Tan, Parker et al. 2001) test to identify and describe impairments of motor function in children aged 3-16 years.

MABC quantitatively assesses a range of motor skills and provides both quantitative and qualitative measures to evaluate children's fine and gross motor competence in three categories: Manual Dexterity, Aiming and Catching, and Balance. Each item is rated on a 6-point rating scale, where 5 equates to the weakest performance and 0 equals the best performance. The Measurement outcome is a total impairment score based on the accuracy and speed of performance on the motor tasks. The total score ranging from 0 to 40 with a lower score representing better task performance is then converted into percentile score with the 5th percentile being regarded as a definite motor impairment cut off and a score at or below the 15th percentile as a clinical risk range (Henderson & Sugden, 1992). Moreover, the MABC provides a questionnaire (checklist) which requires the parents or teachers to rate the child's qualitative motor competence in activities of daily living.

The MABC has a test-retest reliability of 0.75 and an inter-rater reliability of 0.70 (Henderson, Sugden et al. 1992). In addition, the MABC has demonstrated an 80% agreement with the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) with regards to validity (Crawford, Wilson et al. 2001). The most important advantages of the test are: its availability in several European countries, its cross cultural validity which has been established based on multiple local sample comparisons (Smits-Engelsman, Henderson et al. 1998; Soppelsa and Albaret 2004) and its simple administration. The disadvantages of the test are: its large age range ,which entails the loss of specificity, and the mismatch between the number of test items presented and the time required for administration (8 items/20-30 min). Other movement skill tests like the BOTMP measure the child's abilities over a wide range of skills. The Movement-ABC is on the other hand limited to the movement skills of a certain age band (Cools, Martelaer et al. 2009).

D-The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP)

(BOTMP) is also a widely used motor assessment battery for identifying movement difficulties in children and young people between the ages 4-21 years (Venetsanou, Kambas et al. 2007). The BOTMP is a tool for assessment of fine and gross movement skill development . The complete BOT-2 features 53 items and is divided into 8 subtests: fine motor precision, fine motor integration, manual dexterity, bilateral coordination, balance, running speed and agility, upper limb coordination, strength. The items in every subtest become progressively more difficult. In addition to the complete form, the battery also provides an adapted short-form version (Verderber and Payne 1987) which allows the assessment to be performed in 20 minutes compared to 45 min with the long form. The full version of the battery provides a wide-ranging index of motor proficiency including separate measures of gross and fine motor skills whereas the short form consists of 14 items which constitute a brief examination of general motor proficiency. The short version includes the same eight subtests with a smaller number of itmes in each subtest. According to Venetsanou et al. (2007), the two forms demonstrated a high correlation of (r=0.85) for the total scores. However, the short-form total scores were significantly higher than the full version, indicating lower discriminative accuracy (Deitz, Kartin et al. 2007).

The MABC has been known to identify children with motor impairments more successfully than the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Tan, Parker et al. 2001). Crawford, Wilson, and Dewey (2001) reported that the MABC seems to be more sensitive and better able to identify children with additional problems associated with learning or attention. However, the availability of the short version of the BOT-2 gives it a great advantage especially when resources are limited.

Conditional on the battery assessment of choice, various cut-offs have been employed across different studies to determine the performance level at which motor skill is considered to be impaired. The cut-off values were set at the 5th and 15th percentile (Tan, Parker et al. 2001) for definite and borderline motor impairment for the MABC and between the 7th and the 23rd percentile (Venetsanou, Kambas et al. 2007) on the BOTMP. Accordingly, the categorization of the child as "low normal" or "impaired" remains a relatively arbitrary judgement. Several researchers (Dewey, Wilson et al. 2001; Kaplan, Dewey et al. 2001) argued that different tests seem to identify different children due to the heterogeneity of children with motor difficulties as well as the different nature of each assessment tool (Crawford, Wilson et al. 2001). Subsequently, although very useful, none of standardised motor tests qualify for use as a ''gold standard'' for motor assessment in this group (Henderson and Barnett 1998) and no one test should be used in isolation for diagnostic and rehabilitative purposes (Missiuna and Pollock 1995; Venetsanou, Kambas et al. 2011).

1.3.2 Motor assessment: screening

The previously mentioned motor assessment tests, as well as others, serve a very important diagnostic purpose and help categorising participants according to their performance into groups of people who might or certainly have a motor deficiency. This works well for clinical and research purposes (Geuze, Jongmans et al. 2001). However, when considering screening whole school years for purposes of detection and identification of children with coordination problems, applying strict diagnostic criteria excludes an important group of individuals who suffer a moderate or even a substantial degree of poor motor coordination with no significant neurological or intellectual disability but may not satisfy the diagnostic criteria of clinical developmental conditions like DCD. These children study in main stream schools. Undiagnosed, they continue to be at a disadvantage when it comes to participation in physical activity and exercise and are being excluded from participating in sports and physical education (Barnett, Dawes et al. 2013).

Given the importance of involving children of all motor and coordination abilities in exercise and motor training, it is essential to develop tools for detection of these children from a continuum of motor and coordination abilities. Identification of children with motor coordination problems from a school cohort requires motor assessment in the form of mass screening. In previous and current research conducted in our research group, hundreds of school children have been screened using different standardised motor performance tests including both the MABC and BOT-2. The use of these standardised tests in screening had yielded multiple problems:

1- Inefficiency: For each screening session, at least 15 volunteering researchers and multiple PE teachers were required to take part in administering the test items as well as organising and controlling the students' movement. Multiple sessions (at least 4) were required to screen one school year. For multi-sited studies, these screening requirements were extremely costly and required tremendous organisational efforts.

2- Lack of sensitivity: because these standardised tests are designed to detect children with substantial motor disability, multiple BOT-2 test items, including star drawing, opposite hand coordination, ball dropping and dribbling can only detect children who have severe coordination problems and highly prone to ceiling effect (Brahler, Donahoe-Fillmore et al. 2012).

3- Inappropriateness (invalidity): Standardised tests were not initially designed for use in mass screening. Rather, it is clearly stated in the BOT-2 manual, that the test needs to be administered in one-on-one settings (Bruininks and Bruininks 2005). This allows for clear instruction and close monitoring of performance, which may be compromised during mass screening.

It is obvious that, for the purposes of diagnosis and therapeutic intervention, further detailed and careful motor assessment must take place in the clinic or research laboratory on individual basis (Barnett, Van Beurden et al. 2009). However, when research intervention studies are designed to detect and train children with low motor abilities and aim to serve large number of subjects, it is important to provide the schools, PE teachers and researchers with an easy and reliable measure which crudely locates children who are in need of this intervention (Geuze, Schoemaker et al. 2015).

1.5 Theories of Aetiology

Research in this domain has proposed multiple theories to explain the underlying mechanism of the deficient performance in this group, (for review see (Wilson and McKenzie 1998) and (Wilson, Ruddock et al. 2013)), including visuo-spatial processing (Tsai, Pan et al. 2009; Tsai, Pan et al. 2010), kinesthetic perception (Pick and Coleman-Carman 1995), and cross-model sensory integration (King, Kagerer et al. 2011). Several researchers, especially those involved in intervention studies, have proffered a Developmental Motor Learning Disability model which suggests that the motor problems in children with poor coordination can be seen as common difficulties in motor learning (Hands and Larkin 2001; Cermak and Larkin 2002; Dewey and Tupper 2004) and explained by a cerebellar deficiency (Cantin, Polatajko et al. 2007).

Several behavioural studies have been conducted that lend support to a cerebellar hypothesis including studies of motor adaptation (Kagerer, Bo et al. 2004; Cantin, Polatajko et al. 2007), postural control (Johnston, Burns et al. 2002; Geuze 2005) ,and timing of movements (Estil, Ingvaldsen et al. 2002). Clinically, these children struggle with learning complicated tasks needed for everyday life that typically developing children seem to learn smoothly, without any added effort (Bo and Lee 2013; Schoemaker and Smits-Engelsman 2015). The ability to learn a variety of motor skills is critical for many daily activities throughout the lifetime (e.g., dressing oneself, writing letters, or communicating via computers). Studies in this area of research are inconclusive. This renders an aetiological judgement difficult. However, with motor learning and skill acquisition being, by definition, the most important manifestations. This disorder has been widely accepted as a ''learning disorder'' (Bo and Lee 2013). However, the process and time scale of learning differences between these children and typically developing children is yet to be established.

1.5.1 Motor Learning/ skill acquisition deficiency

Motor learning refers to relatively permanent behavioural changes associated with practice or experience (Schmidt and Lee 2013). In general, two forms of motor learning can be distinguished, namely explicit and implicit learning. Explicit learning involves conscious recollection of previous experiences. Implicit learning is defined as an unintentional, nonconscious form of learning characterized by behavioural improvement (Schmidt and Lee 2013). Procedural learning is an implicit motor learning mechanism in which novel perceptual, motor, or cognitive skills are acquired and automated by way of repeated practice. Clinically, the impairment in motor learning manifests itself in the difficulty in automatizing the acquired motor skills even after sufficient practice (Bo and Lee 2013).

One hypothesis which may explain the motor learning deficiency in children with poor coordination is the dysfunction in brain networks responsible for procedural learning including cortico-striatal and cortico-cerebellar circuits (Lejeune, Catale et al. 2013). This hypothesis has initially been suggested by Nicolson and Fawcett (2007) and received considerable attention since. Based on cognitive and behavioural studies and the related functional brain area, the authors have proposed that the impairment in procedural learning explained by a cerebellar deficiency to be as the common underlying deficit in different developmental disorders. Nicolson and Fawcett's proposal would also explain the observed co-occurrence between these disorders (Lejeune, Catale et al. 2013). This theory was based on cognitive and behavioural studies and the related functional brain area. Albeit yielding an interesting typology which helps understanding developmental disorders, (Nicolson and Fawcett 2007) their proposal cannot be generalised until enough brain imaging studies provide more empirical evidence. The procedural learning deficit hypothesis received further support with the emergence of neuroimaging studies that disclosed dysfunction in the cerebellum and basal ganglia in children diagnosed with DCD (Mariën, Wackenier et al. 2010; Zwicker, Missiuna et al. 2011).

Zwicker et al (2011) found that children with DCD compared to TD peers, demonstrate under-activation in cerebellar–parietal and cerebellar–prefrontal networks and in brain regions associated with visual-spatial learning during the process of learning a fine motor tracing task. This study was the first to measure changes before and the learning of a motor task and provides an important insight in the neurobiology of the condition. Nonetheless, these findings should be approached with caution as the sample size in each group was very small (seven) and the training period during which children with DCD did not show any improvement in their motor accuracy was extremely short (three days).

The literature on the acquisition of basic motor skills in this population is scarce. This is surprising, given its characterisation as a motor learning disorder. The small number of studies available has yielded contradictory results. One method frequently used to study motor learning in this population is the investigation of "motor sequence learning" (Bo, Langan et al. 2008) where subjects learn to incorporate individual movements into a smooth, coherent action (Bo and Lee 2013). (Wilson, Maruff et al. 2003) were the first to investigate sequence learning in a group of children with DCD and a control group using a finger tapping classic Serial Reaction Time task (SRT). They found no difference in the amount of learning between the two groups and concluded that "implicit learning for simple sequential movements is intact in children with DCD". However, this study suffered from a small sample size, as well as a methodological flaw. Contradictory results were subsequently reported by Ghyesen and Waelvelde et al. (2011), who applied a similar experimental method with a larger sample size and a corrected design. Their results showed that children with DCD did not improve their performance over the course of training and pointed towards a sequence learning deficit. These results allow no direct inference to the type of dysfunction from which the children suffer i.e. whether the difficulty lies in performing the described motor task or learning the pattern per se.

To answer the question concerning the deficiency in sequence learning and whether it is a symptom of motor/cognitive deficit (as opposed to a genuine deficit in procedural learning), Lejeune, Catale et al. (2013) applied the same paradigm using a touch screen instead of the keyboard as a response mode to reduce the possible impact of perceptuomotor coordination difficulties on children's performance. The results of the study showed that, in contrast to procedural learning deficit hypothesis, children with coordination problems were equally successful at acquiring sequence-specific knowledge, which meant that they did not have a problem with detecting and learning the regularities in sequential information per se, but that their problem was of a motor planning nature (Lejeune, Catale et al. 2013). This is an interesting finding. Nonetheless, the motor component of the chosen task was so simple that even the baseline performance of the DCD children did not differ from that of the control children, a finding which is inconsistent with the vast literature on poor performance in children with DCD (Wilson and McKenzie 1998; Wilson, Ruddock et al. 2013).

A great limitation of the literature on motor learning in this group originates in the nature of the trained tasks, as they barely resemble any of the skills children need to acquire in their activities of daily living or participation in physical activity. The question concerning the ability of children with poor coordination to learn gross motor movement patterns relevant to their daily living and sports remains unanswered. Evidence from the more recent intervention methods, including the Cognitive Orientation to daily Occupational Performance (CO-OP) approach (Polatajko, Mandich et al. 2001; Polatajko and Mandich 2004) and the Neuromotor task training (Schoemaker, Niemeijer et al. 2003; Niemeijer, Smits-Engelsman et al. 2007), provide support for the claim that children with coordination problems are able to learn a particular motor skill if they spend enough time practicing it without distraction (Niemeijer, Smits-Engelsman et al. 2007; Smits-Engelsman, Blank et al. 2013). However, because of the clinical nature of these studies, little is said about the amount of training, its intensity, and whether they are able to improve their performance to a level that is comparable to their typically developing peers.

Only two studies in literature have administered extensive training to children with motor coordination problems using more functional tasks. The first is an early study by Marchiori, Wall et al. 1987 and the second is a recent study by Smits-Engelsman, Jelsma et al. (2015), who trained a group of children with DCD and a matched control group on a motion-steered computer game using the Wii fit. The game required dynamic balance control as players needed to shift their body weight from one leg to the other in a timely order. The authors aimed to answer an important question: Are motor learning difficulties a simple case of lack of practice? To this end, they trained the children twice a week for five weeks with 10 trials of the game and monitored their performance results, viz. the Wii complex score, expressing both speed and accuracy of performance. They found in their results that children with coordination problems had significantly worse baseline performance in comparison to the control group. Interestingly, however, they did not differ in terms of their learning curve, their improvement, retention and transferability of the acquired skill.

This finding is very important. Yet, contradictory to the latter, Marchiori et al. reported that intensively trained children on a hockey slap shot with a total of 1200 performance trials over a period of four weeks. The weaknesses in Marchiori's study design (extremely small sample size: two children) and the lack of an objective measure of performance limit the generalisability of their results. Nonetheless, their finding that children with coordination problems did not improve on the task in comparison to two other control children after such an intensive training period, raises the question what role the difficulty and complexity of the trained task play in the ability of children to learn.

The performance of the Wii fit Ski Slalom game requires balance control and accurate timely shifting of body weight from side to side. Given that it is a closed chain exercise with little threat to balance, this finding is not surprising. It could also be considered consistent with previous findings from Lejeune, Catale et al. (2013), where children with DCD showed ability to learn a motor sequence that did not require highly complex motor planning. Also, the fact that DCD children in this study improved their scores over the training period does not provide any information regarding their movement fashion, their coping strategies and whether they were able to transfer this skill to a meaningful everyday task. Improving game scores does not automatically imply that they have learned to move smoothly or in a more coordinated fashion. Given that there was no motion analysis, we can make no inferences concerning the quality of their movement.

Put together, remarkably little research has been done on motor skill acquisition in children with poor coordination. The results of the available studies are mutually inconsistent; the sample sizes were small and the training period limited. Though informative, results from upper limb studies cannot be generalized to total body or lower limb control as it is known that they are run by distinct control mechanisms (Miyai, Tanabe et al. 2001; Luft, Smith et al. 2002). Importantly, the choice of most trained tasks in the literature is not representative of the type of skills children need to acquire in their daily life, such as those requiring multiple joint and inter-limb coordination, trunk control, and balance, which may also induce a higher level of noise in the neuromotor system in comparison to simple tasks as evident from motor learning literature (Smits-Engelsman, Westenberg et al. 2008; van Beers 2009).

Even in studies which show that children with poor motor coordination do possess the ability to learn motor skills, the reported results are confined to performance outcomes which could simply be the result of adopting certain coping strategies rather than improving movement quality. Evidence from gait studies shows that children with poor coordination cope well with their motor difficulties on a functional level, as they optimise an adaptive walking pattern which appears normal, when its rhythmic component is assessed; however, it sustains a different kinematic pattern, with shorter steps, increased trunk inclination during the entire gait cycle and a less pronounced plantar flexion of the ankle during toe-off (Deconinck, De Clercq et al. 2006; Rosengren, Deconinck et al. 2009). To this end, there is a need for motor learning studies that objectively measure the kinematics of the acquired movement and its change over time. At the moment, there seems to be a vast gap between experimental studies of typical performance and those of coordination difficulties. Research in normal movement has become more advanced and technically sophisticated, while research in poor motor control and coordination is still lagging behind.

The important question here concerns the ability to train children with poor coordination to improve the kinematics of their movement and whether it could reach the level of proficiency of children with no coordination problems. Motion analysis alongside monitoring performance measures will deepen our understanding of how children with poor motor coordination learn a motor task, how well they learn it, and whether the quality of their movement improves as a function of time.

1.6 Summary and Conclusion

Participation in physical activity and exercise requires the development and utilisation of particular motor skills. Given the difficulty in acquiring these motor skills, children with poor motor coordination are at risk of leading a sedentary lifestyle. To tackle this challenge, there has been a strong national effort to engage children in school based exercise interventions which particularly include children with poor motor proficiency (CMO 2011). Adolescence and early teenage years are formative determinants of an individual's attitude towards physical activity, participation and lifestyle in adulthood (Hagger, Chatzisarantis et al. 2002). Particularly, the transition to secondary school has been observed to be associated with reductions in physical activity participation, especially in females (Biddle, Gorely et al. 2004; Knowles, Niven et al. 2011). During adolescence and early teenage years, young people with motor coordination problems show a negative attitude towards participation in exercise programs because of their pre-existent knowledge of lack of competence, which in turn increases their chances of developing metabolic conditions, such as obesity or diabetes, as well as psychosocial problems, such depression and anxiety (Gillberg and Kadesjö 2003).

The nature of motor learning difficulty in this group is still poorly understood, with motor learning studies being scarce and often contradictory in their findings. Current intervention lacks consistent, evidence-based knowledge of the motor learning impairments in children with poor coordination. The requirements of training that would optimize motor skill acquisition in this group are not yet satisfactorily understood. In order to enhance our intervention programmes (school-based as well as clinical) in a way that is tailored to the needs of the children, we must understand the nature, the progression, and the requirements of the acquisition of motor skills, particularly, functional and sport related skills in children and adolescents with motor coordination problems.

This study sets out to test the performance and acquisition of a gross motor functional task in children with coordination problems and comparing it to that of children without coordination problems. The task would be stepping rhythmically in accordance with a pattern produced by visual stimuli presented on a computer screen in front of the participants. The timing characteristics of the stepping performance will be measured using the Inertial Measurement Unit (IMU), an accelerometer, which has been cross validated with motion capture systems to provide information about the timely characteristics of the movement. The first part of the study aims to create a short screening test which we propose to be used to detect children with poor motor coordination. A separate validation study was subsequently conducted to validate the use of IMU for detecting timing events during stepping. The main study consists in a feasibility study, which aims to detect, recruit and train children on the rhythmic stepping task.

1.7 Hypotheses

As a feasibility study, the study did not start from a hypothesis with regards to the intervention results. Yet, in light of the previously discussed literature, it seems plausible to expect that children with poor motor coordination will perform worse on the intervention task. We thus hypothesise that they will be able to improve their performance during the training period. We furthermore hypothesise that running the screening and intervention in school environments will be successful.

1.8 Objective

Following on the described gaps in the literature, this thesis aims to tackle two main objectives; first construct a battery of tests for detection of children with poor motor coordination which is suitable for mass screening in main stream schools. The second is to investigate the motor acquisition of a novel task in children with poor motor coordination. To serve this purpose, using mass screening, we will recruit young people who score in the bottom quartile of motor coordination according to our screening test and explore the extent of differences in their performance and acquisition of an externally paced rhythmic stepping task in comparison to an age matched control group over a period of weekly session training of 11 weeks.

This study is a feasibility study which aims to inform the implementation of a following fully powered trial. So, the study needs to answer feasibility-related questions of the protocol and methods and the second was to test the utility of outcome measures for use in the main trial.

1.8.1 Study aims

Aims of pilot/feasibility trial have been designed with accordance to recommendations on pilot study design (Thabane, Ma et al. 2010; Eldridge, Chan et al. 2016)

Feasibility-related aims

- To test the utility of using the Inertial Measurement Unit (IMU) to detect movement parameters during performance of the stepping task.
- To assess the utility of both the data collection and data analysis software.
- To assess the validity and the utility of the short screening tool.
- To assess the feasibility of the processes of the trial including; recruitment rates, retention rates, sufficiency and utility of eligibility criteria.
- To assess the time and resource requirements for success of the trial; length of time required for screening, testing, intervention, and data processing.

Intervention related aims

- To determine the appropriateness of outcome measures and need for a follow on trial.
- To measure the extent to which children with low motor coordination differ from children with normal coordination in their baseline performance (timing, error) on a gross motor stepping task in order to determine variability on the performance measures.
- To measure the extent to which children with low motor coordination improve their performance as compared to age matched control group over the training period in order to determine variability in performance parameters.

Chapter (2): Developing a screening tool for identification of children with low motor coordination abilities in main stream schools

As portrayed in the introduction, the available motor assessment tools are primarily used for diagnostic purposes. However, when considering screening whole school years with the intention of detection and identification of children with coordination problems, applying strict diagnostic criteria excludes an important group of individuals who suffer a moderate or even a substantial degree of poor motor coordination with no significant neurological or intellectual disability but may not satisfy the diagnostic criteria of clinical developmental conditions like. Given the importance of involving children of all motor and coordination abilities in exercise and motor training, it is essential to develop tools for detection of these children from a continuum of motor and coordination abilities.

To this end, it is important to provide the schools, PE teachers and researchers with an easy and reliable measure which crudely locates children who are in need of intervention (Geuze, Schoemaker et al. 2015). To serve this purpose, we set out to create a battery of motor proficiency tests that has utility for mass screening in main stream schools which is easy to administer and useful for detection of children with low motor coordination abilities.

2.1 General Overview

This research experiment was incorporated within an established clinical trial named "EPIC"; Engagement Participation Inclusion and Confidence in sport. EPIC is a Community Sport Activation Fund (CSAF) initiative which was funded by Sport England (Ref: 2013018570). The CSAF award was part of Sport England's Youth and Community Strategy which sought to encourage participation in sport for young adults.

EPIC's main goal was to create a pathway for sport in children who do not otherwise take part in sport due to motor proficiency problems and to help them develop their motor abilities, fitness and wellbeing. The pathway included four phases: 1.targeted recruitment, 2.confidence and skill building (training intervention) 3.connection to sport and 4.exit to long term participation. The project was approved by Oxford Brookes University Research Ethics Committee (UREC 140844) and three schools within Oxfordshire agreed to take part. The trial was carried out within these schools and on the premises of Brookes's Clinical Exercise and Rehabilitation Unit (CLEAR). During the targeted recruitment phase of the EPIC project, a complete year group was screened during the Physical Education (PE) lesson. Selection of participants for intervention was based on their performance on the motor and fitness tests during screening.

Rooted in the EPIC project, the creation of the screening tool was based on a large scale screening process (as part of the targeted recruitment phase) in which the standardised motor assessment test (BOT-2 short form) as well as multiple items of the Fundamental

Movement Skills (FMS) and an aerobic fitness test were administered. The selection of the items was based on a reduction analysis (principal component analysis) to include the smallest number of valid and meaningful tests.

2.2 Methods

2.2.1 Participants

School children aged 13-14 years (year 9) were the target group of our screening procedure. Prior to the screening session, participant information (PI) sheets, which explained the rationale behind the screening, as well as opt-out consent forms (Appendix 1), were sent to the parents of all students who were eligible for screening. Students who returned a signed consent form i.e. whose parents refused that their children take part, were excluded from the motor assessment and involved in helping with running the session.

2.2.2 Screening

In collaboration with the PE teachers, the screening sessions were organised to be held within PE lessons. The duration of the assessment was approximately 40 min. In order to include the whole year group, multiple sessions took place with an average of 80 students screened per session. Within each session, students were divided into two groups according to their gender (approximately 35-40 per group). The first group performed the aerobic fitness test: Chester Step Test (CST) (Buckley, Sim et al. 2004) while the other group rotated between 12 stations which were set up in a circuit fashion in sub-groups of 3-4 students. Each station involved the performance of a single motor test and was run by one or two trained researchers who gave instructions to the students and recorded their performance results. On the following screening session, the two previously assigned groups switched positions in order to complete the second part of the assessment.

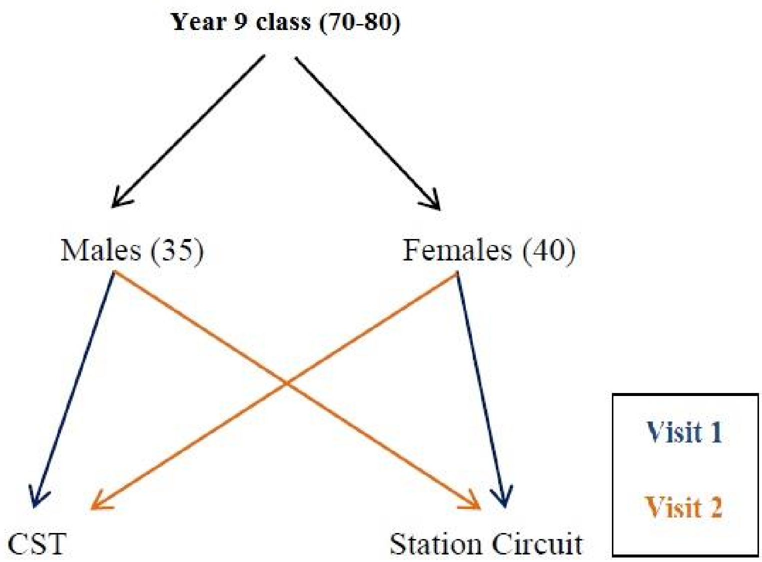


Figure 1: Screening protocol, an 80-90 students are covered over 2 sessions, CST: the Chester Step Test.

During the screening, each student was identified with a number marked on his/her hand and before both groups embarked on the performance test they were assigned to, students were seated in the sports hall for a brief introduction to the research team and an explanation of the purpose and procedure of the screening. Next, the males for example would be were asked to perform the Chester Step Test at one end of the sports hall while the females would be divided into smaller groups and rotated around a circuit of motor assessment stations on the opposite side of the sports hall.

2.2.2.1 Motor proficiency tests

Overall, three main categories of motor proficiency assessment schemes were applied during the screening sessions 1- The short form of the Bruininks and Osteretsky test of motor proficiency (BOT-2), 2- An aerobic fitness test; Chester Step Test, 3- Elements of Fundamental Movement Skills.

A- Second Edition Bruininks and Osteretsky test of motor proficiency (BOT-2) - Short Form

The BOT-2 test of motor proficiency was introduced in section (1.3.1-B). The Short form of the BOT2- is made up of 8 subtests including:

1-Fine motor precision:
-Drawing lines through paths-crooked
-Folding paper
2-Fine motor Integration:
-Copying a star shape
-Copying a square shape
3-Manual Dexterity
-Transferring pennies
4-Bilateral Coordination
-Jumping in place same side synchronised
-Tapping feet and fingers same side synchronised
5-Balance
-Walking forward in a line
-Standing on one leg on a balance beam (eyes open)
6-Running speed and Agility
-One legged stationary hop
7-Upper limb Coordination
-Ball dropping
-Ball dribbling
8-Strength
-Push ups
-Sit ups

All eight subtests with their 14 test items were measured during this screening. Some of the items similar in nature e.g. copying a star and square shapes were grouped together to be performed in one station. The set-up, instructions and scoring system of each of the items are described in detail in the BOT-2 manual (Bruininks and Bruininks 2005) and were followed carefully. Before the screening session, the researchers involved were familiarised and trained to on the specific task that they were assessing and scoring with reference and guidance both from the manual and more experienced researchers. During the assessment, researchers also had a copy of the instructions from the relevant part of the manual to refer to if they needed. For purposes of reliability, the same researchers were running the same stations every session.

B- Fundamental Movement and sport skills (FMS)

Fundamental movement skills (FMS) are considered the building blocks that progress to specialized movement sequences needed for adequate participation in organized physical activity and play for children and adolescents. FMS are commonly developed in childhood and later refined into context and sport-specific skills (Lubans, Morgan et al. 2010). The development of fundamental movement and sport skills allows the adolescents to move confidently and take part in several sports with ease (Higgs, Balyi et al. 2008). The fundamental movement skills are grouped into three types of movement: 1-Locomotor Skills (walking, running, skipping, hopping, jumping) 2-Object Skills (throwing, catching, and striking) 3- Body Control Skills (twisting, turning, and balancing) (Higgs, Balyi et al. 2008). The mastery of FMS contributes to children's physical, cognitive and social development and is thought to provide the foundation for an active lifestyle (Clark and Metcalfe 2002).

In our screening, we conducted a selection of the fundamental movement skills including: seated medicine ball throw, broad jump, tennis ball wall toss, and a 5 meters*10 shuttle run.

Seated medicine ball throw is a valid and reliable test for measuring explosive power in the upper limb. It is used extensively in different populations (Davis, Kang et al. 2008; Santos and Janeira 2012) and has been repeatedly used as an outcome measure of the upper limb power training in adolescents (Salonia, Chu et al. 2004; Santos and Janeira 2012). Participants sat on the floor with legs fully extended, feet (~60 cm) apart and the back against a wall. The 4 kg medicine ball was held with the back of the hands facing the centre of the chest and the forearms parallel to the ground. The participant threw the medicine ball vigorously as far straight forward as he/she could while maintaining the back against the wall. The researcher measured the distance from the wall to where the ball landed using a measuring tape. The best of three trials was recorded.

Broad jump (Ruiz, Castro-Piñero et al. 2010)**:** is a test of lower limb explosive strength assessment which has been validated and tested for its reliability in the Helena study (Ortega, Artero et al. 2008). The broad jump test has also been included in multiple motor proficiency batteries like the ALPHA health related fitness battery for children (Ruiz, Castro-Piñero et al. 2010) and European test of Physical Fitness (EUROFIT) (Adam, Klissouras et al. 1988). The students started in standing position with feet together behind the start line on a jumping mat and were instructed to jump horizontally as far as possible. The researcher measured the distance between the starting line and the heel of the foot that was most backward in landing and recorded the better of two trials [Figure 2-B].

Alternate hand wall toss is a test of eye hand coordination and upper body coordination (Du Toit, Kruger et al. 2011). It is part of the Western Motor Ability test described by (Campbell and Tucker 1967) and has been used in adolescent fitness testing (Watson and O'Donovan 1977; Watson 1988). Students stood one meter way from a wall (a cross was used to mark the exact distance) and a tennis ball was tossed from one hand in an underarm manoeuvre against the wall and attempted to be caught with the opposite hand. The ball was then thrown back against the wall and caught with the initial hand. The test continued for 30 sec. The researcher counted the number of successful catches.

10x5 meter shuttle run is a valid and reliable test of speed of movement, agility and coordination assessment (Baquet, Guinhouya et al. 2004; Ortega, Artero et al. 2008).A distance of 5 meters was marked using tape. Participants started with one foot directly behind the first line and were instructed to run to the opposite line, turn and then run back to the starting line. This was repeated 10 times and the duration (sec) required for running these 50 meters was recorded.

Figure 2: (A) Dynometer used to measure grip strength (B) Broad Jump Test

C- **Hand grip:** is a measure of maximum handgrip strength and total body strength. It is valid and reliable for fitness measurement in adolescents (Ortega, Artero et al. 2008). Students started in a standing position and held the dynometer (Takei 5001, which was adjusted to the fist size (Ruiz, España-Romero et al. 2006) between the thumb and the fingers of their dominant hand. Before they started, it was made sure that the dynometer was set to read 0 kg. They were instructed to squeeze as hard as they could while simultaneously swaying their arm down to their side and then relax their grip. The better of two readings (kg) was recorded [Figure 2-A].

D-The Chester Step Test (CST)

The CST is a sub-maximal multi-staged fitness test that constitutes stepping with a gradually increasing frequency. The CST lasted 10 min and consisted of five stages of stepping on a 30 cm high step (The Step, USA) with a frequency which was set by a metronome beat. Each stage lasted for 100 sec and the stepping frequency increased from 15 to 35 cycles per minute. One cycle is defined as stepping on and off the step with both feet.

The test started with a brief introduction that familiarized the participants with the task, followed by a demonstration of the initial stepping rate (~15 cycles/min). When the CST started, the participants were encouraged to step at the appropriate stepping rate and to continue stepping throughout the duration of the stage until the beginning of the rest period as indicated by the recorder. Expected maximum heart rate is calculated before the test commenced using the equation: [HR_{max}=220-participant's age] and then measured during the first minute of the rest period after each stepping stage using a pulse oximeter.

Because of the number of screened students, which precluded the ability to test them all at once, students were paired up so that while one is performing the test, his or her partner documented the heart rate which was measured by the researchers running the test. The results of this test were in the form of 5 different heart rate readings which were converted into a VO2 max reading using a standard equation. The calculation of V̇O2max from CST heart rate data is based on the extrapolation of a "line of best fit", which passes through the HR readings for each stage, up to a level which equals the participants' estimated HR_{max} (Buckley, Sim et al. 2004) .

2.3 Data Analysis

Test scores acquired from the data collection sheets were inputted into an excel sheet. Names and numbers were matched so that all the scores from one student across the different sessions were placed in one row. HR data from CST was converted into VO2max scores. The paper folding, star and square drawing and following the maze were all scored according to the scoring system described in the BOT-2 manual. After that, all BOT-2 item scores were inputted in a separate sheet and test scores were converted into point scores with reference to the BOT-2 scoring sheet and arithmetically added to give a total score. The total score was then used to work out the percentile rankings and descriptive categories of performance (with reference to BOT-2 standardised tables the standard scores).

2.3.1 Statistical Analysis

All further statistical analysis was done using SPSS 23 for Windows (SPSS Inc, Chicago, IL, USA). Data was explored and averages and standard deviations of all test scores were calculated. Afterwards, a factor analysis was run in the aim of reducing the test items to the least number of meaningful and useful items.

Factor Analysis

Factor analysis is a statistical method of data reduction. It is used in data sets with large numbers of observed variables thought to reflect a smaller number of underlying/latent variables (Field 2009). Factor analysis tries to explain the variability among the measured variables by exploring the patterns in their correlation coefficients (Brown 2014).The patterns of interdependencies between measured variables are thus used to reduce the set of variables in the dataset.

The extraction method of choice for conducting this analysis was: Principal Axis Factoring and the rotation method was oblique "Oblimin" with Kaiser Normalization. An oblique rotation allows the selected factors to be correlated with one another. The Kaiser-Meyer-Olkin (KMO) statistic was used to test for sampling adequacy. The statistic is a measure of the proportion of variance that could be common across variables, with lower proportion of common variance being a better finding. The rule of thumb in this regard is that KMO values less than 0.5 indicate that sampling is not adequate for factor analysis (Williams, Onsman et al. 2010).

In order to determine the number of the underlying factors in the data set, an initial analysis was run to obtain Eigen values for each factor. Eigen values represent the amount of variation explained by a factor. Only factors with Eigenvalues above Kaiser's criterion of 1 i.e. a substantial amount of variation, were included (Kasier 1960; Field 2013). Scree plots were also used for that purpose, the point of strong inflection in a scree plot is regarded as a cut off for the number of factors extracted (Stevens 2002). Missing cases were excluded list-wise. Multiple analyses were conducted before we arrived at the final analysis. The aim of the analysis was to arrive at a simple structure, one in which each variable loaded highly onto one factor only. Item selection was based on field suitability, relevance to research study, correlation coefficient with BOT-2 total, and correlation coefficient with latent factor.

2.4 Results

2.4.1 Screening

Six screening sessions were conducted at CW School. A total of 241 year 9 students were screened, 144 males and 97 females aged 13-14 years old. Table (1) shows the descriptive data of scores obtained on all performed tests. Missing data is attributed to student absences, incomplete data collection and difficulty in matching names and numbers.

Table 1: Descriptive Statistics of Screening Data

Test Item	Mean	Std. Deviation	Min	Max
VO2 max (ml/min)	37.1	4.8	22.3	48.7
Height (cm)	161.7	9.2	101.0	187.0
Weight (kg)	50.7	9.6	32.9	84.9
Dropping ball	4.8	0.8	0.0	5.0
Dribbling Ball	9.4	1.7	1.0	10.0
Push ups/ 30 sec	22	7.6	4.0	50.0
sit ups/30 sec	21	5.1	10.0	36.0
5m.Shuttle run (sec)	19.9	2.2	14.7	29.4
Balance Beam (sec)	8.2	2.9	1.0	10.0
Walking forward (step)	6.0	0.1	5.0	6.0
fPenny transfer (n/15 sec)	16	2.2	7.0	20.0
Tapping-coordinated	9.9	0.6	5.0	10.0
Hand grip (kg)	25.6	6.3	9.0	48.0
Tennis wall Toss (catches/15 sec)	21	8	0.0	40.0
Jumping synch	5.0	0.0	5.0	5.0
Hopping /15 sec	40	7	7.0	58
Broad Jump m	1.6	0.3	0.0	3.1
Medicine Ball(m)	3.5	0.8	1.3	6.4
paper Folding	6.1	1.5	0.0	7.0
Copying (Star)	4.8	0.7	0.0	5.0
Copying square	5.0	0.2	4.0	5.0
Drawing line through Maze	6.8	1.0	0.0	7.0

2.4.2 Total BOT-2 score

The average total BOT-2 score ±SD (min-max) =75.6 ± 4.35 (57-85). Table (2) shows the frequencies of the categorical description of the standardised scores. The distribution of the total BOT-2 standard score shows in Graph (3). The distribution of scores seems to follow a fairly normal distribution.

Descriptive Category	Number
Well above average	2
above average	26
Average	189
Below Average	15
Well below average	2

Table 2: Number of Patricipants in each of the BOT-2 Dscriptive Categories

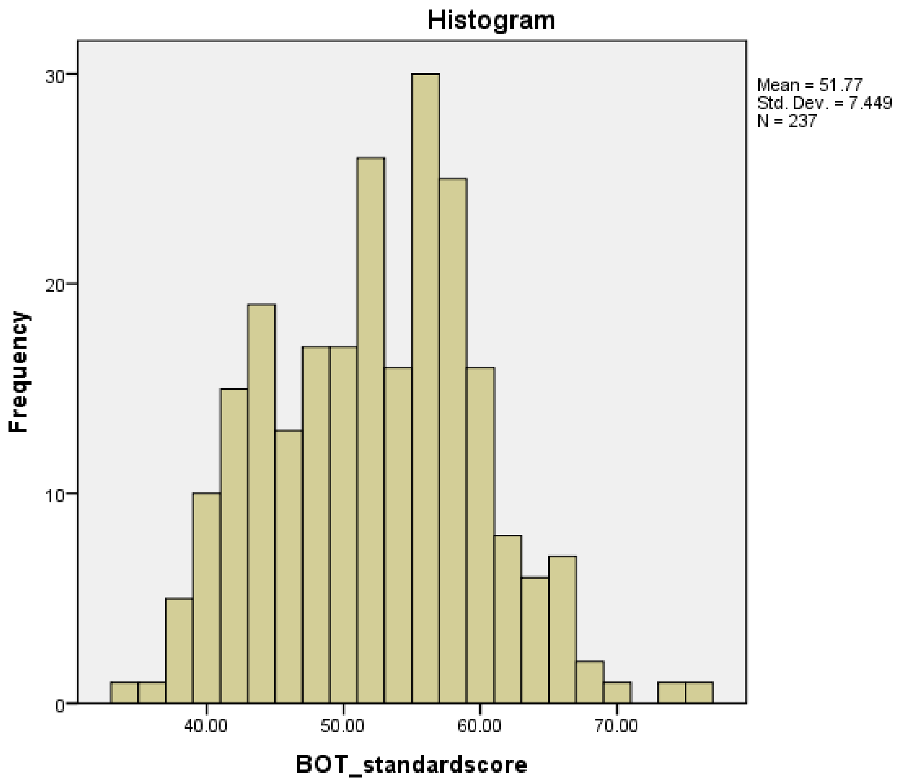


Figure 3: The distribution of BOT-2 standard scores across all the participants

2.4.3 Factor analysis:

Factor analysis was done on the raw test scores collected during screening. BOT-2 total score and the standardised scores were not included in the correlation matrix (Appendix 9). The variables: "Jumping synch", "tapping hand and foot synchronised", and "walking forward in a line" were also excluded, because they had very little or no variability (ceiling effect) which would have hindered the function of the correlation matrix (Field 2013).

A preliminary analysis was run and the initial correlation matrix showed that $VO2_{max}$ score did not correlate with any of the other variables. Accordingly, $VO2_{max}$ was excluded from the analysis (please see section 2.5.1), but due to the importance of measuring cardiovascular fitness in this context, it would be added as an independent factor in all cases.

2.4.3.1 Initial analysis

A principal factor analysis was conducted on 16 tests with oblique rotation (direct oblimin). The Kaiser-Meyer-Olkin (KMO) measure verified the sampling adequacy for the analysis KMO= .67 "Medicore" according to (Hutcheson and Sofroniou 1999) and all KMO values of individual items were larger than the acceptable level of .5 (except for ball dribbling =.416). The resulting scree plot as well as the eigenvalues suggested the extraction of (5) factors.

Test Item	Factor				
	1	2	3	4	5
10*5m Shuttle run	-.747				
Broad Jump CM	.563			.316	
sit ups	.562				
Dropping ball					
Maze		.714	.355		
paper Folding	.403	-.608			
Copying (Star)		-.528			
Copying square		-.425			
Push ups			.600		
Hopping			.592		
Balance Beam			.534		
Penny transfer			.356		
Medicine Ball(m)				.832	
Hand grip				.806	
Dribbling Ball					.655
Tennis wall Toss	.369				.398

Table 3: The Pattern Matrix of the Rotated Factors (oblique rotation).

The results of the initial analysis suggested the exclusion of the two items; ball dropping and catching and ball dribbling for the following reasons: 1- Both items did not correlate highly with any of the other variables in the correlation matrix 2-The item ball dropping and catching did not load on any of the factors after rotation 3- The KMO value of the ball dribbling was below the acceptable level of (0.5) 4- both items are extremely liable for a ceiling effect.

In total, three items were excluded from the following analysis: ball dropping and catching, ball dribbling and $VO2_{max.}$

2.4.3.2 Second Analysis:

A principal factor analysis was conducted on 14 tests with oblique rotation (direct oblimin). The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis KMO= .7 which corresponds to "Meddling" according to Hutchenson & Sofroniou, 1999 and all KMO values of individual items were larger than .66 which is well above the acceptable level of .5 (Field, 2013). An initial analysis was run to obtain eigenvalues for each factor in the data. Four factors had eigenvalues over Kaiser's criterion of 1 and in combination explained 45 % of the variation.

The scree plot suggested the extraction of 4 factors [Figure 4]. Table [4] shows the loadings of the test items (i.e. the correlations of the tests with the factor) on the latent factors after rotation.

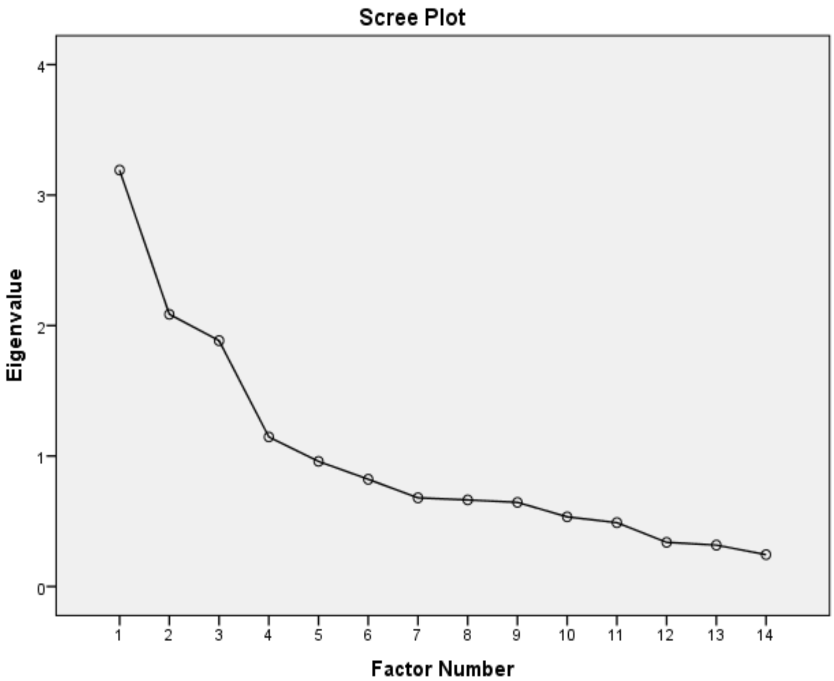


Figure 4: The scree plot resulting from running the second factor analysis. The point of inflection of the plot suggested the extraction of 4 factors.

Test Item	Factor			
	1	2	3	4
Shuttle run	-.778			
Broad Jump CM	**.628**			
sit ups	.573			
Tennis wall Toss	.474			
Maze		.798	.307	
paper Folding		-.690		
Copying (Star)		**-.445**		
Copying square		-.361		
Push ups			.579	
Hopping			**.558**	
Balance Beam			.549	
Penny transfer			.394	
Medicine Ball(m)				.799
Hand grip				**.789**

Table 4: Second Analysis Pattern Matrix

2.4.3.3 Latent Factors

Observing the pattern of clustering of test items, the following (possible) latent variables were considered (cut off of choice for factor loading=.4)
1-(Coordination and power): Shuttle run, broad jump, ball wall toss and sit-ups
2-(Fine motor control): Copying star, following the maze and paper folding
3-(Core stability): Push-ups, hopping and balance beam
4-(General body strength): Medicine ball throw and hand grip

2.4.3.4 Item selection

considering the results of these two analyses, the correlation of test items to the total BOT-2 score, their general robustness, their ease of application and their representation of the general motor abilities, the tests of choice for application during the school screening session are; A shuttle run bleep test as measure of fitness, the handgrip as a measure of upper body and total body strength, the Broad jump test and a measure of power and lower limb coordination, single leg hopping as a measure of balance, coordination and core stability, Tennis wall toss as a measure of upper limb coordination and general coordination, and finally drawing a star shape as a measure of fine motor ability.

2.5 Discussion

This study was set out to create a screening test that has utility for mass screening in main stream schools. The test should be able to crudely detect children with low motor coordination abilities. In order to decide on test items to be included in the screening battery, we ran a factor analysis on data collected in a mass screening of a whole year group in one school. We screened 241 adolescents (13-14 y) using; 14 test items which formed the BOT-2 short form, as well as 5 items which represented Fundamental Movement Skill and the Chester step of cardiovascular fitness.

2.5.1 Item exclusion

Before we ran the factor analysis, three items of the BOT- SF were excluded for having very little to no variability. This also meant that these items, given the normal distribution of the total BOT scores, were redundant as they did not contribute to the variability seen in the total test score in our sample. A finding which has similarly been reported in literature by Brahler, Donahoe-Fillmore et al, (2012) when they described multiple items of the BOT-SF as showing no variability and being highly susceptible to ceiling effect. After running the initial analysis, two items were further excluded.

The VO2max scores obtained from the CST were also excluded for having no correlation with any other test items. This finding could have two possible explanations; the first would be that the cardiovascular fitness is truly a stand-alone construct of ability which does not share any common features with other motor abilities. This is however, very unlikely given the vast literature describing a clear relationship between coordination, motor proficiency and fitness (Barnett, Van Beurden et al. 2009; Haga 2009; Rivilis, Hay et al. 2011). It is true that cardiovascular fitness levels are worthy of being measured whether or not they correlate with other motor skills. Yet, it is not true that other motor skills like coordination and agility do not have any bearing on this score, especially in a test like the CST where lower limb coordination and rhythmic control are required.

The second and more plausible explanation is that the CST did not yield reliableVO2max measures. This could be attributed to the difficulty in reliably measuring heart rate in large group of students during the (10 sec) rest duration between the different test stages using a pulse Oximeters. Often during the assessment, the pulse oximeters did not provide a stable heart rate reading in the available time period. In addition, the measurement was disrupted by poor blood circulation in the finger tips during the winter which precluded the ability to get reliable readings using pulse Oximetry. With these challenges in mind, we concluded that CST is not a suitable method to test cardiovascular fitness during mass screening. It was hence excluded from further analyses. Nevertheless, given our interest in measuring cardiovascular fitness levels, we decided to replace the CST with the 20 m shuttle run test as we expected it to be more reliable for testing large groups of students as it requires no direct HR measurement and is not influenced by the cold weather or number of researchers available for help.

2.5.2 Factor analysis:

16 items were initially included in the factor analysis [Table 3]. The analysis resulted in the extraction of five latent factors. Final reduction was not based merely on this analysis given that two more items of the BOT-SF were excluded. Another analysis was run with 14 items which loaded on 4 factors. Considering the loading of different variables on each factor, we could identify the possible underlying motor ability constructs they represented.

Factor (1): Lower limb coordination and agility
Factor (2): Fine motor control
Factor (3): Core stability and balance
Factor (4): Upper limb and total body strength

2.5.2.1 Item selection

Both analyses were considered during the process of item selection. And given that the decision of selecting an item highly depends on the test purpose, our selection was greatly influenced by the practicality and pragmatism of the test items.

Lower limb coordination and agility:

The 10*5 m shuttle run had the highest loading factor on factor (1). However, bearing in mind our intention to include the 20m shuttle run test in the screening battery, the broad jump was our item of choice due to its sensitivity, objectivity, ease of application and usefulness. Broad jump test has also been included in multiple motor proficiency batteries like the ALPHA health related fitness battery for children (Ruiz, Castro-Piñero et al. 2010) and European test of Physical Fitness (EUROFIT) (Adam, Klissouras et al. 1988).

Fine motor coordination

Even though both test items; “following the maze” and “paper folding” loaded highly on factor (2), the conduction of these two items was somewhat tricky during screening as it seemed that participants (especially boys) lost patience with them and did not try to make any effort to perform them correctly. Given the sensitivity of scoring, results may have been biased due to lack of interest. “Copying star shape” is of course also liable to this bias. It seemed, however, that it was more appealing to the participants and so the results were more sensitive which made it the item of choice for this factor.

Core stability and balance

Push ups loaded highly on factor (3) and certainly served as a very important indicator of core stability and strength. However, the problem with push ups was the difficulty in the technique required for performing it. Many of our students had not done any push ups before the screening, and were not aware of the correct way to do it. "Push ups" as a test item from the BOT-SF is a timed task and students who didn't know how to do the task, (even after the researcher explained and demonstrated) either lost the time trying to do it correctly or performed it with a very bad technique which made their results biased. For these reasons, push ups seemed not practical for purposes of screening at school, which made hopping, our chosen item in this factor.

Upper limb and total body strength

Both the hand grip strength and medicine ball throw loaded highly on this factor. Yet, between these two items, measuring hand grip strength using a Dynometer was preferred for being extremely reliable, objective, easy, and able to predict total body strength (Wind, Takken et al. 2010). Grip strength has also been used in multiple other validated test batteries (Adam, Klissouras et al. 1988; Ruiz, Castro-Piñero et al. 2010).

Upper limb coordination

Although the test "Tennis ball wall toss" (Kayihan, Ersöz et al. 2013) loaded on the first factor, which suggested that this factor may represent a general coordination ability construct, yet we believe that it is important to include this test as well as the broad jump, given that one is more representative of lower limb power and coordination and the other one of upper limb and eye hand coordination respectively. Also, throwing and catching are very important movement skills that are required for participation in any ball sports and need to be part of any motor assessment battery (Lubans, Morgan et al. 2010).

2.5.3 Conclusion

After running the factor analysis, five test items were included in our test battery namely; standing broad jump, hang grip, copying star shape, single legged hopping, and hand wall ball toss. In addition, as we deem it important to test cardiovascular fitness, which would allow us to categorise children according to their fitness level, the 20 meter shuttle run test was the sixth item in the our battery. This screening battery is expected to be quick and easy to use, especially for screening large numbers of students in main stream schools. The time, material needed and number of researchers required for running the session have been drastically reduced and the tests used are to a high extent, not affected by inter-rater differences. This is expected to help both the research team and the schools to run more efficient, organised screening sessions with no redundant items. The reduction of items also allows the complete assessment of all students in one class in the duration of a single screening session, which is expected to considerably decrease the amount of data lost in the process of matching names and numbers from two sessions. This makes it much more likely to obtain complete data sets.

The 6-item test battery will be used to select students who score in the lowest quartile in reference to their school year. The utility and reliability of these test items will be further confirmed or disputed after applying this battery on a large cohort of 13-14 y adolescents.

Chapter (3): Validity of using IMU as measure to detect movement timing parameters during the gross motor stepping task

The overall objective of this thesis is the investigation of the motor performance and acquisition of a novel motor skill in children with coordination problems. Hence, there is a need for detailed analysis of the participants' movement parameters and following the change of these parameters over time. The efficient, objective and reliable study of motor performance and its change over time requires the use of objective and sensitive measures. To this regard, we used Inertial Measurement Units (IMU) to record the time events during the performance of the rhythmic stepping task. Given the novelty of this task, we had to design a protocol in which we validate the use of the IMU for this particular task. This chapter describes the validation study in which we compared the measurements provided by the IMU to the gold standard of motion detection the Optical Camera Motion System (OCMS).

3.1 Introduction:

3.1.1 Motion Analysis

In general, there are two approaches that one could take to evaluate different aspects of human motor performance and its quality. *Kinematics* describes the motion of the body, examining it from a spatial and temporal perspective without consideration of the causes of motion. As a result, position, velocity and acceleration are of particular interest in kinematics (Kavanagh and Menz 2008). The displacement data, which is at the heart of kinematics study, could be taken from different positions such as the centre of gravity of the bod or body segments or centres of rotation of limb segments. Kinetics, on the other hand is concerned with the relationship between the motion of bodies and its causes, namely forces and torques. Motion analysis is extremely useful for studying the kinematics of human movement.

Studying the performance and acquisition of a specific motor skill, i.e. rhythmic stepping, in children with coordination problems is the interest of this research project. Hence, we are primarily concerned with analysis of movement as the children acquire the new movement skill, particularly the timing of the different movement events during the performance of a rhythmic stepping task. Given that coordination is primarily concerned performing action in a timely manner (Bo and Lee 2013), timing is an important construct of motor coordination (Johnston, Burns et al. 2002; Buhusi and Meck 2005). Adherence to a rhythmic stability is considered an important aspect of motor control and coordination, especially in the skills that are naturally rhythmic like walking, cycling, and running (Thaut, Kenyon et al. 1999).

Different methods are used for kinematic analysis of human movement, including observation, foot switches, gait mats, and optical motion analysis. The Gold standard for motion analysis, however, is considered to be the Optical Camera Motion System (OCMS)

(Wong, Wong et al. 2007). It is capable of analysing the kinematics of an object with high resolution in the three dimensional space. However, the OCMS system is expensive, it requires special technical expertise and it is not applicable to gym or school environments (Mayagoitia, Nene et al. 2002). Hence, using it to quantify the outcomes of skill acquisition in school children over an extended period of time is not practical.

An alternative method used for kinematic movement analysis is the Inertial Measurement Unit (IMU). IMUs generally contain orthogonally mounted accelerometers and gyroscopes to measure the accelerations and angular velocities, respectively. Micro-electro-mechanical systems (MEMS) technologies enable miniature sensors suitable for human scale inertial sensing to be used in biomechanical measurements, where the accelerations, angular velocities and orientations of the head, limbs and back of a human subject can be measured (Fong, Ong et al. 2008). IMUs provide accurate vertical acceleration, velocity and position measurements of the Centre of Mass (CoM) in the global frame (Esser, Dawes et al. 2009). Unlike the camera system, the IMUs are relatively cheap, easy to use and could be used in intervention training environments. This makes IMUs the preferred choice for continuous, unobtrusive and reliable method in human movement detection and monitoring (Godfrey, Conway et al. 2008)

3.1.2. Inertial Measurement Unit (IMU)

IMU sensors use inertial navigation, a self-contained navigation technique in which accelerometers and gyroscopes are used to track the position and orientation of an object relative to a known starting point, orientation and velocity (Woodman 2007). IMU sensors use Micro-Electro Mechanical Systems (MEMS), integrated devices which combine mechanical and electrical components, to obtain data (Fux 2008). The mechanical MEMS in the IMU device are an accelerometer and gyroscope.

An accelerometer is an electromechanical device that measures acceleration forces. These forces can be static e.g. constant force of gravity, or dynamic caused by moving or vibrating the accelerometer (Andrejasic 2008). Mechanically, the accelerometer is a transducer, which converts dynamical changes of mechanical variables such as acceleration, vibration and mechanical shock, into electrical output which could be used to measure the rate and intensity of body movement in up to three planes (anterior–posterior, mediolateral and vertical (Godfrey, Conway et al. 2008).

Vibrating gyroscopes measure the angular velocity to describe the exact attitude and position of the sensor, expressed in Euler angles and Quaternions. Both outcomes describe the exact rotation of the sensor (Godfrey, Conway et al. 2008). Using integration methods, angular velocity of the gyroscope could be transferred into orientation information relative to a global frame. In addition, the integration of the acceleration signal provides velocity data and in case the acceleration signal is integrated twice, the position signal is reconstructed.

The popularity of using accelerometer-based systems to quantify human movement patterns has increased in recent years for both clinicians and researchers (Kavanagh and Menz 2008). The benefits of using accelerometers include low cost; suitability for different testing environments; and the small size which allows for free unrestricted motion. IMU has already been cross validated with OCMS for gait analysis for position, velocity and acceleration (Henriksen, Lund et al. 2004). However, because the stepping task practiced in this study is novel, the IMU signal needed to be validated for use during this specific task.

This study aimed to validate the use of the IMU for detecting movement timing events during the rhythmic stepping task and to inform the building of a custom-made IMU signal analysis program by way of defining the most the reliable outcome measures.

3.2 Methods

Ten healthy adults took part in the validation study; they were between the ages of 23 and 60. The set-up of the validation study is shown in [Figure 5]. Six cameras (Qualisys, Göteborg-Sweden) were used to detect and record participants' movement data. These cameras detected the motion of three reflective markers. An IMU (LPMS-B, Japan) was placed on the participants' lower back using double adhesive tape to detect the motion of the CoM. The reflective markers were placed on both heels of the participant and the third marker was placed on top of the IMU sensor, to track the movement of the centre of mass. Using this camera setting enabled the Qualysis camera system to track all markers for the whole duration of the stepping task. Both systems were set to measure at a frequency of 100 samples per second (Esser, Dawes et al. 2011).

3.2.1 Procedure

The task that the participants were asked to perform was a rhythmic stepping task, in which participants stepped up and down an aerobic stepping block in accordance to the appearance of visual stimuli on a computer screen placed 1.5m away from the stepping block (see section 4.1.5.1 for a detailed description of the stepping task).

After LPMS-B sensor was connected to the laptop via Bluetooth, the participant stood in the pre-calibrated space in front of the aerobic stepper. Both Qualysis program and LabVIEW data collection application, which was made for collecting IMU signal, were started simultaneously. Given that both data collection programs ran on two separate computers, before the beginning of stepping the participants were asked to jump in order to create a time stamp to synchronise both signals. When the visual stimuli appeared on the screen, participants started stepping up and down as indicated and continued until the task was finished (~5 min). To validate the sensor for two speeds, participants were asked to perform the stepping task at slow rate and fast rate. Each speed was repeated three times.

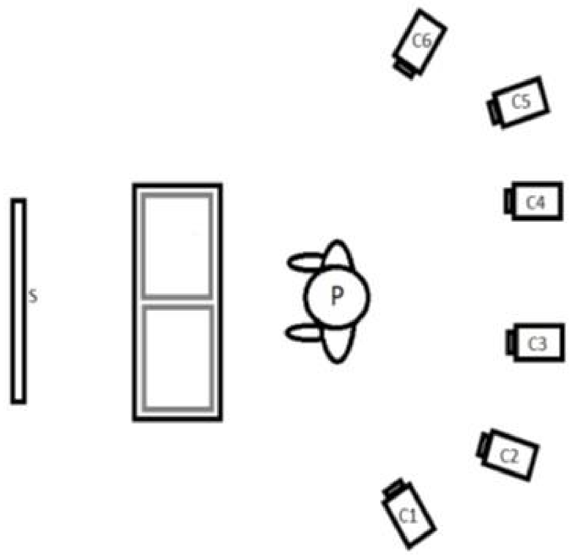


Figure 5: The set-up of the IMU signal validation study; six cameras (C1-C6) detected the motion of three markers placed on the heels and the back of the person (p) who steps up and down a stepping board as indicated by the appearance of visual stimuli on the computer screen (s).

3.3 Data analysis procedure

3.3.1 Post processing:

The IMU acceleration signal was post-processed using quaternion rotation matrices to yield vertical excursion of the CoM in the global frame (Esser 2009). This prevents the signal from being affected by misplacement of the sensor on the CoM. The acceleration signal was then converted to Sum of Vector Magnitude corrected for gravity (SVMg). The SVMg acceleration displays the resulting vector of the three acceleration axes. Before further data analysis took place, the signal was filtered using a 2nd order bandpass Infinite Impulse Response (IIR) Butterworth filter with a high cut-off frequency of 9 Hz and a low cut-off frequency of 0.35 Hz. Those cut-off frequencies were selected because the maximum frequency of the protocol was 1Hz and any frequency below 0.35Hz contained no relevant data. The resulting data was easier to analyse with more distinguishable peaks and troughs. After that, SVMg signal was integrated to obtain the velocity signal. A Zero phase filter was applied (National-Instruments 2014) to prevent the possible time-shift in the signal caused by integration.

For further technical details on treatment and analysis of Qualysis and IMU signal, please refer to the Bachelor thesis titled: "The Development and Application of a Novel Methodology to Motor Skill Acquisition of Children with Developmental Coordination Disorders" by Ruben Zijlstra, 2016 (Appendix 9)

3.3.2 Signal Analysis

The output file of the Qualysis described the displacement of the three markers in the X, Y and Z directions. Before any stepping movement had commenced, the cameras collected positional data so that the first instance of measured motion was considered to be the offset (t0). This offset was used for the synchronisation of the Qualysis and the IMU signals in Lab View analysis software. Analysis was done per step and the time stamps of the given visual stimuli (which marked the signal for initiation of each step) were obtained from the protocol data.

Given the accumulated knowledge about gait analysis and the relative similarity between the stepping cycle and the gait cycle, we expected the IMU signal in stepping to have some of the time events prominent in gait. One of the time events that we set out to search for is a distinguished peak in the IMU velocity signal which appears early in the gait cycle and has been found to correspond with heel strike (Steins, Sheret et al. 2014). We expected that the foot placement on the stepping board and the following elevation of the centre of gravity to produce such a prominent peak. Time events were detected using the peak detector function in LabVIEW. A prominent peak in the velocity signal which appeared right before the centre of gravity was stable on the stepping board (as apparent from the position/camera signal) was detected and further examined for reliability [figure 6]. Nonetheless, multiple other time events which corresponded to other troughs or peaks in the IMU signal were also marked and examined for concurrent validity (Zijlstra, 2016).

3.4 Statistical Analysis and Results

To test the validity of the detected velocity peak, Intraclass Correlation Coefficient (ICC) test was run in (IBM SPSS Statistics 21). The purpose of this test was to determine the relative strength of the correlation between the timing of the velocity peak as measured using the IMU and the concurrent change of the position signal as detected by the Qualysis.

The results of the ICC are provided in Table 5]. Multiple time points were tested for their agreement with the Qualysis data. However, the most important tested time point was the velocity peak which indicates the heel placement and COM elevation. The resulting correlation coefficient of this time event was 0.51 which corresponded to a moderate agreement. Subsequently, the velocity peak was accepted as marker for the start of the stepping cycle which was defined as the time duration from one velocity peak to the next.

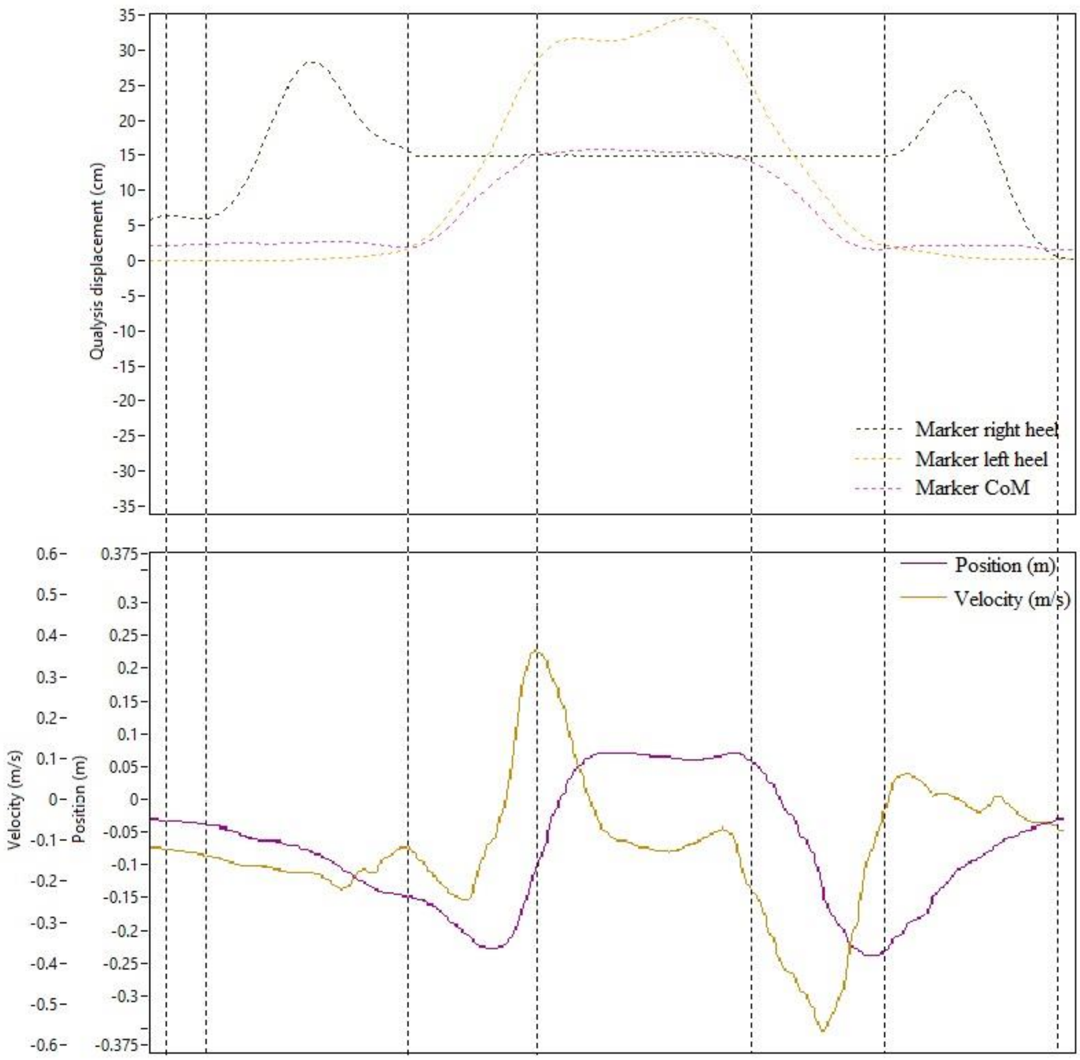


Figure 6: Over lapping position (Qualysis) data and velocity (integrated acceleration obtained from (IMU) signal

	Intraclass Correlation Coefficient ICC (95% CI)			
	Slow		**Fast**	
Events/Phases	**Overall** *r*[Lb-Ub]	**MD ± LOA** [s]	**Overall** *r*[Lb-Ub]	**MD ± LOA** [s]
First Foot Initiation	.04 [-.03-.11]	.24 ± .41	-.26 [-.35--.08]	.10 ± .42
COM up (velocity peak)	.51 [.44-.58]	-.02 ± .40	.45 [.15-.64]	-.12 ± .34
COM Initiation Down	.35 [.27-.43]	-.03 ± .58	.40 [.30-.48]	-.08 ± .61
END of movement	.58 [.21-.76]	.22 ± .57	.49 [.38-.59]	.10 ± .54

Table 5 : Concurrent Validity of the Identified Time Points

ICC, intraclass correlation coefficient (*r*); MD: mean difference; 95% CI, 95% confidence interval; Lb-Ub: lower and upper bound of associated 95% confidence interval; LOA: limits of agreement.

3.5 Discussion

The results of the validation study revealed that we can reliably detect the timing event in the IMU velocity signal which corresponds to CoM elevation on the stepping board. This timing event allows for breaking the signal into the individual stepping cycles as well as calculating movement time with reference to the timing of the visual stimulus.

To this regard, IMU is a useful and reliable means to detect this timing event during stepping. It is easy to use, doesn't require expert knowledge and is relatively cheap which makes it, together with the reliability of recorded signal, an optimal tool for detecting movement timing during the stepping task in schools and gym environments.

Chapter (4): Motor skill acquisition of an externally paced stepping task in children with poor motor coordination: A pilot study

This chapter describes the main intervention trial i.e. the feasibility study which investigates the motor skill acquisition of a novel rhythmic stepping task in children with poor motor coordination in comparison to typically developing age matched children. At first, the methods are described in detail, including the screening process (using the previously developed motor assessment tool), the selection and recruitment process, and a detailed description of the intervention. The outcome measures are then listed and defined. After that, the data analysis and statistical analysis methods are described and results are reported. Given the importance of the feasibility related results to the development of the full trial, the feasibility results are provided independently (procedure, recruitment and retention rates, grouping criteria, validity of the outcome measures and the used methods) followed by the intervention trial i.e. the results of the motor performance of the different participating groups and the performance change over time.

4.1 Methods

Study design: An exploratory, pilot/feasibility study for setting up a non-randomised controlled intervention of skill acquisition training in children with low motor coordination abilities.

4.1.1 Participants

Young people aged 13-14 years old (school year 9) with low motor coordination abilities and a control group of children with normal general motor and coordination abilities. Participants have been recruited from three different schools in Oxfordshire which have consented to taking part in the project.

4.1.1.1 Inclusion criteria:

For the low motor ability group, participants had to score at or below the 25th percentile on the motor skill tests administered during the screening session and to have no significant neurological conditions or intellectual disabilities which require special education. Participants had to be able to walk independently and follow orders. For the purposes of testing a wide range of movement abilities, our control group consisted of children scoring above the 25th percentile.

4.1.1.2 Exclusion criteria

Exclusion criteria included having a significant neurological disorder like muscular dystrophy, cerebral palsy or traumatic brain injury as well as showing evidence of behavioural issues which would preclude safe participation or put the participant, investigators and others at risk. Individuals with a diagnosis of asthma, diabetes and epilepsy were free to participate as long as they were stable on medication for a period of at least 12 weeks.

4.1.2 Consent and study flow

The study was been approved by the Oxford Brookes University Ethical Committee UREC number 140844. Different levels of consent were obtained in this study. The first was the consent of the school principal who agreed to adopt the project. After making arrangements with the head PE teacher for screening participants, an opt-out consent form (Appendix1) was sent out to the parents informing them about the organised screening session and asking for permission to keep their children's data for further analysis and recruitment. After selection of the students who were eligible for participation in the intervention study, participant information sheets Appendix (2) were delivered to parents and invited students and written consent was obtained from the parents or legal guardians who agreed for their children to take part in the intervention study (opt in) (Appendix 3).

The intervention program was provided within a pathway to sport in children with lower motor abilities; the EPIC program described in chapter 2. The first phase of the pathway is the targeted recruitment phase; this phase included screening the motor abilities of all year 9 students. After that, the performance data from the screening was analysed and participants who were eligible for participating were invited to take part in an 11 week intervention program which involved fitness and general motor ability training as well as a specific training of lower limb rhythmic stepping task. [Figure 7]

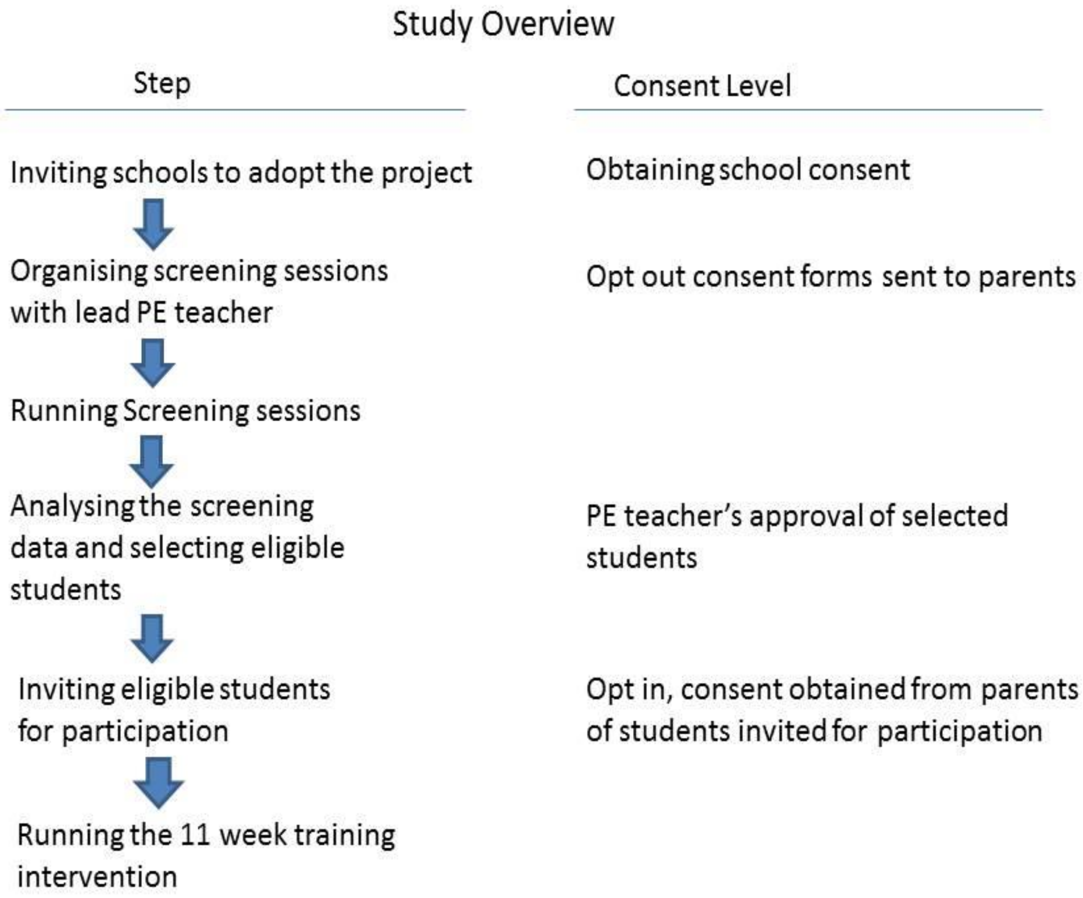


Figure 7: An overview of the intervention pilot study with its multiple phases

4.1.3 Recruitment

4.1.3.1 Screening

Motor screening sessions were held in order to identify children with low motor coordination abilities. The individual motor abilities of the students in the cohort of year 9 were measured using the shortened screening test described in [Chapter 2]. The screening sessions were arranged with the head Physical Education (PE) teachers and took place during PE lessons in the schools' sports hall.

The screening consisted of a multi stage fitness test (the bleep test) as well as a 5-item motor skill assessment. These tests covered the main areas of motor ability including cardiovascular fitness, strength, power, general coordination, and fine motor coordination. The screening was set up in a circuit fashion and lasted for approximately 40 min. A total of ~45 students were measured every session. The number of sessions required to screen the whole year group varied between the schools depending on the size of the cohort. A minimum of 7 researchers are needed to run every screening session.

When participants arrived into the sports hall, they were given identification numbers in the form of pre-prepared sticky labels that they wore on their chests. This made it easier to split them into 3 groups of 15 participants according to their ID number and facilitated the bleep test as the participants were identifiable from distance. For the whole duration of the screening, participants were identifiable with their numbers. However, for recruitment purposes, the PE teachers were asked to match the ID numbers with the students' names.

A maximum of 15 students were allowed to do the bleep test at once, as to ensure providing them with enough space for running as well as enough researchers to record their scores immediately after they dropped put from the test. This grouping warranted a fair and sensitive measurement of the bleep test. Given that the bleep test required about 10-15 minutes in total, we could only run a maximum of 3 bleep tests per session. At any given moment, one group (e.g. Group 1) would do the bleep test, the second group (Group 2) would sit on the side and encourage/cheer for their running class-mates, while a third group (group 3) would be split into smaller groups of 3 participants to undergo the circuit motor tests. Every 15 minutes, the groups exchanged their positions so that by the end of the session, all participants would have undergone all the testing [Figure 8].

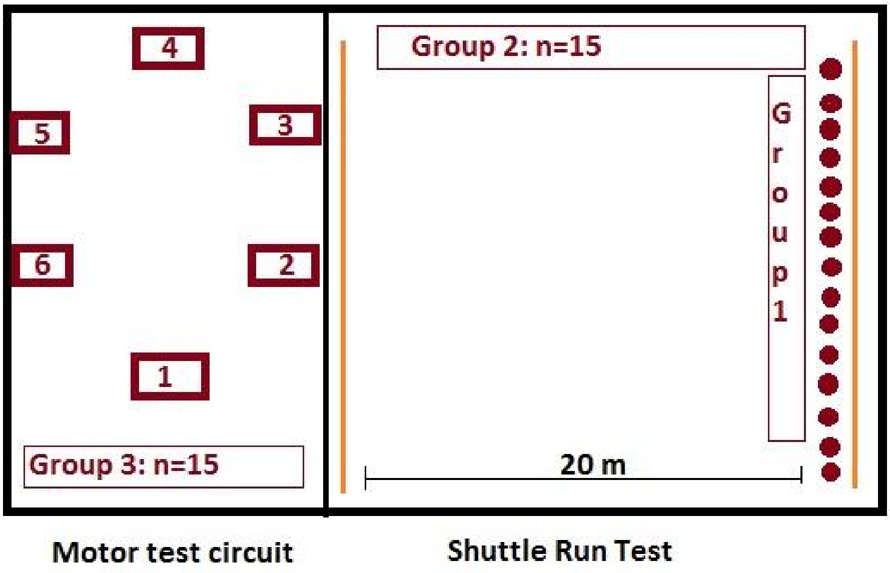


Figure 8: The set-up of the screening session

The motor skill assessment items were;1-single legged hopping (BOT-2 item power, balance, and core stability), 2-alternate hand wall toss (eye hand coordination and bilateral hand coordination), 3-broad jump (explosive leg power), 4-grip strength measurement (General body strength) described in section (2.2.2.1-B), 5- copying a star shape (fine motor skill measurement BOT2 item).

Students rotated in groups of 3-4 around the 6 allocated testing stations, [Figure 8]. An additional station was set to measure participants' height (Holtain stadiometer) and weight (Seca scales). Each station was run by one member of the research team who was trained to instruct the students, measure and record their performance. To ensure consistency of the measurement and reduce inter-rater variability, to the extent possible, the same station was appointed to same researcher the every testing session.

Bleep Test

The shuttle run test is a multi-stage fitness test which indicates the maximum aerobic capacity (Leger, Mercier &Lambert 1988) and it has been validated and frequently used in studies on children and adolescents (McVeigh, Payne et al. 1995; Olds, Tomkinson et al. 2006). It involves running forward and backward on a 20 meter track. The start and the end of time duration within which the participants should have run the 20 meters (speed) are indicated by an audio recording.

At the beginning of the test, students stood behind one of the lines [Figure 8] and facing the second line. When participants heard a beep, it indicated the beginning of the running and participants ran to the other line. The speed at the start was quite slow (8.5 km/h). The participants continued running between the two lines, and turned only when signalled by the recorded beeps. Each minute represented a level of intensity (Level) which was announced by the recording and the beeps became closer together increasingly. The students were instructed to try and keep their pace similar to that set by the beeps and to wait for the beep in case they reached the line before the beep sound. If the line was not reached before they heard the beep sound, the subject was given a warning and encouraged to continue running to the line, then turn and try to catch up with the pace within two more beeps. The test ended for each subject when they dropped out or failed to reach the line (within 2 meters) for two consecutive ends after a warning. The whole test was stopped when the last participant had dropped.

Participants were instructed to remember the last number that was called before they stopped and report that to the researchers who were recording the scores. A minimum of 3 researchers were supervising the bleep test, monitoring participants, recording their scores, encouraging them and warning them when they were too slow for the pace. Before the start of the test, participants were given clear instruction on what the test was about, how to do it and the normal vs abnormal physical signs they could experience.

Single-legged hopping

Participants stood with both feet together on a small cross marked on the floor and placed hands on their hips. Participants were then instructed to raise their non-preferred leg behind with the knee bent 90 degrees and shin parallel to the floor. When indicated by the researcher, they hopped up and down on the preferred leg maintaining proper form with each hop [Figure 9]. The researcher recorded the number of correct hops performed in the period of 15 seconds. The hop was considered incorrect if the participant touched raised foot to the floor or failed to keep hands on hips (Bruininks and Bruininks 2005).

Copying star shape

A table and multiple chairs, (when possible, alternatively a bench) were prepared for the performance of this fine motor task. Participants were provided with pencils and asked to copy a star shape in a free space on a paper and make it as similar as possible to the original shape. They were allowed to take as much time as they needed and to start and stop but not erase what they drew. Number of points of the star, the orientation, size, angles and closure of the shape were the five marking criteria. The scores varied between 0-5.

Image of child removed from
electronic version

Figure 9: Single Legged Hopping. **Taken from the BOTMP manual (Bruininks and Bruininks 2005)**

4.1.3.2 Screening data analysis and participant Selection

Data, from the data collection sheets, recorded by each of the researchers during screening was inputted into excel. Scores obtained from the bleep test were first converted into their corresponding VO2 max equivalent for that age using the table from (Leger, Mercier et al. 1988). In their paper, they provide an estimated VO2max level for each stage (min) of the bleep test. However, since every stage is made of multiple levels (laps of 20 m) which the participant could drop at, the increase of VO2 max per stage was calculated and divided over the number of levels within the stage. A more precise table was created which describes the exact estimated VO2 max from each level within a stage [Appendix 4].

The scores for one participant on all the different tests were inputted into one row while each column represented a different test and names were matched to the IDs. Data was then treated separately based on sex. Also, data was analysed separately for each part taking school.

In order to compare the performance across the different tests (which had different measuring units), the individual scores on the 6 motor skill tests were transformed into standardized scores (Z-scores) based on the average and standard deviation calculated per school/ gender and the data was ordered by rank. The percentiles were then calculated using the "PERCENTILE" function in Excel. For each individual test, the scores that fell at or below the 25th percentile were highlighted. An arbitrary score, created by averaging the Z scores of all 6 motor tests, was then calculated and used as an overall score for the participant. Participants who scored at or below the 25th percentile on at least 3 out of the 6 tests where selected for potential recruitment.

The list of selected students was then taken to the PE teachers who further examined the performance scores and the suggested selection. They wrote notes on whether the selected participants had indeed showed signs of long standing poor motor and coordination abilities. The final decision for invitation was not taken by the PE teachers, but the PE teachers' advice was taken into account, in cases where the participants which we selected were known to the PE teacher to be athletes who are competing on a high level. This step was necessary to counteract for poor performance being the result of lack of motivation to perform to the best of student's abilities during assessment or other behavioural issues. This case was rare, and the selection in almost all cases was agreed by the PE teachers (see results).

In order to facilitate recruitment and inform parents and children about the nature, importance, and content of the intervention program, parents of the selected children were invited to attend a meeting at the school with the lead coach and researcher. Separate (lunchtime) meetings were also held at the school for the selected students themselves. All invited students and their parents were handed participant information sheet sand consent forms. For recruitment of the normally coordinated group, the students were offered to bring along their friends. After that, the selected, recruited participants whose parents provided consent for their participation proceeded to the training intervention.

4.1.4 Training Intervention

Training intervention consisted of an hour long weekly training session for a total duration of 11 weeks. The location of the intervention depended on whether or not the school had a gym facility. For W Park and CW schools, the training took place at the school gym while for C school, training took place at the CLEAR unit-Oxford Brookes University for proximity of location.

The total session lasted for 60 minutes with the inclusion of 5 min before and after the intervention for changing and washing if necessary. The training session started with 10 minutes of total body warm-up. The 40 minutes of training were then divided between cardiovascular training and a circuit of weight training (20 min each) with the practice and measurement of the stepping task (5 min) being embedded in the cardio training. The structure of the training session was based on the experience in our research group and research clinic CLEAR unit in which we regularly run training sessions for children with coordination problems. The training was documented using training diaries. At the start of each training session, the participants were handed their training diaries and they kept it during the whole duration of the training session. They used the diaries to record, together with their coaches, the parameters of their training on each of the exercises (exercise type, intensity repetition and weight used) for monitoring and progression of training.

4.1.4.1 Cardiovascular training

Table [6] provides detailed description of each of the training exercises. Students had the choice of spending the 20 minutes of cardiovascular training either on the treadmill, the cross trainer, the stationary bicycle or the rowing machine or any combination of the four. The distance, duration, average RPE and heart rate were recorded for every cardio training session. Participants were encouraged to get to and stay in a heart rate zone that is at least 60% of their maximum heart rate. This is the safe zone of training which also corresponds to moderate to vigorous activity level i.e. the level required for improving fitness (American College of Sports Medicine 2013)

4.1.4.2 Strength training

Students performed three repetitions of a full circuit of weight training including; leg press, leg extension, kettle bell swings, two arm pull-down, bench press, and arm abduction with dumbbells Table [6]. Participants spent two minutes on each station. The baseline intensity of training depends on the individual abilities of the student. The intensity and repetition was gradually increased over the course of training sessions, in a rate that that is fixed for all participants, and recorded in the training diary. The number of repetitions and the intensity (weight) were recorded.

Training Element		Description
Cardiovascular training (20-25 min)	Cycling	Pedalling on a cycle ergometer (try to maintain 60 rpm or higher)
	Treadmill	Jogging/running on a treadmill starting at 3.5 km/h with speed increasing throughout warm-up block. Incline was added if desired
	Cross-trainer	Non-impact cardiovascular workout varied from light to high- intensity based on the speed chosen and the resistance selected. The participant could either use the upper body handles to move the arms or place their hands on the lower handles.
Muscle strengthening (25-30 min) **2 min each station then rotate**	Leg Press	The participant was seated on a leg press machine with feet propped up shoulder-width apart and at approximately 90° angle. A trained instructor increased amount of weight starting from 25kg and onwards depending on how comfortable the participant is and increase volume and repetitions accordingly. When possible, exercise intensity was adjusted to meet 65-90% heart rate max (HRmax).
	Leg Extensor	The leg extensor machine was used to improve strength of the quadriceps muscles. Participants were asked to slide their feet behind the pad (feet pointed forward) and when instructed, to push and kick upward extending legs to maximum exhale while using the quadriceps muscles then slowly lower the weight back to its original position.
	Arm Pull-downs	This station consisted of the participant standing either shoulder-width apart or with the right or left foot in front. Then the participant was instructed to hold the pull-down handles and pull while tightening their core until their hands reach their hips. The volume increased from 4.25 kg and upwards.
	Dumbbells	The dumbbells started with 2 kg and 5 kg weights and were used to perform sets of side arm raises, standing bicep curls, upright row and straight up into the air alternating sides. In addition, dumbbells were incorporated into bench press exercises when a bar was unavailable.

	Kettle Bells	Participants used a kettle bell for this exercise, which varied from 3 kg to 10kg (increased gradually) and standing with feet shoulder-width apart with arms straight holding the kettle bell. From there, they were instructed to use their hips and perform a thrust motion while swinging the kettle bell up and back down into a squat position. The bend of the legs during the squats help propel the body for the next motion. For some sessions, sit-to-stand exercises could also be done using the kettle bell with the participant sitting on the edge of a bench holding the kettle big and standing up then sitting down in a slow, controlled manner.
Cool-down (5-10 min)	Group Circle	In the last part of the session, the participants had a group cool-down consisting of core exercises, squats, lunges and stretches

Table 6 Description of EPIC exercise elements

4.1.5 Stepping training

The stepping task was designed to investigate the motor skill acquisition in children with poor coordination. It is an implicit procedural learning task which was inspired by the popular Serial Reaction Time task (SRT) which has been repeatedly used for study of motor learning in this group (Wilson, Maruff et al. 2003; Gheysen, Van Waelvelde et al. 2011; Bo and Lee 2013; Lejeune, Catale et al. 2013). This task has been modified to allow the learning to involve lower limb, multiple joint and inter-limb coordination, trunk control, and balance. The modification also included making the movement pattern easy (2,3, or 4 items per pattern in comparison to 10 items in the classic SRT task, so that there is little cognitive load (Lejeune, Catale et al. 2013).

The training of different patterns was introduced to increase the variability of practice which is known to improve motor learning (Schmidt and Lee 2013). In order to decide on the frequency of the stepping pattern, we ran a pilot study in which a group of children with coordination problems were asked to step according to a metronome beat with increasing frequency. The frequency of stepping used here was that which the participants described as comfortable and natural speed. Objectively, this frequency kept the Heart Rate (HR) below 60% of HRmax (American-College-of-Sports-Medicine 2013). Please note that a higher stepping frequency would have required higher cardiovascular loading, which would have been a confounder to the skill acquisition/ motor learning findings as would be complicated with fitness changes. Augmented Feedback and knowledge of performance were also provided, verbally, by the researcher to optimise motor learning (Schmidt and Lee 2013).

The rhythmic stepping task was set as an independent station in the training session. During the performance of the cardio task, participants were called one by one to perform the stepping task before the circuit of weight training had commenced. The task is a simple stepping pattern induced by rhythmic appearance of visual stimuli on a computer screen placed in front of the participants. In training sessions with more than 10 participants, two researchers ran two stepping stations simultaneously to ensure testing all of the attending participants; especially that it took an extra 5 minutes to prepare the participants and the apparatus for performance with a total duration of ~10 min/ person.

4.1.5.1 The stepping task

Participants were asked to step in response to the appearance of a visual stimulus (star) on a computer screen placed in front of them. The stimuli appeared either on the right or the left side of the screen indicating the side to which the participants should step. The stars which indicated right side steps were presented with a red background whereas the left side steps stimuli had a blue background to help reduce the cognitive effort of the task (Lejeune, Catale et al. 2013).

Repeated sequences of 2, 3 or 4 stimuli created a pattern (rhythm). Alternating the order and number of stimuli which formulated the sequence allowed for creating variable patterns.

There were 4 main practiced patterns; (Right-Left), (Right-Right-Left), (Left-Left-Right), and (Right-Right-Left-Left).

Twenty five stimuli were presented per minute. This frequency was fixed for the four main practiced patterns above. Subsequently, the duration of one stepping cycle i.e.; first foot up, second foot up, second foot down, first foot down is 2.4 seconds. Each stepping sequence was made of 2, 3, or 4 stepping cycles [Figure 10].

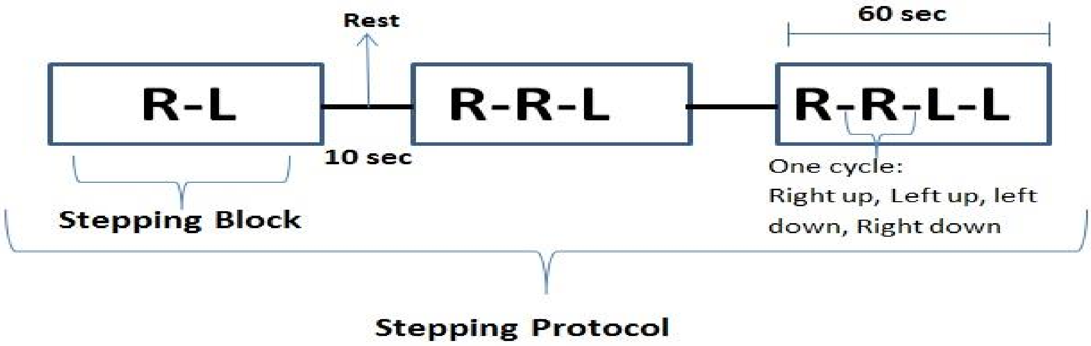


Figure 10: A stepping protocol example. The protocol is made of 3 stepping blocks; each block is made a repeating sequence of stimuli. A single stimulus represents a full stepping cycle.

The stimulus was shown on the screen for half of the duration of the stepping cycle i.e 1.2 seconds for the frequency of 25. At the end of each stepping block, the sign (WAIT) appeared on the screen and remained for the duration of the rest period (10 sec). The sign (GET READY) flashed 2 seconds before the beginning of the next stepping block. The total duration of the stepping paradigm was 4-5 minutes depending on the protocol.

4.1.5.2 The set up

An Inertial Measurement Unit (IMU) (LPMS-B Japan) was used to measure the acceleration of the centre of mass to detect correctness and pattern of movement [Figure11-a]. The IMU was placed on the centre of mass (roughly at the level of the 4th Lumbar vertebra) using anti allergic double sided body tape (Eylure, London) [Figure 11-b].

A lap top (Lenovo-ThinkPad, IBM), placed on a 1 m high table in front of the stepping board was used to project the visual stimuli. The computer was connected to the IMU via Bluetooth and a custom-made Labview program (Labview, 2014 National Instruments, UK) was used to run the stepping program, connect to, collect and save the acceleration data from the IMU.

.

Figure 11: A-The Inertial Measurement Unit (IMU) used to measure acceleration of movement. B- IMU was placed on the lower back roughly at the level of centre of mass

A stepping board (MiraFit 108cm, Norfolk UK) was placed in front of the participants and used as the platform on which participants stepped up and down. The middle of the stepping board was marked using white tape to create two sides; right and left. Two riser blocks were placed under each side of the stepping block to raise it to the height of 21cm [Figure 12]. This height ensured a good quality of the stepping signal while not posing a cardiovascular burden on the participants as the task was not intended to train fitness

Figure 12: The set up. A-The stepping board is placed in front of the participant and divided into two sides using white tape B-appearance of the stimuli on the computer screen placed in front of the participants' signals the start and the side of the movement.

4.1.5.3 Instructions

On their first visit, participants were introduced to the task and given clear instructions on how to perform it. To further facilitate their understanding of task requirement, the researcher performed the task in front of them. Then, they trial practiced the task for 30 seconds without data recording and invited to ask questions. When the participants were ready, the IMU was placed on their back and the stepping program was run with accelerometer data being recorded.

When the stimulus appeared on the right side of the screen, participants were instructed to start the movement with their right foot first, raising it to step on the right side of the stepping board, then lift their left foot off the floor, tab with it on the same side of the board and finally return to the starting point on the floor with the left foot first.

Participants were asked to respond to the stimulus as quickly and as accurately as possible and to return to the starting point on the floor after every step (a step is a full cycle: up-up-down-down). They were also asked to try not to step before the next stimulus appears and to avoid jumping.

4.1.5.4 Stepping Protocols

On each of the 12 training sessions, participants practiced a different protocol. Each stepping protocol consisted of 3-4 stepping blocks (1-1.5 minutes each) alternated with 10 seconds of rest where the participant stood still. Each stepping block is made of one pattern and so the single protocol was made of 3-4 different patterns.

Four main patterns were practiced regularly over the whole training period; (Right-Left), (Right-Right-Left), (Left-Left-Right), and (Right-Right-Left-Left). The patterns were (fixed randomly) alternated over the whole training period to induce variability of practice and avoid boredom. Some of the protocols had a novel pattern, which was practiced only once. This would allow for testing the transferability of the learned skill. These novel blocks were created by changing the stimulus sequence (pattern) and/or the frequency (speed). The two other frequencies used for the novel patterns were 30 and 40 stimuli per minute Table 77.

Participants always performed the protocols in order of attendance. So protocol number 1 was performed on the first session (for the participant), and whenever participants missed a session, they carried on from where they stopped.

	Protocol1	Protocol2	Protocol3	Protocol4	Protocol5	Protocol6
Block1	Pattern 1	Pattern 1	pattern 3	Novel Pattern	Novel Pattern	Pattern 1
Block2	Pattern 2	Pattern 2	Pattern 2	Pattern 1	Pattern 1	Novel Pattern
Block3	pattern 3	pattern 3	Novel Pattern	pattern 3	Pattern 2	Pattern 2
Block4		pattern 4		pattern 4		pattern 3

Table 7: The distribution of different stepping patterns over the first 6 sessions (protocols)

4.1.5.5 Visual inspection and augmented feedback

During stepping, the researcher closely observed the performance of the participants and made notes of the number of faulty steps the participants had made in each stepping block as well as the overall performance and movement pattern. At the end of each block, participants were informed of the number of the mistakes that they did and reminded, if necessary) of the correct way to perform the stepping task. Participants were encouraged to stay focused and to do their best to step accurately (not too fast or too slow).

4.2 Participant grouping:

The process of grouping participants was done blindly (names and IDs hid from the researcher) to prevent bias. In order to control for the effect of fitness, participants were initially grouped according to their fitness levels as measured during screening (bleep test/VO2 max); a fit group and an unfit group. Within each homogeneous fitness group, participants were further categorised according to their performance on the coordination related skills (broad jumping, ball toss, and hopping) into four groups:

Fit participants:

> 1-Fit and coordinated: participants who scored above the 25^{th} percentile on the fitness test and scored above the 15^{th} percentile on all other motor tests.
>
> 2-Fit uncoordinated: participants who scored above the 25^{th} percentile on the fitness test but scored below the 15^{th} percentile on at least one of the coordination measures.

Unfit participants:

> 1-Unfit uncoordinated: participants who scored below the 25^{th} percentile on the fitness test and scored below the 15^{th} percentile on all or a minimum of 2 of the coordination measures.
>
> 2-Unfit and coordinated: participants who scored below the 25^{th} percentile on the fitness test but scored above the 15^{th} percentile on all the coordination tests (or a maximum of 1 test below the 15^{th} percentile).

4.3 Outcome Measures

The outcome measures are grouped into two categories, the first is concerned with the feasibility aspects of the study i.e recruitment, retention, and utility of different outcome measures reported as recommended by Thabane et al, 2010. The second category is concerned with the outcome measures of the actual performance and learning of the stepping task, the exploration of which will of course be preliminary given the feasibility nature of the study (Thabane, Ma et al. 2010)

4.3.1 Feasibility Outcomes

a- Recruitment: number of the participants who attended the intervention training out of those who were invited.
b- Retention: the extent to which participants committed to attending the training sessions calculated as the percentage of attended sessions.
c- Data: the percentage of the usable collected data out of the total number of attended sessions.
d- Utility of stepping outcome variables; i.e. accuracy, timing, rhythmic stability.

4.3.2 Task Performance and Learning:

1- Baseline performance: Number of wrong steps, movement time, and stability of stepping pattern during the first ever session.
2- Performance change over time: Within and cross group change in (number of mistakes, movement time and pattern stability) over the training period.
3- End of training performance: Number of wrong steps, movement time, and stability of stepping pattern during the last ever session performed by the participant.

4.4 Definition of Outcome Variables

Accuracy:

Number of correct steps was used as an indication of performance and was considered to be the simplest outcome variable of learning. Correct steps were those steps where the participant had responded to the stimulus in good time by stepping on the indicated side of the stepper, used the indicated foot first in good time to be able to respond to the next appearing stimulus. Consequently, faulty steps were those where the participant 1-did not perform a step (missed a step), 2- was too late to respond i.e. the next stimulus appeared before they had returned to the starting point, 3- used the wrong foot to climb the step, 4- stepped on the opposite part of the stepper (whether using the correct foot or not), 5- had not returned to the middle point before taking another step.

Timing: Adherence to stimulus:

Movement Time was the time from the appearance of the stimulus on the screen until the centre of mass was stable on the stepping board as measured by the IMU (velocity signal).

***Rhythmic Stability:**

The stability of the rhythm would be expressed using the standard deviation of movement time within the single block and over the training sessions.

4.5 Data Analysis

4.5.1 Screening Data Analysis

A custom-made Lab-view program was built in order to analyse the stepping data obtained from the IMU. The raw IMU signal was obtained from the data collection program and fed to the analysis program together with the protocol data which gives the details of the time stamps of each given stimulus. The analysis program both pre-processes the measured IMU data (as described in section 3.3.1) and measures the outcome parameters. The software was designed to detect movement events, stepping direction, and mark incorrect and missed steps.

a- Movement Time Calculation

Based on the previously described validation study, movement time was defined as: "the time span from the appearance of the visual stimulus until the occurrence of the time that the CoM is stable on the step marked by a prominent velocity peak". The analysis program calculated the movement time for each performed step.

b- Step Direction

Step direction was calculated using the gyroscope data (roll X). Whenever roll X from the gyroscope was >0 at the same point of the velocity peak, the step direction was marked as: "right". When, on the other hand, the roll X was <0, the step direction was marked as "left". The analysis program compared the originally indicated step direction with the actual performed step direction and marked the incorrect steps [Figure 13].

c- Step exclusion: missed steps

For detection of missed steps, the program calculated an average amplitude (n) velocity peaks in the data series where n= number of steps as dictated by the protocol. When the amplitude of the velocity peak fell outside a range of two standard deviations from this calculated average, the step was considered to have been missed. All the "non-performed" steps during the rest period were excluded.

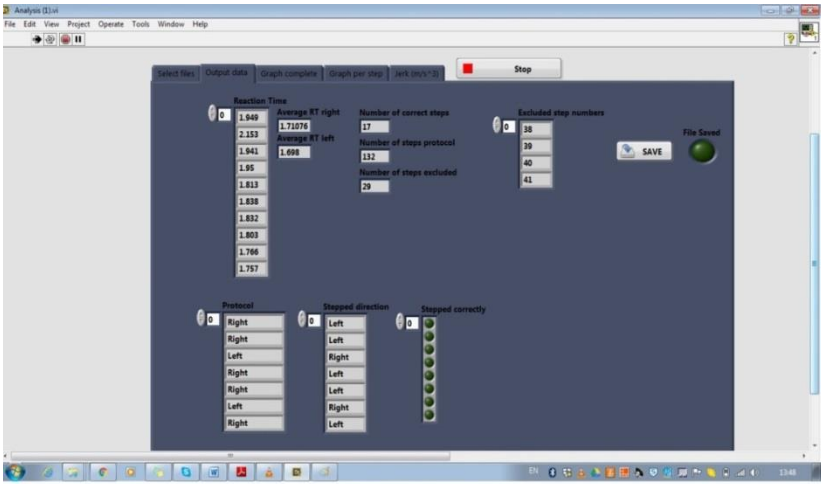


Figure 13: The IMU analysis software interface

The output of the analysis program presented the data as continuous series of numbers without separating the output for the individual pattern types. But in order to account for the potential difference between the difficulty of these stepping patterns, data had to be analysed in a block-wise fashion.

The analysed data was taken into excel, where it was, manually, separated to yield independent results per block. This was done by matching the step numbers to the original protocol (to know where each block starts/stops). This analysis also allowed for counting the number of missed steps with the exclusion of the resting period.

The initial analysis of the IMU data yielded the following information (for each participant per session):

1- Movement time: average of movement time per block.
2-Rhythm stability: standard deviation of movement time per block.
2-Correctness: number of steps done in the direction indicated by the stimulus.
4- Number of missed steps.

Please note, that the first step of each block was excluded from the analysis as it was missed by most participants even those who later performed well on the task.

For this initial analysis, the wrong steps were excluded from the calculation of the average movement time and standard deviation. This was done to avoid affecting the data with these reaction times that resulted from doing incorrect steps.

The data for each participant was then put together, and ordered based on the type of the stepping pattern and the chronological performance of each repetition of the main 4 practiced patterns. The novel patterns were excluded from this analysis as they had different frequency. Statistical analysis was first run using this data set.

A second analysis was done where the movement time of the incorrect steps was also included in the calculation of the average movement time and variability. This way, participants were "taxed" for their mistakes and so the resulting average movement time became more representative of their general performance. Results from analysis on both data sets (correct only steps and taxed movement) time proved to be very similar[1]. Here we show results of analysis on the taxed data set for the reader's convenience.

4.5.2 Scatter plots and outlier detection

Before running the statistical analysis, scatter plots were visually inspected and outliers were detected. To prevent these outliers from affecting the results, data was tested for outliers (each group separately) by way of running outlier detection tests in SPSS using "explore" function, which marks the highest and the lowest 5 points in the data set and calculates percentiles. Whenever a data point seemed to be an outlier, it was further tested using this formula;

$$\text{Upper limit} = Q3 + 2.2\,(Q3 - Q1)$$
$$\text{Lower limit} = Q3 - 2.2(Q3 - Q1)$$

Q1 and Q3 are the first and third quartiles, respectively (Hoaglin, Iglewicz et al. 1986)

If the point was outside the range between the upper and the lower limits, it was marked as an outlier. When the participant had his/her average performance as well as most of the individual points outside this range, the participant was excluded.

A total of (4) participants were excluded from the analysis based on this method, 2 from the fit and coordinated group and one from the unfit and uncoordinated group, 1 from the fit and uncoordinated. In addition, participants who attended only one session were excluded from the repeated measures analysis (n=2).

4.5.3 Statistical Analysis of stepping data

Stepping data was copied to SPSS (IBM SPSS Statistics 23) for further statistical analysis. Mixed model analysis was used to test the outcome measures in this study, because it allows

[1] Possible explanations are; 1- averages were based on a large number of data points so that when a couple of data points are excluded it does not affect the total average; 2- it is probable that wrong step itself is not the one with too long or short time, but the following step which would have been included in the calculation anyway 3- most participants didn't make many mistakes 4- mistakes did not always cause instability of the pattern, especially when participants had learned the pattern.

for multiple levels of repeated measures and addresses the shortcomings of the classic repeated measures ANOVA with regards to missing data and multi collinearity (Field 2013).The linear mixed model was set with two repeated variables; 1- Block type (pattern), with 4 levels each representing a practiced pattern 2- Repetition (with 6 levels each representing the repetition number of each individual pattern). The covariance structure used on the repeated measures was first order autoregressive (AR (1)). This covariance matrix describes a certain natural time-varying process in which the output variable depends linearly on its own previous values and on an imperfectly predictable term.

The contribution of the fixed effects; group, repetition, block type and their interaction was obtained using the Restricted Maximum Likelihood method (REML)[2]. When the statistics were applied, the p-values were taken from a type III ANOVA test. For post-hoc analysis on the mixed effect models, pairwise comparisons were performed using the Sidak method for p-value adjustments.

For most participants, the total number of repetitions for each practiced pattern was (5). For this reason, the number of repetitions which were included in the analysis model was limited to five. This was done in order to include the maximum number of available data points into our model, which would improve the model fit, while at the same time avoid using data which is estimated based on a very small number of data points (which would be the case if we included 7 or 8 repetitions/pattern).

[2] REML is used as a method for fitting linear mixed models. In the process of estimating variance components, the original data set is replaced by a set of contrasts calculated from the data. The likelihood function is calculated from the probability distribution of these contrasts, according to the model for the complete data set. REML can produce unbiased estimates of variance and covariance parameters.

4.6 Results

4.6.1 Feasibility Results

[8] displays the characteristics of the schools which took part in the study and Figure 14] is a flow chart which shows the number of students who participated in the different stages of the trial.

Characteristic/ School	C	CW	W	National Average
Number of pupils	1404	1890	1017	
GCSE performance[3]	43%	71%	58%	53%
Free school meal	14%	8%	12.90%	13.64
First language not English	32%	23%	7%	13%

Table 8: Characteristics of Participating Schools

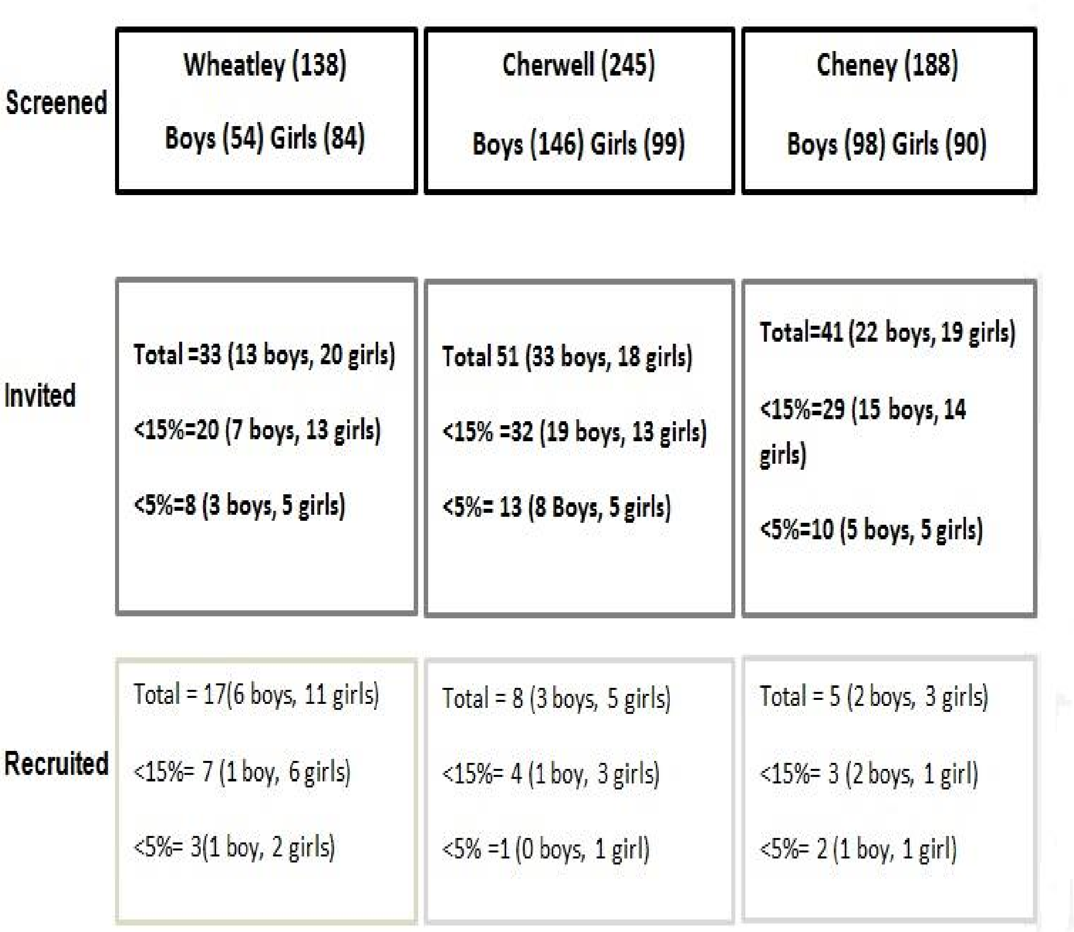


Figure 14: Recruitment Flow chart

[3] A*-C in 5 subjects including English and Mathematics.

4.6.1.1 Screening Results

The total number of students screened across the three participating schools was 571 (273 females height mean ±S.D= (161.7±7.4), weight = (55.4±9.4) and 298 males height (165.8±9.4), weight= (55.4±12.1) over 12 screening sessions.

Table 9[9] shows the overall screening results of all participants.

We invited a total of 117 (20.5%) children to take part in the study (53 females and 64 males). All of the invited children scored below the cut off of the 25th percentile. Eighty one (69%) of the invited students (40 females and 41 males) scored below the 15th percentile on our short screening test while 31 (26%) of the invited students scored below the 5th percentile (15 girls and 16 boys).

Test Item	Females					Males				
	N	Mean	Std. Deviation	Minimum	Maximum	N	Mean	Std. Deviation	Minimum	Maximum
Bleep test-Level	269	4.9	1.8	2.00	11.40	290	6.8	2.5	2.0	13.3
Hand grip (kg)	272	26.3	5.1	8	40	285	29.8	7.1	15	55
Ball toss	262	17	7.4	0	38	289	23.6	8.0	0	44
Broad jump (m)	268	1.5	0.2	0.8	2.3	284	1.7	0.3	1	3
Hopping	267	45	11.0	16	80	278	52	13	28	84
Copying star	267	4.8	0.9	0	5	296	4.7	1.0	0	5

Table 9: Descriptive Statistics of all participants who took part in screening

Figure 15] describes the distribution of the screening data, running the statistical tests of normality, all screening tests showed a significant Shapiro-Wilk test results at significance level *p*<.05. However, this might be the result of the large sample size (Field 2013).

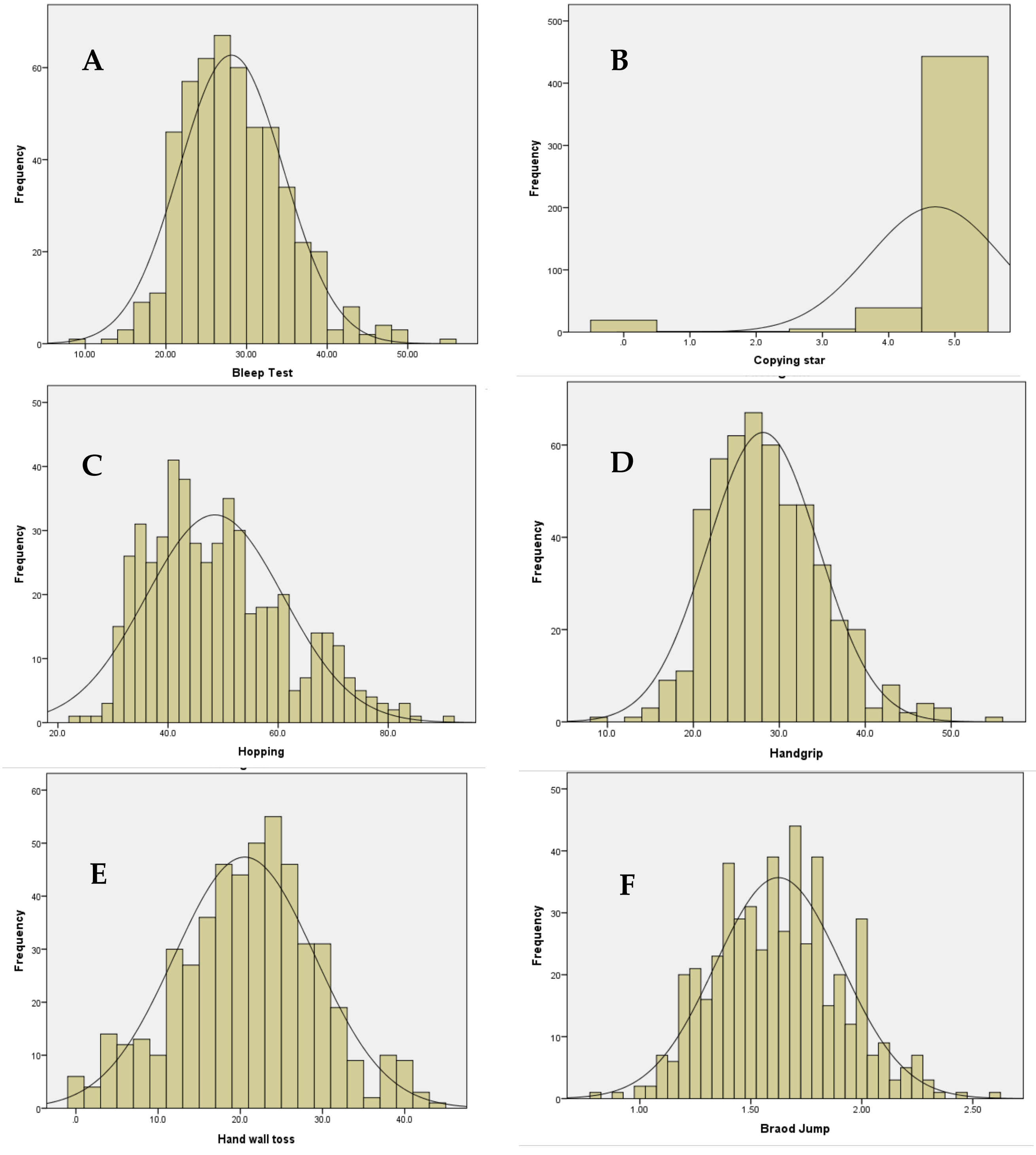


Figure 15: Distribution of screening results with a normal curve a-Bleep Test, b-Copying Star, c-Hopping, d-Hand grip, e-Hand wall toss, f-Broad Jump

4.6.1.2 Participation in training

The total number of children who took part in the intervention study was 33 (21 girls and 12 boys) which is 26 % of the total invited students. To be considered for this analysis, participants need to have attended at least one training session. This is not criteria for analysing the intervention results. However, in this analysis we wished to know which students are more likely to respond to the initial invitation. The number of recruited students was unequally distributed across the participating schools (C School n=5, CW School =8, W School =20).

Looking at the total score of the motor test, 24 of the recruited students scored at or below the 25th percentile (16 girls and 8 boys) 14 of them (10 girls and 4 boys) scored below the 15th percentile while 6 scored at or below the 5th percentile (4 girls and 2 boys). There was one student who took part in the training intervention but was absent at the time of screening and so we had no measure of her motor abilities. In total, 17.3% of the invited students who scored below the 15th percentile and 19.4 % of those invited who scored below the 5th percentile have attended the training intervention. Individual scores of motor tests for recruited participants and their percentiles could be found in Appendix [5]. Table [10] provides group based averages and standard deviations of motor test scores.

Group	N	Percentile (%)	Height (cm)	Weight (kg)	Bleep Test	VO2 max	Grip strength (kg)	Ball Toss (Rep)	Broad Jump (m)	Hopping (Rep)	Copying Star
Fit and Coordinated	10	**44.6±** (25.4)	**162.8±** (7.9)	**56.4±** (15.6)	**5.6±** (2.0)	**43.8±** (5.2)	**29.2±** (5.8)	**18.7±** (5.4)	**1.6±** 0.22	**51 ±** (15.4)	**3.8 ±** (2.2)
Fit uncoordinated	6	**26.1 ±** (13.1)	**161.8±** (5.6)	**44.5±** (20.4)	**5.4±** (1.6)	**43.2±** (4.2)	**25.8±** (6.6)	**18.2±** (13.3)	**1.55±** 0.28	**37.8 ±** (12.4)	**4.0±** (2.0)
Unfit and coordinated	5	**20.5 ±** (4.2)	**158.7±** (6.4)	**54.1±** (6.7)	**3.9 ±** (0.7)	**39.4±** (2.0)	**22.6±** (2.5)	**16.2±** (8.1)	**1.61±** 0.13	**42.8 ±** (8.9)	**4.8±** (0.45)
Unfit Uncoordinated	11	**6.4 ±** (6.1)	**161.3±** (6.5)	**69.8±** (18.3)	**2.9±** (0.6)	**36.6±** (1.5)	**23.5±** (2.9)	**5.5±** (4.5)	**1.17±** 0.14	**38.5 ±** (5.1)	**4.1±** (2.0)
Total	32[4]	**23.6 ±** (21.4)	**161.5±** (6.6)	**58.5 ±** (18.5)	**4.3±** (1.8)	**40.4±** (4.6)	**25.4 ±** (5.2)	**13.5±** (9.5)	**1.4 ±** 0.28	**42.7**	4.1

Table 10: Descriptive statistics of the participating groups

[4] One participant we have no data of her motor skills during screening

4.6.1.3 Retention (Attendance)

Attendance data was obtained from the training diaries.

Average attendance for W= 8.7 sessions (79%) of the total number of sessions n=11

Average attendance for CW = 5.33 sessions (59%) of the total number of sessions n=9

Average attendance for C =3.8 sessions (34.5 %) of the total number of sessions n=11

Please note that for C schools, one participant had attended all the training sessions while the remaining participants attended between1-3 sessions. Moreover, for CW School, the stepping training intervention was stopped due to school term holiday before the completion of the 11 week intervention and a delay in start.

4.6.1.4 Stepping Data attainment

The percentage of the successful recordings of IMU stepping data in comparison to the number of sessions attended per participant was calculated and the resulting average of all these ratios for all participants is 80%. This means that sometimes the participants came and we did not test them, or we did test them and the data was not usable.

4.6.2 Stepping Training Results

After excluding the participants who attended only one session and those whose performance was an outlier in their respective groups, 26 participants were included into the statistical analysis of the stepping task performance and change; Fit and Coordinated =7 (5 females and 2 males), Fit Uncoordinated (3 females and 2 males), Unfit and Coordinated =5 (2 females and 3 males), and Unfit Uncoordinated =9 (7 females and 2 males).

4.6.2.1 Baseline performance:

Table 11[11] shows the averages and standard deviations of performance parameters of the four groups during the first session.

Group	Movement Time [sec ±SD]	Variability	Wrong Steps	Missed Steps
Fit & coordinated (n=7)	1.036± [0.11]	0.225± [0.12]	28± [3.8]	0.46± [1.1]
Fit uncoordinated (n=5)	1.151± [0.17]	0.248± [0.15]	20± [1.9]	0.55± [0.89]
Unfit &coordinated (n=5)	0.985± [0.14]	0.228± [0.11]	18± [1.7]	0.35± [0.59]
Unfit uncoordinated (n=9)	1.206± [0.15]	0.246± [0.11]	36± [4.2]	0.57± [1.23]

Table 11: First session performance of the outcome measure expressed in group means (for all block types) and standard deviation [between brackets]

First session cross group comparison was investigated by way of running a simple linear mixed model analysis with "group" as the sole fixed factor. Four different analyses were run to test the effect of group on each of the outcome measures.

A- Movement time

Movement time during the first session was significantly different between the groups: (F (3, 28.2) =6.97, p<.001) as taken from type III test of fixed effects. Further, pair wise comparison analysis with Sidak corrections revealed that the unfit and uncoordinated group was significantly different to both fit and coordinated *p*= .012 as well as the unfit and coordinated *p*=.003. No other comparisons were significant.

B-Variability of movement time (Standard Deviation):

Average variability for each participating group is shown in Table 11]. Although both uncoordinated groups seem to have higher means of variability, it is found to be statistically insignificant. Type III tests of fixed effects revealed no significant effect of group on variability of movement time (F (3, 42) =0.36, p=0.79).

C- Error:

Type III test of fixed effects revealed no significant effect of group on the number of wrong steps during the first session (F (3, 33) =0.66, p=0.58). Figure 16] illustrates the distribution of wrong steps across the participating groups during the first session.

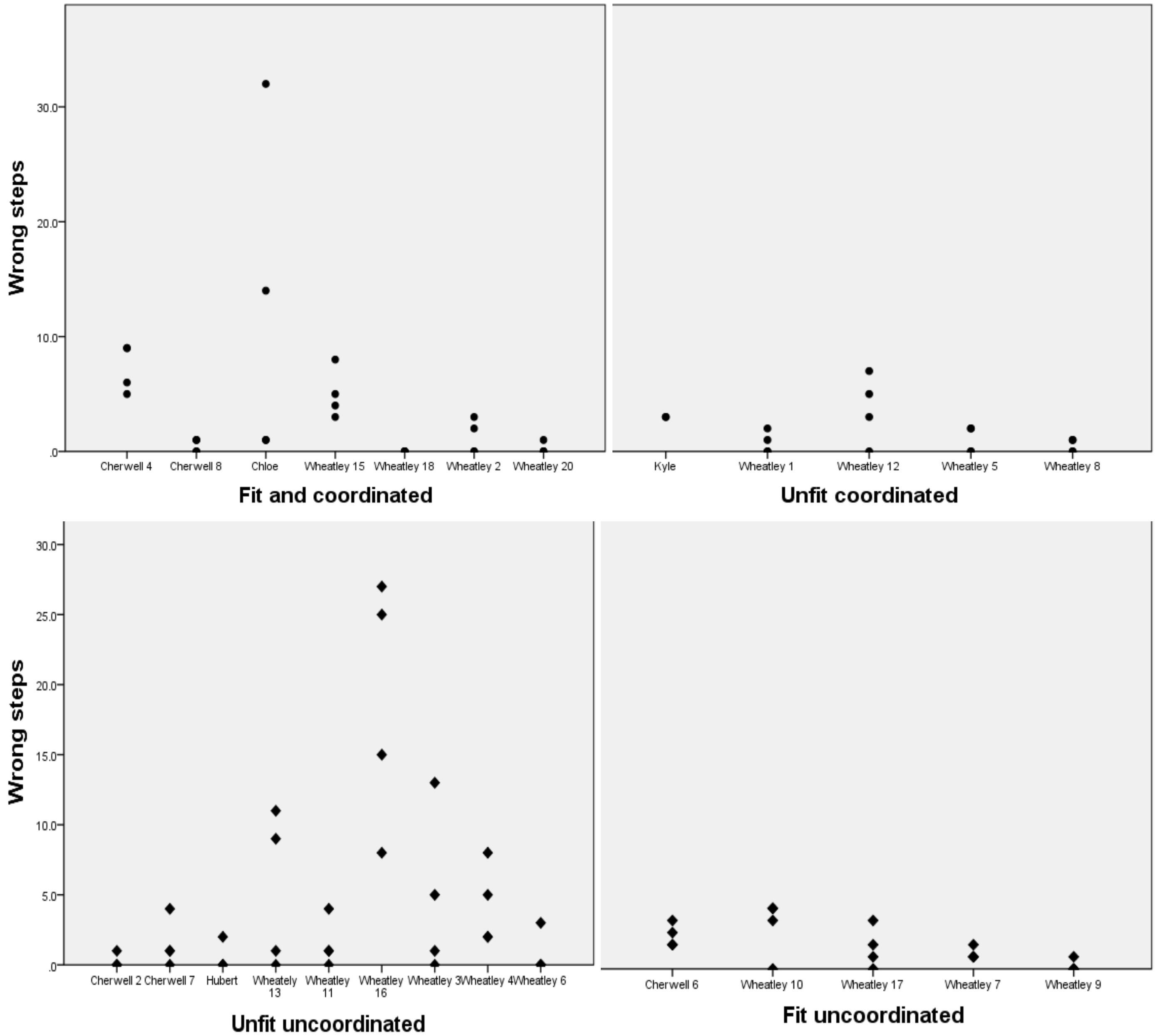


Figure 16 Number of wrong steps during the first session across groups

4.6.2.2 Skill Learning

Table Table 12[12] shows the detailed mean and standard error of the estimated marginal means for the performance of the different groups over the 5 first training sessions. Please note that these means are calculated from different models. They are presented in one table for convenience.

Group	Repetition	**Movement Time**	Std. Error	**Variability**	Std. Error	**Wrong Steps**	Std. Error
Fit & coordinated	1.0	1.039	.040	.212	.025	3.655	1.304
	2.0	.973	.041	.196	.025	3.305	1.324
	3.0	.954	.044	.194	.026	3.322	1.398
	4.0	.916	.054	.181	.027	1.530	1.502
	5.0	.974[b]	.071	.178	.029	.624	1.851
Fit uncoordinated	1.0	1.159	.048	.251	.028	1.852	1.542
	2.0	1.006	.048	.236	.029	1.008	1.541
	3.0	.978	.050	.233	.029	2.466	1.591
	4.0	.882	.060	.220	.030	2.480	1.733
	5.0	.916[b]	.059	.218	.031	.716	1.832
Unfit &coordinated	1.0	.985	.049	.245	.030	1.642	1.576
	2.0	.946	.050	.229	.030	2.816	1.610
	3.0	.886	.055	.227	.030	2.967	1.722
	4.0	.894	.069	.214	.032	4.416	2.023
	5.0	.979[b]	.095	.212	.033	2.896	2.364
Unfit uncoordinated	1.0	1.193	.036	.248	.022	4.141	1.150
	2.0	1.130	.037	.232	.023	3.225	1.172
	3.0	1.100	.038	.230	.023	4.002	1.219
	4.0	1.073	.043	.217	.024	1.033	1.296
	5.0	1.012	.050	.215	.026	1.815	1.344

Table 12: Estimated Marginal Means and standard error of movement time, variability of movement time, and number of wrong steps for each of the groups b: calculated using population means

4.6.2.2.1 Movement time

Multiple linear mixed models were created to test the effect of group, repetition and block type as well as their interaction on the movement time. The first model was the simplest model with a total of (13 parameters), 26 subjects and 3 main fixed effects; Group (4 levels), Repetition (5 levels) and Block type (4 levels) with no interaction effect. This model had two levels of repeated effects: the first is the repetition variable (i.e. session number) and the block type, because within each repetition level different patterns were repeated (practiced).

Running the analysis on this model showed a significant effect for Group ($F (3, 74.5) =13.4$ $P<0.001$) Repetition ($F (4, 187) = 7.9$ p $P<0.001$) and Block type ($F (3, 256) =6.1$ $P<0.001$) on movement time. More complicated models were created gradually by adding one level of complication at a time to test the effect of possible interactions on the fit of the model.

For convenience of the reader, only the final model will be described here. Table [13] shows the dimensions of the final model. In this model, only main fixed effects are included with no interactions. In order to account for the variability of the subjects within groups, a random variable (ID) was added to the model. In this case, SPSS calculated a different intercept for each participating individual. This addition had greatly increased the fit of the model. Including the random factor (ID) helps in quantifying the amount of the total variability explained by differences between the individuals within each group. This variable is not of direct interest to the study but variability due to this difference needs to be accounted for**.**

		Levels	Covariance Structure	Parameters	Subject Variables	Subjects
Fixed Effects	Intercept	1		1		
	Group	4		3		
	Repetition	5		4		
	Block type	4		3		
Random Effects	Intercept	1	Identity	1	ID	
Repeated Effects	Block type * Repetition	20	First-Order Autoregressive	2	ID	26
Total		35		14		

Table 13: Final model dimension- Movement Time

The results of the main effects are shown in table [14]. All three fixed effects had a significant effect on the movement time and would be described independently.

Variable	Numerator df	Denominator df	F	Sig.
Group	3	25.6	5.2	.006
Repetition	4	293.1	21.7	<.001
Block type	3	140.9	3.9	.010

Table 14: Type III Tests of Fixed Effects: Movement Time (df): degrees of freedom.

A-Groups

Type III test of fixed effect showed a significant effect of group on movement time [Figure 17]. Means and standard error of movement time across the four groups are found in table [11]

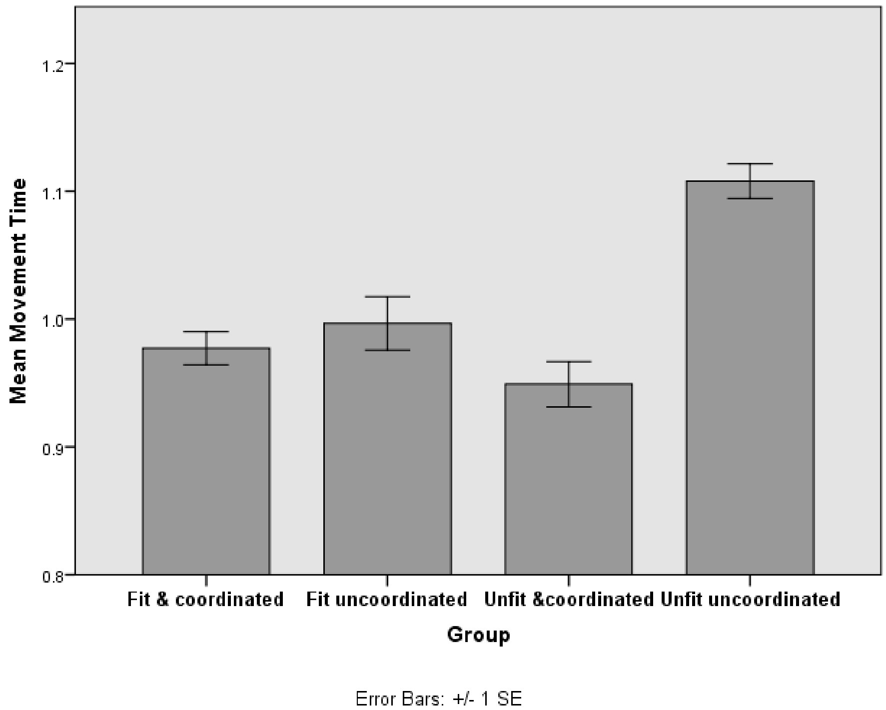


Figure 17: Mean movement time across groups according to the chosen model. The error bars are standard error

In the post hoc analysis with Sidak corrections, the unfit and uncoordinated group mean±SE= (1.089±.030) was significantly different to both fit and coordinated (.955±.034), p=0.038 and Unfit and coordinated (.91 ±.041) p=.009 but not to the fit and uncoordinated group (.993±.04). The pairwise comparison did not show any other significant interactions.

B-Repetition

Type III test of fixed effect showed a significant effect of repetition on movement time. Figure 18] shows the average movement time over the intervention training sessions for all groups. In this model, there is a gradual decrease of movement time over the training period with a significant change taking place after the first session and a gain between the second and the fourth. Movement time also seems to stabilise after the fourth session. For further details on the change of movement time, pair-wise comparison results are shown in Table [15].

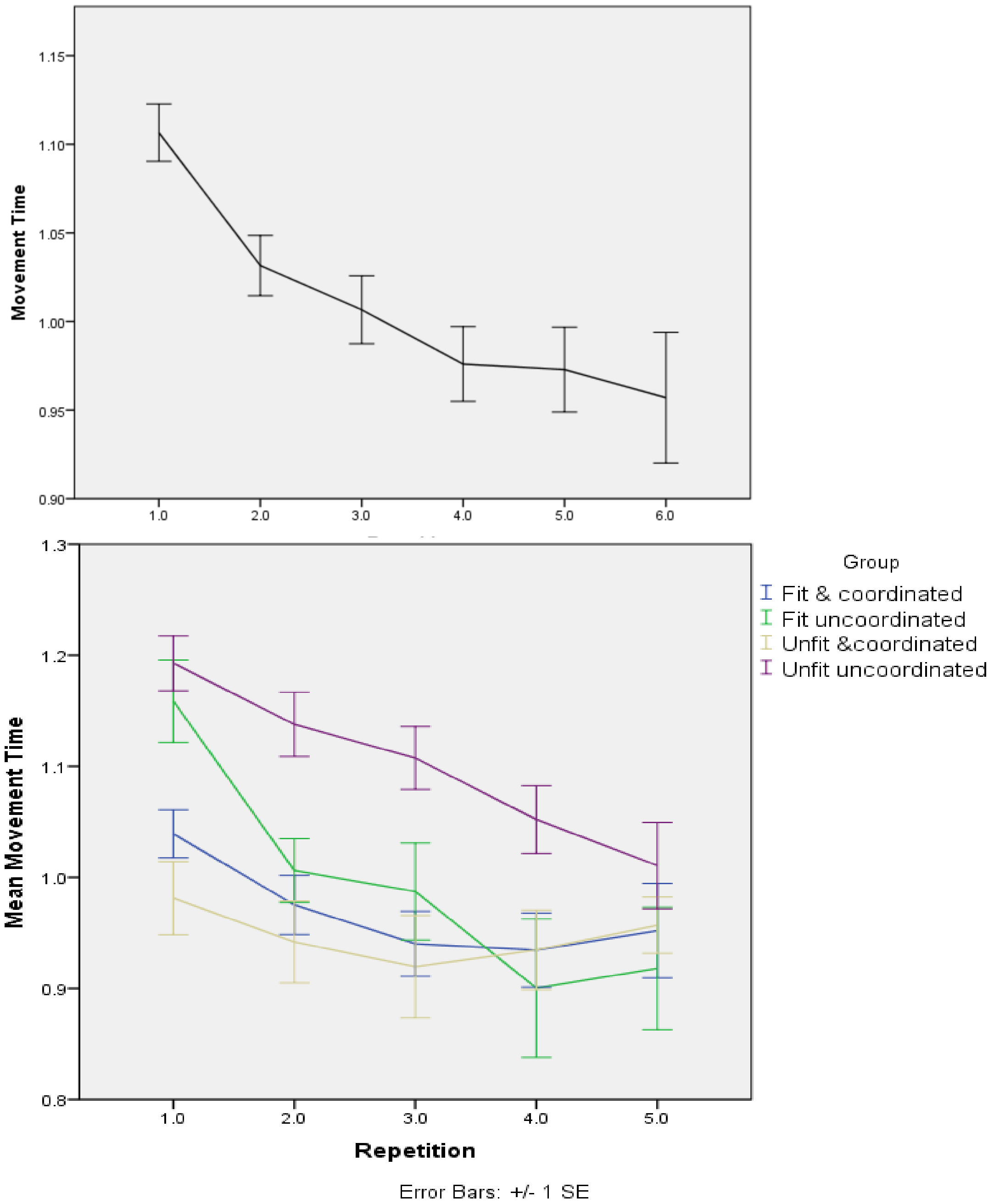


Figure 18: Change of movement time over the training period a-average all groups, b-each groups independently. Given the smaller number of data points in session 6, the means were mostly estimated which explains the large marginal error. Analysis was run with 5 sessions only

Repetition	Repetition	Mean Difference	Significance
1.0	2.0	.077*	<.001
	3.0	.115*	<.001
	4.0	.154*	<.001
	5.0	.176*	<.001
2.0	1.0	-.077*	<.001
	3.0	.038	.297
	4.0	.077*	.002
	5.0	.099*	<.001
3.0	1.0	-.115*	.000
	2.0	-.038	.297
	4.0	.040	.403
	5.0	.062	.082
4.0	1.0	-.154*	<.001
	2.0	-.077*	.002
	3.0	-.040	.403
	5.0	.022	.986
5.0	1.0	-.176*	<.001
	2.0	-.099*	<.001
	3.0	-.062	.082
	4.0	-.022	.986

Table 15: Pair-wise comparison of Movement time over the training sessions

C- Block Type

Type III test of fixed effect showed a significant effect of block type on movement time. Mean effect of block type on the movement time is displayed in Figure [19].

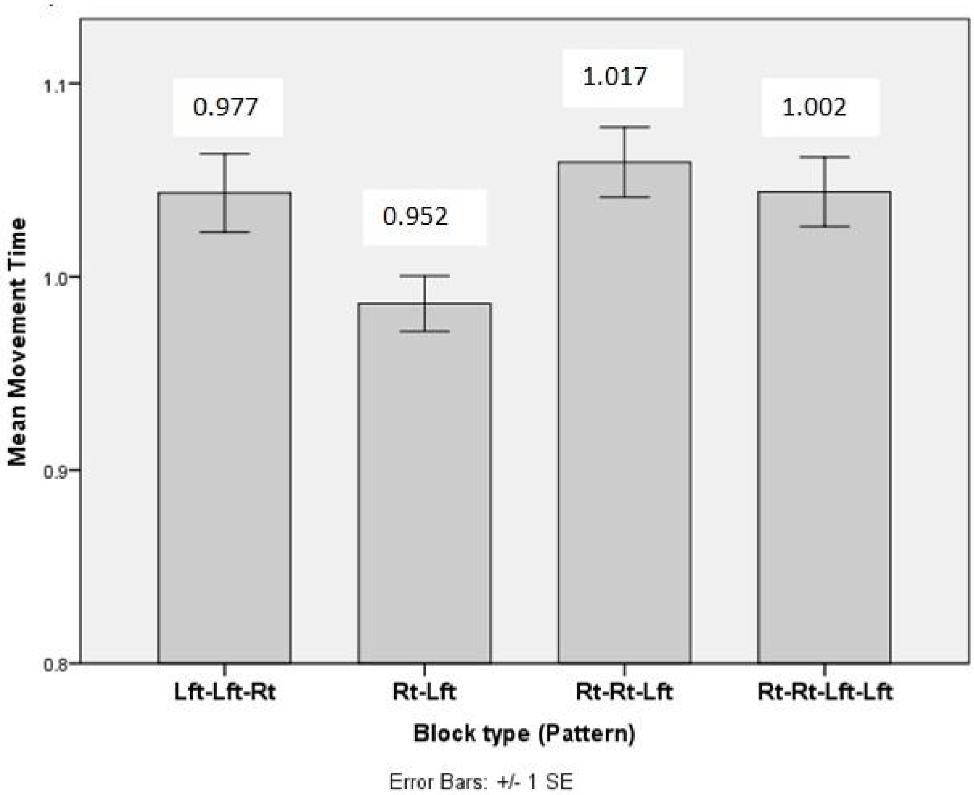


Figure 19: Mean movement time during the different stepping patterns (Mean for all groups)

When running the pot hoc analysis, it showed that the R-L block was significantly different to Rt-Rt-Lft (p <.001) and Rt-Rt-Lft-Lft (p=.022). There were no other significant pair comparisons.

D- Interactions

In order to test whether the effect of the main factors on movement time was different between the groups, interactions were added to the model one at a time. The interaction (Group*Repetition) showed a trend for significance p= .06 but didn't reach it. This is an interesting finding but statistically insignificant but may be observed in larger sample. The addition of this interaction to the model improves the fit slightly but at the cost of adding 12 parameters to the model (total=26). Given that the interaction increases the model complexity but does not reach statistical significance, this model was not explored any further.

4.6.2.2.2. Stepping Variability (Standard deviation of movement time)

In order to test the effect of the main factors (Group, repetition and block type) on the stepping variability, a simple repeated linear model was run with group, repetition, and block type set as fixed factors. No random factors or interactions were added. The effect of each of the factors will be shown independently.

A- Group

Type III test of fixed effect showed a non-significant effect of group on movement time variability (F (3, 103) =.57, p=.14). Figure [20] shows the mean values and the standard deviation of movement time variability for each of the participating groups. Please note the large standard deviation which may have caused the results to be insignificant.

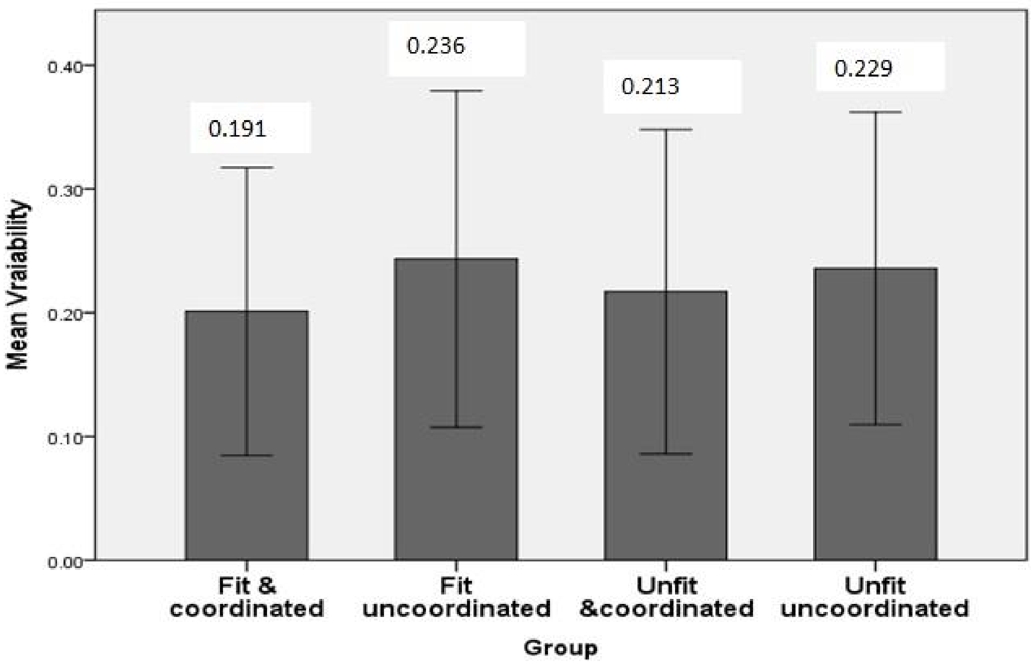


Figure 20: Mean variability of movement time across the different groups. Error bars are standard deviation

When the same model was executed on 2 groups only (the most contrasting groups; (Unfit Uncoordinated and fit and coordinated), "group" had a significant effect on variability F (1, 92.4) = 5.9, p=.016.

B- Repetition

Although looking at Figure [21], it may seem that the variability of movement time decreases over time. However, type III test of fixed effect showed a non-significant effect of repetition on movement time variability.

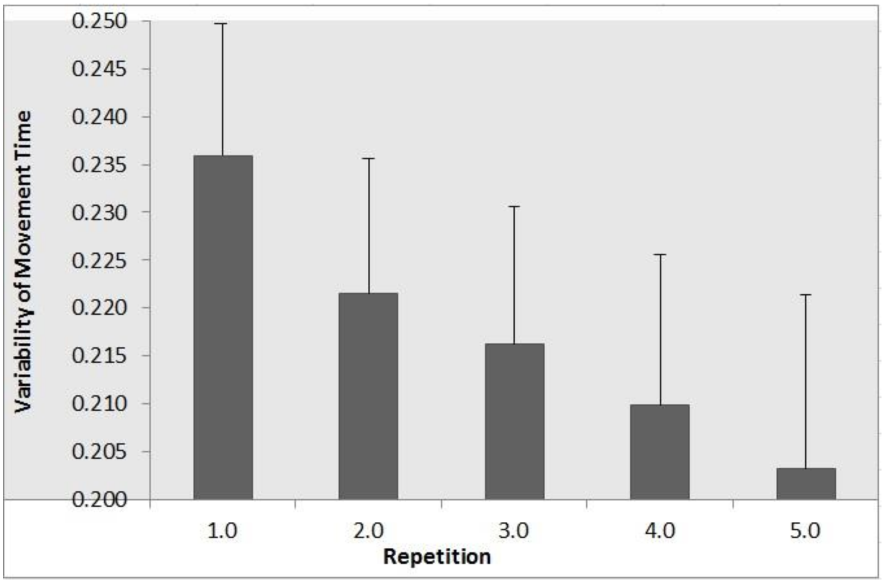


Figure 21: Change of variability of movement time across the different repetitions, Error bars are standard error

C-Block type (pattern)

Type III test of fixed effects shows that the type of pattern practiced has a significant effect on variability of movement time (F (3, 265), p=.001). In the post hoc analysis, block type LLR (mean= 0.18) induced significantly less variability than both R-R-L-L (mean=0.237, p=.015) and R-L (mean 0.245, p=.003). Other models, with the addition of a random variable or interactions, have not yielded any significant in results.

D-Number of wrong steps:

A simple repeated linear mixed model was run to test the effect of group, block type and repetition on the number of mistakes that the participants in the four different groups had done, none of the variables had any significant effect on the outcome measure. Figure 22 (a & b) show the distribution of the wrong steps over the training period for the 2 groups who made the largest number of mistakes (unfit uncoordinated and fit and coordinated).

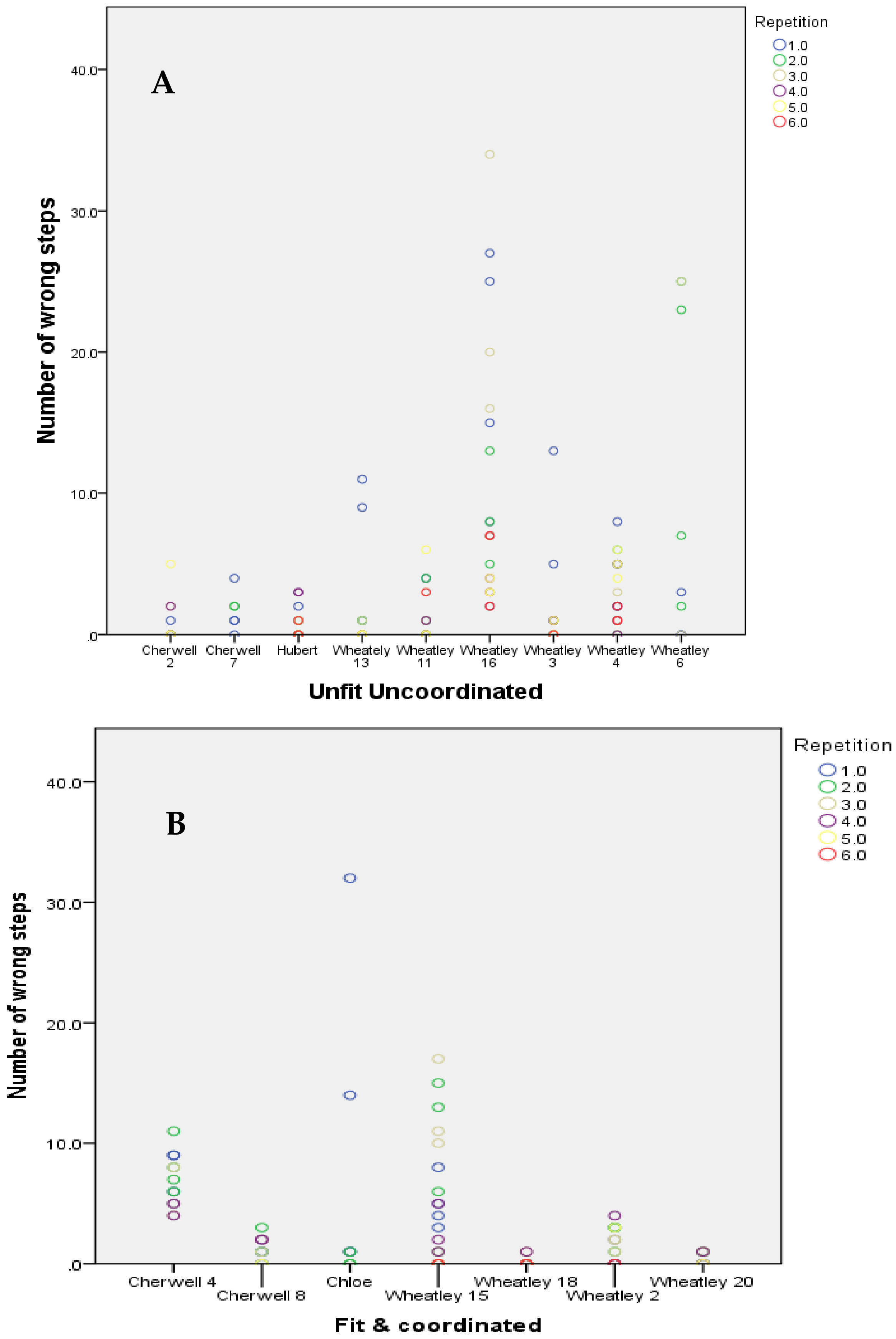


Figure 22: Number of wrong steps from both groups (unfit and uncoordinated) and (fit and coordinated) during the first session

4.6.2.3 End of intervention performance:

In order to run between-group comparison at the end of the intervention, a data set was created which included only the last repetition of each of the practiced blocks for each individual. When the last repetition was also the first, that block was excluded from the analysis. A linear mixed model analysis was set with no repeated variables, and "group" as a single fixed variable. The variable group was tested for having any effects on the main outcome measures.

A- Movement time

The analysis showed that at the end of training there was still a significant difference between groups (F (3, 69) = 3.4, p=.021).

The pot hoc analysis revealed that the significant pair comparison was between the Unfit uncoordinated and the fit uncoordinated groups p=.037. However, when another contrast was run between the two extreme groups of fitness and coordination "Unfit uncoordinated" and "fit and coordinated", there was also a significant difference between the two groups (F(1,45)= 5.13, p=.028) with the unfit and uncoordinated group maintaining a higher movement time mean=1.038 in comparison to 0.939 for the fit coordinated group.

B-Variability of movement time and number of mistakes

There was no significant effect of group on either variability of movement time or number of mistakes which is not surprising given that there was no difference in baseline performance.

Chapter (5): Discussion

This study set out to create a screening tool for detecting children with poor motor coordination from main stream school cohorts. Children who scored at the bottom quartile of their school year were invited to participate in a school-based physical training intervention which included practicing a rhythmic stepping task. We were successful in the attempt to detect, recruit and train children with poor motor coordination. The results of the study revealed a pattern of recruitment which was highly variable between participating schools with 26% of all invited students and 19.4 % of students scoring below the 5th percentile having attended the training sessions. Using the IMU enabled reliable detection of movement time, movement time variability and error during performance of the stepping task. Analysis of stepping movement time at baseline showed that children with poor coordination performed significantly worse than control children irrespective of their cardiovascular fitness level. Importantly, children with poor motor coordination were able to improve their performance on the stepping task with no significant difference in the rate of improvement in comparison to the control children.

The discussion of the findings of this study will be presented in 2 sections; the first will focus on the feasibility aspects of the and the intervention trial in line with the CONSORT outline (Eldridge, Chan et al. 2016) and the second discusses the outcomes of the intervention pilot.

5.1 Feasibility results

5.1.1 Success of the Procedure

The provided screening test proved to have face validity for detection of children with poor motor coordination. It is a very useful, easy and quick means of screening. It helped, to a large extent, in reducing the number of PE teachers and researchers needed to run the screening session as well as the time requirement for data collection and analysis, and facilitated the collection of full data sets. It is sufficient for localisation of poor motor coordination when the purpose of screening is recruitment for physical activity interventions.

The feasibility results presented us with an insight regarding the recruitment pattern; with more than 80% of the more severely affected children refusing to attend the intervention. This emphasised the importance of parent involvement in the recruitment process and highlighted the significant role that schools played, with very different rates of recruitment and retention between the different schools. The schools with higher recruitment rates also had higher retention rates, which indicated the importance of team building and the experiencing of fun during physical training.

5.1.1.1 Utility and validity of the screening tool

The screening tool described earlier was created to serve the purpose of detecting children with low motor coordination in main stream schools. It needed to be short, simple and easy to apply to large student cohorts. After applying the tool in three schools to screen a total of 571 students, it showed to be useful and practical. The screening sessions were highly organised, as described by both the participating researchers and the PE teachers, and we were able to assess the performance of all the attending students on the complete test battery with barely any data loss Table [15].

With regards to test items, both BOT-2 items; "single legged hopping" and "copying star shape", were somewhat problematic. The implementation of the single legged hopping test was difficult for the research team due to differences in speed and height children performed it with. The majority of students were jumping very fast, at the expense of the height. Still, their jumps counted correct according to BOT-2 manual. Thus, participants who jumped higher scored lower than those who jumped really fast but not high enough.

The fine motor test "copying star shape", although more discriminative than the other fine motor tests we examined earlier, had a very high ceiling effect and very little variability table [1].

Test Item	**Included**		**Excluded**	
	N	Percent	N	Percent
Bleep Test	549	97.2%	16	2.8%
Handgrip	557	98.6%	8	1.4%
Hand wall toss	550	97.3%	15	2.7%
Broad Jump	551	97.5%	14	2.5%
Hopping	545	96.5%	20	3.5%
Copying star	557	98.6%	8	1.4%

Table 16: Missing values when using the developed screening tool

The screening test could be considered to have face validity for detection of children with low coordination across the cohort, as when we cross checked the selection of the participants who scored in the lowest quartile, PE teachers confirmed the need for intervention in 93% of the total number of invited students. Teachers reports have been considered a valid detection method for poor coordination in literature (Faught, Cairney et al. 2008).

Our face-valid screening tool is useful in localising children with poor motor coordination, particularly when the aim of screening is delivering exercise intervention. On the other hand, when the purpose of screening and recruitment is investigating specific mechanisms underlying the motor dysfunction in this group, the sole use of this screening tool is bound to yield difficulty in categorising and describing participants, due to the innate heterogeneity of the group and the relatively loose cut off applied. For purposes of the main trial, and since the aim of the study is to investigate the mechanisms of motor learning, we recommend that children suspected to have poor motor coordination be further assessed using multiple standardised assessment tools and questionnaires (Linde, Netten et al. 2015). This will ensure that each assessed motor skill is evaluated across multiple tests, and protects against the possible error which could result from basing categorical judgements on individual test items. Detailed and multi-sourced description of participants gives rise to better understanding and considered to be an important condition for the generalisability of research findings (Geuze, Jongmans et al. 2001; Wilson 2005).

5.1.1.2 Recruitment

It is very important to develop an insight regarding the pattern and requirements for recruiting adolescents for physical activity interventions from mainstream schools given the governmental (Davies, Lemer et al. 2013; Brooks 2014) and international effort in favour of school-based interventions (Pate, Davis et al. 2006; Centers_for_Disease_Control 2013; Guerra, Nobre et al. 2013) which apply inclusive strategies as to reach to children from all motor abilities and socioeconomic classes. Questions like" who attends or refuses screening? "what are the characteristics of the students attending the training?" and "what keeps them coming?" are not the direct outcomes of this trial. However, the data we collected provides an insight which not only informs our main trial, but also helps guide researchers and organisations who set up similar projects.

Research on physical activity in children with coordination problems revealed that lack of participation in this group is mediated by a generalized low self-efficacy regarding physical activity (Cairney, Hay et al. 2005). When children do not perceive themselves sufficiently adequate to meet performance expectations, they develop sedentary behavioural patterns and avoid structured physical activity opportunities as a coping strategy to deal with the risk of failure and humiliation (Holloway, Beuter et al. 1988; Fitzpatrick and Watkinson 2003). With this mind, we hypothesize that children who opted out of screening were the ones who needed the intervention the most. Unfortunately, we did not collect data regarding the motor proficiency profile of students who did not take part in screening, which precludes the possibility of commenting on this subject any further. It would be very useful though to obtain this information in the future.

Out of the 53 males and 64 females who were invited to participate in the intervention training, more females (34% of invited) than males (23% of invited) responded with a very clear discrepancy in the number of participants between the different schools. C School had the worst response rate; we invited 41 students and only 5 participants attended at least one session. This could be attributed to two reasons; the first being the location of training which, for C School, took place on the premises of Oxford Brookes University, which is in a close proximity to the school (less than 10 min walk). However, when the training sessions were held within the school premises, more students were willing to attend. This means that, whenever possible, after school training should be organised to take place within the schools to avoid "convenience excuses" from becoming a barrier to participation (Nahas, Goldfine et al. 2003). Perhaps it seemed more convenient, familiar and safe to the invited children and their parents (Walia and Liepert 2012).

With regards to the higher rate of female recruitment, this could have been just a coincidence, given that in previous years we had a higher rate of males in our intervention paradigms. However, this finding could also be related to the different social weight placed on lack of "sportiness" between males and females (Garcia, Broda et al. 1995; Tergerson and King 2002). Hence, it might have been the case that females did not feel too embarrassed to participate in a program designed to improve fitness whereas males found it more psychologically challenging.

The second aspect relates to the involvement of parents. None of the parents of the invited children from C School attended the parent meetings we organised for them, which had certainly influenced the participation of their children and highlighted the importance of face to face communication and marketing of the intervention. We also felt that when the PE teachers were enthusiastic about the project and took ownership of it, students were more involved and keen on attending. Certainly, these are only observations, the objective assessment of which requires specific data collection and analysis. Nevertheless, we believe that it is important to consider these points when designing a school-based intervention trial.

It is also noteworthy, that the school with lowest GCSE grades, highest rate of free school meals (which is a measure of socioeconomic status), and highest rate of children with different ethnic backgrounds, had the lowest recruitment and retention rates. The relationship between socioeconomic status (Yang, Telama et al. 1996; Tandon, Zhou et al. 2012), ethnicity (McMurray, Harrell et al. 2000) and physical activity has already been established in literature (Powell, Slater et al. 2004) and not surprising to have influenced our results.

When evaluating the recruitment rates provided in figure [14] we can see that only 16% of the total invited children who scored below the 15th percentile and 19% of those who scored below the 5th percentile on our screening tool attended the training intervention. It is an unfortunate, yet unsurprising finding that more than 80% of the students who are particularly in need of physical activity interventions refuse them. This is in line with the literature on barriers to physical activity in this group being mediated by low self-esteem (Skinner and Piek 2001) and a generalized low self-efficacy towards physical activity participation (Piek, Baynam et al. 2006) are attributed to the internalisation of symptoms and avoidance of failure experience and social embarrassment (Cairney, Hay et al. 2005; Cairney, Rigoli et al. 2013; Kwan, Cairney et al. 2013). Given that this study is the first of its kind, no recruitment rates are available in literature for comparison.

The ratio of the total number of recruited students who scored below the 5th percentile to the total number of screened participants is 1%. Thus, when the researcher choses the recommended strict cut off of 5th percentile to describe substantial coordination problems and wishes to study motor learning in this group with school screening being the method of choice, a total of 3000 children need to be screened to recruit a group of 30 participants with substantial motor coordination difficulties. Alternatively, more recruitment effort needs to be put in place to maximise the number of recruited children from the screened group.

5.1.1.3 Retention

The retention rates for W, CW and C schools were 80, 60 and 35% respectively. Similar retention rates (78.9%) have been reported in literature (Sothern, Loftin et al. 2000). Retention rates, similar to recruitment rates largely varied between schools, which might indicate their positive correlation. It is interesting to draw the link between the recruitment of a larger group of participants and the rate of their retention. In W school for example, we recruited 20 participants and they had the highest retention rate. Although multiple other factors may have been involved in this effect including PE teachers involvement and school ethos (Brooks 2014), we cannot deny the importance of the team spirit and peer support in sports and physical activity training (MacPhail, Gorely et al. 2008) especially in this age group. Children perceived it to be more "fun" when they trained with their friends. Our control group, which we recruited by asking the invited children to bring a friend along seem to play an important role in keeping them coming (MacPhail, Gorely et al. 2008).

We also think that it is important that the participant's experience during the training sessions is a positive one. Training sessions do not only have a health benefit, but also play a social role of providing a friendly environment where students create bonds with each other and with the research team, which in itself helps to create a more positive attitude towards physical activity (Alexander and Luckman 1998; MacPhail, Kirk et al. 2004). Thus, the general atmosphere of the training session needs to be positive and encouraging with attention being payed to the music played, encouragement from the coaches and the generally relaxed atmosphere where students feel cared for but not watched.

One of the great limitations to retention, though, is school term holidays. We have observed that the students' momentum decreased after they had a long break and less number of students came back for training. To try and limit the effect of this challenge, we started the interventions as soon as the term started, and during the autumn semester because summer holidays have even a more detrimental effect on retention.

5.1.2 Validity and utility of the selection criteria- the ease of selection and categorisation of participants.

5.1.2.1 Participant Selection

Given the large size of our screened sample, the distribution of the data scores seemed relatively normal (judging from the histogram [Figure 15]) which gives us confidence in using percentile scores. For the initial selection procedure, the bottom quartile was used a loose measure of poor general coordination. Our interest in involving children with poor motor proficiency and coordination in an inclusive skill building program dictates that the cut offs used allow for a relatively wide spectrum of poor motor abilities to be involved in the intervention program. In the literature, similar cut offs had been used even in context of standardised motor assessments (BOT-2). More widely, the cut offs of the 5th or 15th percentiles are used as indicators of established and probable coordination disorder respectively (Barnett, Hill et al. 2015). However, these cut offs are usually used in contexts of diagnosing particular pathology and providing specific treatment interventions. EPIC, on the other hand is an inclusive project which primarily aims at promoting exercise and physical activity in all inactive and uncoordinated children regardless of the exact level of their motor and coordinative disability. Therefore, the 25th percentile was used as a cut off for participant selection.

5.1.2.2 Participant Grouping

Because this study was primarily set as a pilot study, creating criteria of participant grouping was one of the purposes of the study. Having not further assessed the participants using more detailed motor tests after the short screening, participant grouping was based on a small number of test items which is, admittedly, not optimal. The grouping strategy was based on two concepts that should be considered during participant selection and grouping in the main trial: first is the importance of controlling for cardiovascular fitness levels, which means that participants belonging to the same group should have similar levels of endurance/cardiovascular fitness ability.

It is accepted that cardiovascular fitness and motor coordination are correlated to each other (Morris, Dawes et al. 2013). The logic being that moderate to vigorous exercise necessary for challenging the cardiovascular system requires the development of basic movement skills and efficient movement patterns that facilitate exercise. However, cardiovascular ability is strictly related to the amount of training that the individual had been exposed to (Armstrong and van Mechelen 2008). Hence; poor motor performance in this context could be the result of lack of opportunity for skill development or the direct manifestation of a true motor deficiency independent of practice opportunities (Lopes, Santos et al. 2012). Given that the direction of causality in the relationship between fitness and coordination is not known within an individual, it is only fair to put participants with the same level of training in one group.

The second level of categorisation would involve skill related (and in our case: gross motor) proficiency. Because of our particular interest in lower limb and total body coordination, the tests we referred to in our grouping criteria were those most relevant to the task.

After excluding the fine motor ability tests (copying star shape), and total body strength (grip strength), we were left with three motor tests that collectively resembled coordination; both lower limb and total body coordination. And because no one test could be representative of the persons total coordination ability (because every test measures a different aspect of coordination), especially that the hopping test was relatively subject to inter-rater biases, scoring low on at least two of the tests seemed like a reasonable criterion for poor coordination. Similar strategy was used by (Smith, Fisher et al. 2015). Using the 15th percentile as a cut off for poor performance is in line with the world wide use of this cut off to mark probable coordination difficulties wen using standardised tests.

Having examined multiple other grouping strategies, this grouping has produced the most homogenous groups. For the purposes of the main trial, it is advised that participants are assessed and described using standardised and other coordination tests as to make the grouping criteria more reliable and robust by way of having multiple test items assessing each motor ability to protect results from bias. In case researchers are interested in answering the question with regards to motor learning in DCD specifically, then the description of the participants should include the investigation of the satisfaction of the 4 criteria of the DSM-5 and adhere to the 5th percentile cut off.

5.1.3 Time and resource requirements for success of the trial;

5.1.3.1 Screening

For the success of the screening session, a total of 7-8 researchers and at least one PE teacher are required to run the motor assessments and help organise the flow of students respectively. The total number of sessions required to screen a whole school year depends on the number of students in the cohort, with a rough average of 5 sessions per school. To ensure the quality of the data, it is advised that the same researcher runs the same test every time. A very successful alternative to organising multiple screening sessions is measuring the whole school year during a school open day, so that the screening takes the form of multiple consecutive sessions where each class (30-40 students) is measured at a time. This set-up makes it easier to recruit volunteering researchers. When organising any activity with schools, however, the research team is forced to work around schools' fairly strict schedules, which are also greatly influenced by school term holidays and exam times.

5.1.3.2 Training:

The total number of coaches required to run the training session depended of the number of students attending, but as a rule of thumb; 4-5 coaches were needed to run the session. For running the stepping task, having two researchers running one station was optimal. When more than 10 participants were attending the training session, setting up two stepping stations was necessary to measure all of them. This meant that at least 3 researchers were involved in running the stepping task which included; calling the children, placing the IMU, explaining the task, running the program, writing notes and giving verbal feedback on performance. To ensure the assessment of the stepping task in all the attending participants, it was best to have an extra researcher who was not directly involved in data collection but who was responsible for monitoring the traffic. It is also advised that a log is kept with the date, time of measurement, name of the participant, and the number of the protocol used for every session. This helped clarifying any ambiguity with regards to stepping data files and keeping track of the exact protocols the participant had completed.

5.1.4 Utility of the IMU for detection of movement timing parameters during stepping task performance

Based on the results of the validation study described in chapter [3] revealed that we can reliably detect the timing event in the IMU velocity signal which corresponds to CoM elevation on the stepping board. This timing event allowed for breaking the signal into the individual stepping cycles as well as calculating movement time with reference to the timing of the visual stimulus.

To this regard, IMU is a useful and reliable means to detect this timing event during stepping. It is easy to use, it doesn't require expert knowledge and it's relatively cheap which makes it, together with the reliability of recorded signal, an optimal tool for detecting movement timing during the stepping task in schools and gym environments. Timing is an important construct of motor coordination (Johnston, Burns et al. 2002; Buhusi and Meck 2005) and adherence to a rhythmic stability is considered an important aspect of motor control and coordination, especially in the skills that are naturally rhythmic like walking, cycling, and running (Thaut, Kenyon et al. 1999). Although interesting and highly informative, the sole measurement of timing events limits our outcome measures to performance and excludes movement quality. This problem has been discussed earlier [Section 1.5.1] and considered to be a limitation of the available literature on motor learning in children with poor motor coordination. It would be of interest and great use to tackle the question of movement kinematics (e.g. joint angles, energy expenditure, contact force, velocity profiles etc.) i.e. Can children with DCD or poor motor coordination improve the quality of their rhythmic movement patterns with training?

An understanding of movement quality and its "possible" improvement over time will tremendously improve our understanding of the condition. As such, even in children who managed to respond timely to the visual stimuli, our observation during training was that the movement patterns of poorly coordinated children were obviously inferior, less controlled, and contained more unnecessary movement elements (e.g. extra small steps, associated upper limb movement, and jerky hip and trunk movement) in comparison to their coordinated peers. In order to answer such a question, in depth motion analysis needs to take place in a controlled lab setting. Thus, it is recommended that when running the full intervention trial, a sub group of the most affected participants be measured over time using both IMU and the camera motion capture.

Measures of movement smoothness e.g. jerk would be very useful in studying movement quality and possibly attainable using IMU only. However, in our current task, it was not possible to reliably calculate measures of smoothness from the IMU signal because the task was not a completely cyclical movement like gait for example. Every interruption of the signal, caused by the participant stopping (at the end of the stepping cycle when the participants returned to the starting point and momentarily waited for the next stimulus) would have appeared like a jerky movement. Moreover, authors and researchers working on movement smoothness analysis have concluded that there is not yet a reliable method for calculation of movement smoothness using wearable accelerometry (Balasubramanian, Melendez-Calderon et al. 2015).

The IMU is capable of providing further information about the movement e.g. velocity profiles and energy expenditure perhaps with further expert analysis of the signal or with the aid of extra measurement units. The use of Wii fit balance boards, together with the IMU, which also had been piloted (Zijlstra, 2016), improved the utility of the IMU signal and the quality of the analysis and allowed us to involve not only single timing events but movement phases, the analysis of which may provide more insight than single time points. The Wii balance boards also provided a foot placement pattern which could also be a useful measure of movement quality.

Practical issues to consider when using the IMU during stepping

Because the stepping was part of the intervention training session, the application of the IMU was sometimes difficult due to the sweat, which lead in some cases to data loss or time delays when the adhesive tape failed to stick to the wet skin and the IMU fell off. Careful drying of the lower back with alcohol wipes before the IMU placement reduced this problem to a large extent. Yet, this limitation remains in the nature of the data collection method (provided that good quality double adhesive tape is used, which was the case in our study).

Another pragmatic issue was that some participants, had excessive body fat which yielded poor signal. IMU measures vibration, and in case of the presence of a wobbly mass, the accelerometer detected change of acceleration of that fat mass which does not exactly correspond to the CoM acceleration. At lease on of the outliers might have been excluded for that reason. Moreover, some of the female participants felt uncomfortable with the IMU placement on their backs. It is important to realise that our teenage participants, especially the uncoordinated ones, are susceptible to having low levels of self-esteem (Gillberg and Kadesjö 2003) and since our goal is to improve children's attitude towards participation in sport, participants were not forced to wear an IMU when they expressed their anxiety.

When they preferred it, we allowed participants to place it by themselves in the changing room and more often, participants gained confidence in the research team and they allowed for IMU placement.

5.1.5 Utility of the data collection and analysis software

The custom made data collection software, described in the attached thesis (Zijlstra, 2016) was successful in connecting to and reliably collecting IMU data. It did not drop any data or suffer any connection problems. In addition, it had a friendly user interface and it was easy to handle by researchers who had no technical expertise. The data analysis program was also reliable and easy to use. The limitation of the analysis program was the fact that it produced the output for the whole stepping session at once without breaking it into the different stepping patterns that it constituted of. This means that the average reaction time would, sometimes, be based on reaction times of two different frequency patterns. Because were interested in examining the differences between the practiced stepping rhythms, the data had to be manually divided into sections each corresponding to a certain pattern, a process which was extremely lengthy and time consuming. The automatization of this task would add value to the analysis program, save a lot of time on the researcher’s part, and reduce the likelihood of human error.

5.2 Stepping training intervention

Bearing in mind the fact that the intervention trial was primarily set as a pilot, the results of the stepping training are inconclusive and should be interpreted with caution, especially since no effect sizes could be calculated (Thabane, Ma et al. 2010). Our study is not powered for making any conclusions with regards to group differences or time-related performance change. However, the results do give an indication of the utility of the outcome measures and a general feel for how the behaviour of each group changed over time. The results should primarily be used as standard deviations for calculation of sample sizes in a full powered trial.

The analysis of the stepping signal yielded three main outcome parameters; movement time, variability of movement time and stepping error. Baseline comparison between groups revealed significantly higher movement time in children with poor motor coordination in comparison to control children irrespective of their fitness level. With regards to the effect of training, in our study, children with poor motor coordination were able to improve their performance on the rhythmic multi limb coordinated stepping task as measured by decrease in movement time. The other two measures; variability of movement time and error did not show and differences between groups neither at baseline nor over the training period.

5.2.1 Baseline Performance

5.2.1.1 Movement time

It is noticeable, when looking at average movement time of the four participating groups Table 11, that the severely affected group (unfit and uncoordinated) has a higher movement time in comparison to the other groups. The analysis revealed that the unfit and uncoordinated group was significantly different to the two coordinated groups (fit coordinated and Unfit coordinated). This is in line with the literature on movement timing in this group as they have consistently been seen to be slower than control children (Henderson, Rose et al. 1992; Rosenblum and Regev 2013). It is interesting to see that there is a steady increment in movement time as the motor proficiency level worsens; with an average of 1.2 sec for the unfit and uncoordinated group, 1.15 for the fit and uncoordinated group, 1.04 for the fit and coordinated group and .099 for the unfit and coordinated group.

Previous research findings in movement timing in this group indicated that children with DCD manifest with internal timing deficits which affect their ability to perform precise, synchronized movements at a reasonable pace (Barnhart, Davenport et al. 2003; Missiuna, Rivard et al. 2003; Mackenzie, Getchell et al. 2008).This timing problem has been seen to be correlated with handwriting performance (Rosenblum and Regev 2013) and to be particularly evident when the stimuli are of visual nature (Johnston, Burns et al. 2002). Multiple theories have been proposed to explain the time deficiency; some of them argued that clumsy children have a problem translating the stimulus code to a response code (Dellen and Geuze 1988), or have an inherent timing deficit (Lundy-Ekman, Ivry et al. 1991;

Williams, Woollacott et al. 1992; Rosenblum and Regev 2013) On the other hand, (Piek and Skinner 1999) suggested that the timing problems in children with coordination problems are based in the executional stage of motor control.

Furthermore, the analysis results showed that the unfit and uncoordinated children were significantly different to both coordinated groups (fit and coordinated and unfit coordinated) but not to the fit and uncoordinated children. This is an exciting finding which further supports the importance of controlling for fitness in the grouping process. It also sheds light on the nature of the stepping task being particularly challenging for children with poor coordination and not unfit children in general, since uncoordinated children (with different levels of fitness) weren't statistically different in their performance, at least in the first session.

5.2.1.2 Variability of movement time

The test of fixed effects showed no statistically significant differences between the four groups on movement time variability, although the mean values seemed to be higher for both uncoordinated groups. This statistical insignificance could very well be driven by the large within group variability seen from the large standard deviation values (almost half of the mean). In literature, children with poor motor coordination have consistently been found to have higher levels of variability in their movement timing (Geuze and Kalverboer 1994; Johnston, Burns et al. 2002; Ben-Pazi, Kukke et al. 2007; Mackenzie, Getchell et al. 2008; Rosenblum and Regev 2013).

We expect larger sample sizes to reveal the significant difference between groups, especially when the cut offs used for inclusion are strict; which would create more homogenous groups.

5.2.1.3 Error

Looking at the distribution of wrong steps Figure 16] and the mean values of the number of wrong steps [Table 8], it is seems that the unfit and uncoordinated group had higher number of wrong steps, especially in comparison to the middle groups (unfit coordinated and fit uncoordinated). However, this comparison yielded no statistically significant results; it is worth mentioning though, that the fit children also seem to make a relatively large number of mistakes. *From observation*, these two groups made very different types of mistakes and for different reasons; the uncoordinated group stumbled, sometimes were unable to follow the rhythm, or were too slow to adhere to the pattern. The coordinated children (especially the fittest) made consistent mistakes when they learned the pattern because they were expecting the location of the next stimulus but did not wait for its appearance to step, which meant that they were out of synch with a consistent margin of time ahead of the stimuli. In this study we could not work out a way to explore the nature of mistakes that the children from different groups made. There has been a trial to calculate number of steps (within each block) which were a certain distance away from a grand mean. These trials did not produce any meaningful results and won't be displayed here.

There are multiple possible theoretical reasons why unfit uncoordinated group made a large number of mistakes including; visual motor deficits (Zoia, Castiello et al. 2005; de Castelnau, Albaret et al. 2007) and rhythmic instability (Getchell, McMenamin et al. 2005; Getchell 2006) but its arguable that the number of errors is indicative of a motor learning difficulty; i.e. when the children with coordination did not manage to automate the rhythmic stepping process (as explained by the cerebellar deficit hypothesis (Brookes, Nicolson et al. 2007; Zwicker, Missiuna et al. 2011), they continued to make mistakes throughout the block

5.2.2 Skill Learning

5.2.2.1 Movement Time

The previously described finding of movement time being significantly different between the groups has been confirmed when we ran the analysis on the complete data set. This indicated that the groups are not only different in the first session but across the training period. Again, the post hoc analysis confirmed the previous difference between the unfit - uncoordinated group and the two coordinated groups.

The results of the analysis revealed a significant effect of repetition on movement time. This is also obvious from looking at table [9] and Figure [18]. Consistently across all groups, a learning effect has taken place with the movement time consistently decreasing over time. Looking at the overall average of the groups [Figure 18], we could see that the greatest change took place after the first session, known as "the initial/fast stage". During the initial phase of implicit motor learning, individuals figure out the correct movement and establish a novel sensorimotor association. This phase requires that subjects attend to sensory cues, make decisions regarding their movements and process sensory feedback (Halsband and Lange 2006). This stage is marked with large gains in performance.

With practice, sensorimotor maps are reinforced and stored in long-term memory allowing the visual cues to be transformed quickly and accurately to the precise motor response. Thus, movement can be performed with less intensive sensory feedback processing and at higher speed (hence the decrease in movement time in our stepping task). The second largest change in movement time in our results took place between the 2nd and the fourth session "the intermediate phase". The observed reduction in movement time indicates a more skilled performance ,improved speed of translation of the visual stimuli into motor commands and a more automated movement pattern with less need for conscious control (Halsband and Lange 2006).

The learning curve, as measured by stepping movement time, seemed to stabilise after the fourth session (at least for the coordinated groups). This stability of the curve could be explained by the relative easiness of the task, and the fact that there is a limit to the amount of change in movement time given that the stimulus patterns and frequencies were fixed.

The results of the analysis indicate an important finding with regards to motor learning in children with poor motor coordination. In our study, children with poor motor coordination were able to improve their performance on a rhythmic multi limb coordinated stepping task. This task required visumotor control, multi limb coordination, balance, and spatiotemporal coordination. This finding is not novel in the literature on motor learning in this group (Bo and Lee 2013), in fact, there were multiple previous that proved children's ability to learn (Lejeune, Catale et al. 2013; Smits-Engelsman, Jelsma et al. 2015; Fong, Guo et al. 2016). However, this study is the first one of its kind to show that these children are able to improve their performance on a gross motor multi limb rhythmic functional task.

Although there has been no direct measure of movement quality, reduction of movement time could be considered as an indirect measure of improved movement quality, especially that the pattern (RT-Lft), which is considered more natural and well-practiced pattern, was found to have a significantly shorter movement time. We could use this as an indication that movement time reflects "automatization".

From our observation during training, the children with poor motor coordination do eventually improve their pattern as they learn the task. However, they take longer than the control children to do so. In order to confirm this observation, in depth motion analysis need to be done. Nonetheless, looking at the learning curve shown in [Figure 18]; it seems that the children with poor coordination require more time to improve their performance and do not reach a plateau when the other groups did. In addition to this, there has been a clear trend for significance in the interaction: (repetition *group) when this interaction was added to the model. The uncoordinated group, as clear from the learning curve, seem to take longer to stabilise their performance and given that the curves do not cross, continue to be slower and less efficient than the others. This finding, if further confirmed in the main trial has a very important clinical application namely that children with poor coordination are capable of improving their movement performance and quality but require longer periods of training.

The theoretical framework for this motor learning "slowness" could be rooted in the internal modelling deficit suggested by (Wilson, Maruff et al. 2004; Kagerer, Contreras-Vidal et al. 2006). This, relatively well-supported theory explains movement difficulties in this group as a: "difficulty in generating or using predictive estimates of body position as a means of correcting actions in real time" (Wilson, Ruddock et al. 2013). This problem is suggested to affect the ability to learn new internal models (sensorimotor maps) or modify existing ones over repeated learning trials. In the context of the stepping task, internal modelling involves the ability to map the rhythmic stepping response in a feedforward manner to the required frequency.

5.2.2.2 Block Type/Pattern

The different practiced patterns were mainly created for variability of practice (Schmidt and Lee 2013) with no preconceived knowledge concerning which patterns may be more challenging in comparison to others. We intentionally, had the maximum number of stimuli in a sequence be four. It was certainly possible to create more complex patterns made of sequences of 7 or 10 stimuli (similar to serial reaction time task studied abundantly in literature). However, because the main interest in our study is the motor aspect of performance, we kept the rhythms simple in structure and easy to recognise so as to avoid the possible cognitive demand (Lejeune, Catale et al. 2013). We did expect though, that the (Rt-Lft) pattern, which resembles- to a high extent- normal stair climbing or even gait, to be the least challenging pattern among the four other patterns.

Results showed a significant effect for "pattern" on movement time. The post hoc analysis revealed, as expected, that (Rt-Lft) pattern had smaller movement time in comparison to the more complex patterns: (Rt-Rt-Lft) and (Rt-Rt-Lft-Lft). This finding confirms the importance of calculating individual block means and not relying on the software-produced total session mean. In case the researcher is not interested in further exploration of the differences between the patterns, which is the case in this study, between pattern differences should at least be accounted for in the model. The lack of significant difference between (Rt-Lft) pattern and (Lt-Lft-Rt) is not a finding that needs to be taken seriously given the smaller number of repetitions of the Lft-Lft-Rt pattern in comparison to the other patterns [Table 7]. This finding could be considered more of a statistical error than a true lack of difference in performance because theoretically, there is no reason why (Lft-Lft-Rt) pattern should be any easier than (Rt-Rt-Lft).

Another interesting and possibly useful analysis would be the comparison between the different groups on the non-regularly practiced novel blocks. The results of this analysis would show the different groups' ability to transfer the acquired skill. Furthermore, assessment of performance on a retention task would be very important to make conclusions regarding motor learning of this task in a larger sample (Schmidt and Lee 2013).

5.2.2.3 Variability of Movement Time

The mean values of variability of movement time, as could be seen in Table [9] seem to be both different between groups and consistently decreasing over time. However, there have been no statistically significant differences between groups in variability of movement time and there was no statistically significant effect of repetition on variability. This could be well explained by the large standard deviation just like in baseline performance.

It is possible that reducing movement variability requires more training. But given the lack of any statistical significance, no conclusions could be made with regards to decreased variability over time, especially that there were no group differences in the baseline performance or change over time. Movement variability is still a very important outcome variable that should be explored in detail in the main trial.

5.2.2.4 Number of Mistakes/Error

Although observing Table [9] and Figures 16 and 22 it seems obvious that children with poor coordination had a higher number of mistakes, there was no statistical significant effect of "group" or "repetition" on number of mistakes.

When the number of mistakes was plotted across time for each group individually, it was interesting to note that our insignificant findings may be attributed to the finding that in both (unfit and uncoordinated group) as well as the (fit and coordinated group), a small number of individuals were responsible for driving the mean higher and so the group means were not always representative of the group performance [Figure 22 a&b]. It would be very explore the characteristics of the individuals who made the largest number of mistakes. Unfortunately, for this trial this was not possible given the little amount of information we had of the participants.

5.2.3 End of training performance:

Bearing in mind the fact that we did not control for the number of sessions the participant had attended before running end of training analysis, the results should not be taken by face value. This is merely an exploratory analysis where the last session attended by one participant may be the 6th session and for another one the 4th. The results of the analysis showed that the performance of the unfit and uncoordinated group remained inferior to that of the fit and coordinated group. In case this finding is confirmed in a larger sample size and when included participants have attended a similar number of sessions, it would have an important clinical and PE related implications e.g. children with poor coordination should not be left to competing with typically developing children in team sport and they should be treated on a separate scheme. However, this finding is inconclusive especially that the training period was relatively short.

5.3 A comment of the utility and validity of outcome measures:

Our conclusions with regard to the utility and validity of the outcome measures are based on the previously shown results and discussion.

- Movement time: in this task, movement time had been an important and informative outcome measure. It was easy to measure and sensitive to convey between- group differences. It also served as a good indication of motor learning.

- Movement time variability: in this task, variability of movement time is generally considered a very meaningful measure. However, in our analysis it did not show sensitivity to group differences. We do expect though that in a larger and more homogenous sample, it would play an important role in highlighting learning and movement characteristics and is recommended to remain as an outcome measure.

- Number of missed steps: this outcome measure has yielded no significant or meaningful results and since we did not have any knowledge of the nature or cause of the missed steps, it had no bearing on performance and could be abandoned in the main trial.

- Error (number of mistakes): This outcome measure is not meaningful or useful in isolation. Given the different possible reasons and patterns in which participants could have made those mistakes, it was not a sensitive measure of performance. Although it is logical to consider it as a performance marker, it needs not to be taken as an absolute value, but preferably as a ratio to movement variability or movement time.

Summary and Conclusion:

This project was set out to recruit a sample of children with poor motor coordination by way of motor screening in main stream schools, involve them in a physical training intervention and study the characteristics of their motor skill performance and acquisition of a rhythmic functional task. The following conclusions can be made:

1- The described screening tool provided an easy and quick tool for use in main stream schools to detect children with poor motor coordination. This identification is sufficient when the purpose of intervention is improving fitness and motor skills. However, for purposes of studying particular mechanisms underlying the deficiency, it is suggested that more extensive motor assessment is done (with more than one motor test for each motor ability) to ascertain the categorisation of participants and facilitate the creation of coherent and well-described groups.

2- The study was successful in recruiting participants from the bottom quartile of motor coordination (n=33) and involving them in an 11 week exercise intervention. Nevertheless, the recruitment pattern suggested that more than 80% of participants who scored below the 5th percentile did not participate in the physical training intervention and were less likely than more able children to want to take part. This finding shed the light on the importance of investing time and effort in recruiting these children with the help of parents and PE teachers as well as the use of school premises as primary locations for physical training interventions in a non-judgemental friendly environment.

3- The use of the IMU has proved to be reliable and useful in the detection and analysis of timing events during the stepping task, specifically; "movement time", "variability of movement time" and "stepping direction/error". It is a cheap, easy to use and reliable measure of movement that has utility for gym and school environments. In our results, the IMU was able to detect differences in movement parameters between children with coordination problems and control children.

4- Children with poor motor coordination in our study were significantly different than control children in their movement parameters (movement time) at baseline irrespective of their fitness levels. All participants in our study achieved a training effect over the training period, and they seemed to progress with no statistically significant difference. However, a larger sample is expected to reveal more differences in the pattern of progression as the group*repetition had a trend for significance (p=0.06).

Conclusion and progression to the main Trial

This study serves an important clinical purpose concerning the trainability of children with poor motor coordination who study in main stream schools and may or may not satisfy the clinical criteria of DCD diagnosis. These children have a significantly worse motor performance in comparison to their peers and are in danger of leading an inactive lifestyle. The results of this study suggest that these children are capable of acquiring a novel motor skill, in a comparable rate to control children and are able to improve the quality of their movement. Given these findings, more attention and exercise interventions should be directed towards detecting these children in school environments and involving them in physical interventions. The results of this study need to be further examined and confirmed with a follow up trial with a larger number of participants.

Appendices

Appendix (1)

Screening Opt out Consent Form

Dear Parent,

Your child has been invited to participate in a fitness screening organized and run by Oxford Brookes University at your child's school and funded by Sport England.

During the screening held during their PE lesson, we will be testing aspects of your child's fitness, including their muscle power, endurance and flexibility using standard exercise tests. We will give feedback on how your child has done and we would like to be able to keep and use the results of the tests for reference. Any personal information such as their name will be removed and the data stored anonymously. However, the research team would like to keep your contact details to keep you and your child up to date regarding upcoming events including 'Have a go' Sports Taster Days and research projects running.

With your permission we would also like to keep the information regarding your child's fitness and skills so that we can contact you and your child about activities and research that might be of interest, to keep your contact details and possibly take photographs to record the event. These may be used in future promotional material.

We look forward to meeting your child this January and hope they find the day enjoyable and rewarding. However, if you do not wish for your child to take part and would like to have your child opt-out then please sign and have this form returned.

Student Name:…………………………………………….. (Please print)

Parent/Guardian:………………………………………….(Name and signature)

From

The Movement Science Group

Appendix (2)

Parent Information Sheet

OXFORD BROOKES UNIVERSITY

Headington Campus, Gipsy Lane, Oxford

OX3 0BP

Wala Mahmoud Tel: 01865 483272

Email: 14108009@Brookes.ac.uk

Contact: Dr Anne Delextrat Tel: 01865 483610

Email: adelextrat@brookes.ac.uk

Research Project: Exploring the impact and feasibility of a pathway to sport and long-term participation in young people

Your child is being invited to take part in a PhD student research study. Before you make your mind up we would like you to understand why the research is being done and what it would involve. Please take time to read the following information carefully to help you decide whether or not you would like for your child to take part.

What is the study about?

Physical activity and exercise improves health and well-being, positively influences mood and behaviour, and enhances performance in school. The UK physical activity guidelines for children and young people (ages 5-18) from the Chief Medical Officer (CMO) recommends regular participation in moderate to vigorous physical activity (PA) for at least 60 minutes a day to reduce the risk of young people developing cardiovascular conditions later in life, however, physical activity rates have not improved. With this in mind, we have presented a pathway to sport and longer-term participation for young people who may not regularly participate in sport and physical activity. The aims of this study are to explore the feasibility of this pathway along with appropriate evaluation of outcome measures to support community sport activation in young people. This will include looking at health markers (physiological) and non-motor measures (self-perception, cognitive function, sleep) before and after the training programme to objectively explore the impact of a training intervention.

Why have I been invited to participate?

Your child is being invited to participate because they took part in a fitness screening supported by their school and they and were informed by a Headperson or Head teacher/coach about this study and/or showed interest in being involved in research projects being run at Oxford Brookes. Following the fitness screening, we were not clear as to which activities would best suit your child. Therefore, we would like to invite your child to take part in an exercise training programme (EPIC Club) to work on improving their fitness along with building up their skills and confidence and introducing them to sports and activities they may find interesting and fun.

The inclusion criteria include being able to walk with or without support and to be able to follow instructions safely. Motor skill level will have been assessed during the screening day session. It is up to you to decide whether or not you are happy for your child to participate.

Are there any exclusion criteria?

The exclusion criteria for this study include any behavioral issues that would prevent safe participation or may put the participant, investigators and others at risk. Any young person with contraindications to performing maximal exercise will be excluded. Children diagnosed with a muscular degenerative condition will be excluded from partaking in the study. Children with a diagnosis of asthma, diabetes and epilepsy are free to participate as long as their medication is stable. If your child does have asthma we would ask for them to bring their inhaler with them to the training sessions.

A General Health Screen questionnaire must be completed by you and your child if they volunteer to participate in this study.

Does my child have to take part?

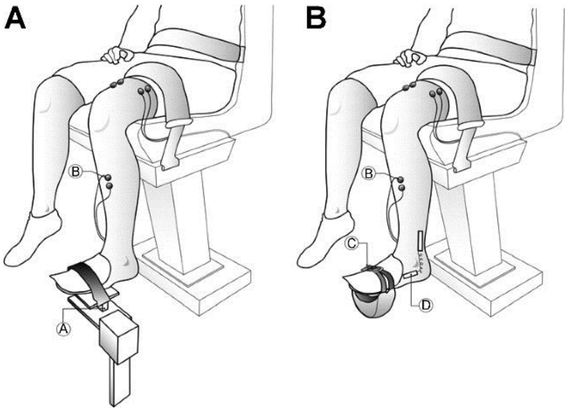
No, your child's participation is entirely voluntary. If you and your child are interested in taking part you will have the opportunity to discuss any questions or concerns you may have with the research team. If your child does have any of the conditions mentioned above and is interested in participating, and you have any concerns we recommend discussing your child's participation in the study with your child's GP. We can provide you with a letter explaining the details of the study and a form requesting a signed consent or we would be happy to contact them for you on your behalf following informed consent. If you still wish for your child to take part you would then be asked to sign a consent form stating that your child is allowed to take part. The safe participation of your child is our top priority therefore, if the research team feels the need for your child to be checked by the GP prior to testing, we would like to be able to say so. Any involvement in the study will not compromise any on-going or future treatment you may be receiving nor affect their progress at school.

What will happen to my child if they take part?

Your child will be asked to take part in a 6-week exercise training program (EPIC Club) running for 45 mins, two to three times weekly in a group circuit setting during or after school either at the school's gym or at the Oxford Brookes University Sports Centre. This will be pre-arranged with you, your child and the school. The exercise training program will incorporate work stations set up for repetitive practice of an exercise with participants moving between stations, practicing functionally based exercises including cardio exercise (cycling/treadmill/warm-up) and resistance-strength training (utilizing bodyweight and/or free weights). Prior to and immediately after the training period (week 0, week 6 and 6 months post), your child will be asked to attend a baseline and follow-up assessment lasting approximately 1 hour to evaluate health/physiological and non-motor measures. The assessment will either take place at the gym where their training takes place or at the Oxford Brookes University Movement Science Laboratory as pre-arranged. The first visit will take place before the start of the training, the second will be after the 6 weeks of training and the final one will just involve questionnaires 6 months after your child completes the training programme.

The first visit will consist of baseline measures and your child will be asked to participate in a submaximal fitness cycle test (Astrand-Rhyming) to determine his or her fitness level.

They will be asked to fill out a questionnaire asking about how they feel about themselves and exercise, their physical activity participation and their strengths/difficulties. Through a series of scientific measurements, we will also measure their leg and arm strength, blood pressure, height and weight. A short cognitive task (Eriksen Flanker Task) will also be administered requiring your child to respond to different computer stimuli to look at their reaction time.



Maturation level is also of importance to the physiological responses during and following exercise, therefore we will ask you to identify the level of puberty your child is at by ticking a box on the Tanner scale questionnaire on the first visit. We will also ask for you to complete questionnaires regarding your child’s sleep and strengths and difficulties. Further details of the exercise and assessment sessions are provided at the end of this information sheet.

Following baseline measures, your child will then be randomized to either immediate start or delayed entry to EPIC Club. Those in the delayed entry group will be asked to wait 6 weeks, be assessed again and then start the 6 week training program. This is only to ensure the training groups are balanced and will receive the appropriate personal training. Your child will repeat the same assessment as a follow-up once they have completed the training program. At 6 months post training we would like for your child to complete similar questions as during the assessments.

All testing is safe following standardized tests and will be monitored by a trained tester to ensure your child is comfortable and confident with all tasks.

Is there anything I need to do before the sessions?

• We will ask you to complete several forms so that we are confident your child is in good general health and will be able to complete the exercise tasks during the study.

• If your child has asthma, we would ask for them to bring their inhaler with them.

What type of clothing should my child wear?

Your child should bring comfortable shoes and sportswear or PE kit clothing (e.g. shorts, T-shirt, trainers) that they can wear for the exercise sessions. If you child wears orthopaedic shoes or orthotics in daily life we would ask for them to wear these during the exercise session. **Please note** – children are not advised to wear tracksuit trousers during exercise as they can overheat. They will not miss out on lessons.

What are the possible benefits of taking part?

The benefits of participating include exercising with personal training and working out in a gym setting that may improve measures of health and increase their physical activity. Your child will learn the proper techniques in strength and resistance training and undergo cardio training. We hope that this will also help build up their skills and confidence. The proposed study and pathway is meant to not only improve the health and well-being of young people, but also to introduce them to sports and physical activities for longer-term participation that they find enjoyable. Therefore, during the study, your child will also be invited to take part to 'Have a go day' Sports Taster days in which they can try different sporting activities offered and be in contact with local coaches. The focus of the study is to also gain a comprehensive look into the impact of exercise and training on health/physiological parameters, cognitive function and on self-perception/esteem.

Are there any risks in taking part?

The procedures and tests in this study are routinely used for assessing children and young person's health, fitness level and performance. However, exercising is not without risk and some individuals may find exercising uncomfortable or unpleasant. If your child does not regularly take part in physical activity, the training and exercise.

tests will constitute an effort not normally undertaken in their daily living and his or her muscles may ache the next day after the session. This is perfectly normal and is a sign that your child has worked their muscles. All tests performed during assessments may include potential risks of physiologic stress including fatigue and muscle pain. However, the tests are widely used within paediatric fitness testing and have been performed at numerous sporting events with children and adolescents.

Furthermore, the researchers are fully trained first aiders and heart rate and breathing will be monitored throughout training and testing. Proper warm-up and cool-down will be done before any exercise. Your child would be able to stop at any time without giving a reason.

What will happen if I don't want to carry on with the study?

Participation is entirely voluntary. Your child is free to decline to enter or withdraw at any time, without having to give a reason. They can withdraw from any part of the study at any time. If your child does withdraw, the information collected may still be used, unless you request otherwise.

What if there is a problem?

If you have a concern about any aspect of this study, you should contact the researchers who will do their best to answer your questions. If you have any concerns about the conduct of the research you may contact the Chair of the University Research Ethics Committee on ethics@brookes.ac.uk.

What happens when the research study stops?

The study would end for your child after completion of the final assessment post-training program. At this point, we will have hopefully provided a connection to a sport or activity for your child to carry on with for longer-term participation. After this time you would still be free to contact any of the researchers with any question or queries you may have regarding the study. The results from the study will form part of a PhD thesis and will also be presented at academic conferences and published in peer reviewed sources.

What will happen to the findings of this study?

The data will be kept strictly confidential and securely stored, identified with only a number, rather than their name. Confidentiality can be protected only within the limitation of the law. All information collected will be retained for 10 years in accordance with the University's policy on Academic Integrity and will be destroyed when no longer needed. Results of this study will contribute to an ongoing PhD research project, which will be intended for publication. If you are interested in the data collected during your participation we would be happy to send you a report.

Who should we contact if my child or I have some more questions?

Wala Mahmoud Tel: 01865 483272

Email: 14108009@Brookes.ac.uk

Contact: Dr Anne Delextrat Tel: 01865 483610

Email: adelextrat@brookes.ac.uk

Who is organising and funding the research?

This study is organised by researchers in the Movement Science Group (MSG) and funded by the Community Sport Activation Fund (CSAF).

Who has reviewed the study? It has been reviewed and ethical permission approved by the University Research Ethics Committee.

If you are interested and/or have any questions regarding the study, please contact the Supervisory team using the contact details at the top of the page. We would be more than happy to speak with you. Thank you for taking time to read this information sheet.

Appendix (3)

Parent Informed Consent Form

Title of Project: Exploring the impact and feasibility of a pathway to sport and long-term participation in young people

Principal Investigators:

Wala Mahmoud, PhD Student

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX3 OBP

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Dr. Anne Delextrat

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX3 0BP

Tel: 01865 483610, Email: adelextrat@brookes.ac.uk

Study Number:

Participant Identification Number for this trial:………………………

Name of Researcher taking consent:……………………………

Please Initial Box

1. I confirm that I have read and understand the information sheet (version 2) for the above study and have had the opportunity to ask questions
2. I understand that my child's participation is voluntary and that he or she is free to withdraw them at any time, without giving any reason.
3. I understand that in all instances where we disseminate the results my child's identity will remain anonymous and that all data will be treated as confidential (within the limitations of the law)

Y N

4. I agree to take part in the above research study.
5. I agree to the data collected for this being made anonymous and retained for use in other subsequent studies

6. I agree to the health questionnaire being used to screen and assess eligibility for my child to take part in the study. If the researchers cite any concerns, I give them permission to contact my child's GP or physio on my behalf to check that my child will be able to safely take part in the study. If YES, please give contact details below. If NO please respond to section (7) below.

7. I agree to contact my child's GP if I have any health or medical concerns to check that there is no reason why they should not take part in the study and to let the researchers know if is advised that my child does not take part.

8. I agree to my child's data being used in publications of the research ☐ ☐

9. I give permission for the researchers to keep my contact details for future studies ☐ ☐

Name and address of child's GP/Physio:

____

____

________________________ ____/____/____ ________________

Name of Child Date of Birth Signature

________________________ ____/____/____ ________________

Name of Parent/Carer Date Signature

Telephone: ________________ Email: ______________________

Appendix (4)

Bleep Test score -VO2 conversion table

These numbers are calculated for the age of 14 years

Level 1	31.4	Level2	34.1	Level 3	36.7	Level 4	39.4	Level 5	42.1	Level 6	44.8	Level 7	47.5
1.1	31.786	2.1	34.425	3.1	37.0375	4.1	39.7	5.1	42.4	6.1	45.07	7.1	47.77
1.2	32.172	2.2	34.75	3.2	37.375	4.2	40	5.2	42.7	6.2	45.34	7.2	48.04
1.3	32.558	2.3	35.075	3.3	37.7125	4.3	40.3	5.3	43	6.3	45.61	7.3	48.31
1.4	32.944	2.4	35.4	3.4	38.05	4.4	40.6	5.4	43.3	6.4	45.88	7.4	48.58
1.5	33.33	2.5	35.725	3.5	38.3875	4.5	40.9	5.5	43.6	6.5	46.15	7.5	48.85
1.6	33.716	2.6	36.05	3.6	38.725	4.6	41.2	5.6	43.9	6.6	46.42	7.6	49.12
1.7	34.102	2.7	36.375	3.7	39.0625	4.7	41.5	5.7	44.2	6.7	46.69	7.7	49.39
		2.8	36.7	3.8	39.4	4.8	41.8	5.8	44.5	6.8	46.96	7.8	49.66
						4.9	42.1	5.9	44.8	6.9	47.23	7.9	49.93
										6.101	47.5	7.101	50.2

Level 8	50.2	Level 9	52.9	Level 10	55.6	Level 11	58.3	Level 12	61	Level 13	63.7	Level 14	66.4
8.1	50.445	9.1	53.145	10.1	55.825	11.1	58.525	12.1	61.225	13.1	63.925		
8.2	50.69	9.2	53.39	10.2	56.05	11.2	58.75	12.2	61.45	13.2	64.15		
8.3	50.935	9.3	53.635	10.3	56.275	11.3	58.975	12.3	61.675	13.3	64.375		
8.4	51.18	9.4	53.88	10.4	56.5	11.4	59.2	12.4	61.9	13.4	64.6		
8.5	51.425	9.5	54.125	10.5	56.725	11.5	59.425	12.5	62.125	13.5	64.825		
8.6	51.67	9.6	54.37	10.6	56.95	11.6	59.65	12.6	62.35	13.6	65.05		
8.7	51.915	9.7	54.615	10.7	57.175	11.7	59.875	12.7	62.575	13.7	65.275		
8.8	52.16	9.8	54.86	10.8	57.4	11.8	60.1	12.8	62.8	13.8	65.5		
8.9	52.405	9.9	55.105	10.9	57.625	11.9	60.325	12.9	63.025	13.9	65.725		
8.101	52.65	9.101	55.35	10.101	57.85	11.101	60.55	12.101	63.25	13.101	65.95		
8.11	52.895	9.11	55.595	10.11	58.075	11.11	60.775	12.11	63.475	13.11	66.175		
				10.12	58.3	11.12	61	12.12	63.7	13.12	66.4		

Appendix (5)

Recruited Participants Screening Descriptive

Females n= 21*

ID	Bleep Test	VO2 max	Handgrip	Hand wall toss	Broad Jump	Hopping	Copying star	*Total %*
C 5	3.2	37.4	20	0	1.25	41	0	0.70%
		15.20%	6.90%	0.00%	11.60%	37.50%		
W 13	2.3	35.1	20	7	1.1	32	5	2.10%
		1.10%	6.90%	9.60%	2.60%	6.00%		
C 1	2	34.1	22	13	1	32	5	2.80%
		0.00%	17.20%	25.40%	0.70%	6.00%		
W 6	2.1	34.4	25	7	0.9	38	5	3.20%
		0.30%	35.20%	9.60%	0.30%	26.30%		
W 11	3.1	37.0	23	0	1.25	38	5	7.20%
		13.40%	23.80%	0.00%	11.60%	26.30%		
CW 2	3.4	38.1	21	1	1.35	38	5	8.60%
		20.80%	13.20%	1.10%	23.20%	26.30%		
W 18	4.1	39.7	32	18	1.4	37	0	9.40%
		31.30%	83.80%	47.10%	30.30%	23.60%		
W 4	2.5	35.7	25	12	1.05	40	5	9.70%
		3.70%	35.20%	20.40%	1.80%	33.40%		
C 6	6	44.8		12	1.3	39	5	10.10%
		73.80%	0.00%	20.40%	18.70%	31.20%		
W 3	3.1	37.0	29	5	1.25	33	5	11.20%
		13.40%	68.70%	5.70%	11.60%	9.30%		
W 9	4.3	40.3	25	6	1.3	32	5	15.20%
		39.90%	35.20%	7.30%	18.70%	6.00%		
W 10	4.2	40	22	13	1.3	30	5	15.50%
		36.10%	17.20%	25.40%	18.70%	2.60%		
W 5	3.1	37.0	19	5	1.7	44	5	15.90%
		13.40%	5.10%	5.70%	76.40%	53.00%		

CW 7	3.4	38.05	27	8	1.2	48	5	21.30%
		20.80%	55.80%	11.90%	7.10%	65.70%		
W 1	3.2	37.4	22	13	1.55	41	5	24.20%
		15.20%	17.20%	25.40%	54.30%	37.50%		
W 17	4.9	42.1	19	13	1.5	33	5	28.20%
		55.20%	5.10%	25.40%	46.80%	9.30%		
CW 1	4.1	39.7	28	20	1.35	48	4	38.70%
		31.30%	61.30%	55.20%	23.20%	65.70%		
CW 3	4.5	40.9	29	11	1.3	48	5	42.30%
		46.20%	68.70%	17.70%	18.70%	65.70%		
CW 4	4.3	40.3	20	10	1.6	69	5	51.80%
		39.90%	6.90%	15.00%	60.60%	96.20%		
W 21	5.1	42.4	26	22	1.8	32	5	63.70%
		58.50%	43.00%	68.30%	88.00%	6.00%		

Boys (n=12)	Bleep Test	VO2 max	Handgrip	Hand wall toss	Broad Jump	Hopping	Copying star	*Total %*
CW 8	9.4	53.88	32	18	2	72	5	83.80%
		83.90%	60.20%	22.20%	78.30%	93.10%		
W 19	8.5	51.4	33	19	1.6	70	5	
		71.30%	63.70%	26.70%	29.60%	89.50%		70.70%
CW 5	4.9	42.1	24	44	1.4	62	5	50.80%
		26.20%	22.50%	100.00%	11.40%	79.80%		
W 2	5.5	43.6	23	24	1.65	39	5	27.60%
		35.10%	17.60%	46.50%	35.50%	16.50%		
W 12	4.5	40.9	22	24	1.4	57	5	25.20%
		19.70%	12.60%	46.50%	11.40%	67.60%		
W 7	8.5	51.4	38	18	1.95	30	0	23.50%
		71.30%	85.90%	22.20%	74.50%	1.00%		
CW 6	5.3	43	27	15	1.85	40	4	23.20%
		31.30%	36.20%	12.10%	64.40%	19.40%		
W 8	4.6	41.2	25	15	1.7	39	5	20.20%
		22.50%	27.80%	12.10%	39.00%	16.50%		
C 4	4.3	40.3	25	24	1.7	33	4	16.80%
		17.40%	27.80%	46.50%	39.00%	3.90%		
W 15	5.1	42.4	39.5	26	1.5	44	0	13.40%
		29.60%	92.60%	57.60%	20.90%	32.30%		
C 3	3.5	38.387	24	4	1.15	38	5	3.70%
		11.60%	22.50%	1.30%	1.70%	14.00%		
W 16	3.3	37.71	22	3	1.35	45	0	0.30%
		10.90%	12.60%	0.60%	9.00%	33.80%		

Appendix (6)

Parent Invitation Letter

Project Title: Exploring the impact and feasibility of a pathway to sport and long-term participation in young people

We are looking forward to working with you and your child, and pleased to announce that your son/daughter has taken part in a sport and physical activity fitness screening session supported by their school, as part of an initiative by Sport England's Community Sport Activation Fund (CSAF) to identify their current fitness levels. Participation in play and physical activity (including sports and exercise) helps to build and develop confidence, social skills and self-esteem.

What is Epic Club?

Founded by concerned parents, students and teachers, EPIC Club is a fun and exciting exercise programme running with local schools in Oxfordshire, supported by Sport England and Oxford Brookes University. Our program has been designed as a pathway to allow them to try different types of physical activities they find interesting to encourage long term physical activity.

Why Epic Club?

Children and adolescents are not as active as they should be. They need daily vigorous physical activity to build strength, endurance, healthy muscles and bones or they may face tough problems like obesity, anxiety, and lower self-esteem. With Epic Club, we are committed to helping students develop the skills, knowledge and desire they need in order to be physically active now and for the rest of their lives. Parents and the community also play a critical role in the solution for healthier, active children by providing motivation, encouragement and daily opportunities for recreation beyond the classroom.

At our screening day, we felt your child had the potential to improve their scores on one or more areas of fitness including: strength, power, motor skills, speed, endurance and flexibility. Therefore, we would like to invite them to join us for Epic Club, which includes aerobic exercise and resistance/strength training 2-3 times weekly (45 min each session) during or after school. Throughout the six weeks, we would also like input from your child regarding which activities he or she would like to incorporate into the program and the types of skills they would like to build.

How does your child participate in Epic Club?

The EPIC Club is free of charge and is being delivered as part of a research project and will be arranged to be held at the school's gym or at the Oxford Brookes University Clear Unit Gym to make it as convenient as possible for you and your child. The timing of the clubs will be determined by the Head teacher of participating schools.

Prior to starting the programme, we would ask for your child to participate in an initial fitness assessment and then again following the completed training and post 6 months. This is to allow for appropriate measures to evaluate and keep track of their progress. Alongside the EPIC Club, there will be opportunities to have a go at different sports. EPIC Club participants will help determine the sports they would like to try. Further details regarding the pathway and training programme are attached to this letter in the Participant Information Sheet.

This is a wonderful program that is sure to benefit your child and the school. If you or your child has any questions or concerns, please feel free to contact us. We will be holding a parent information night at 6 **pm on Wednesday, 24th of February at the school campus.**

We look forward to hearing from you and we hope you will support the pathway by encouraging your son/daughter to attend regular sessions.

Kind regards,

Movement Science Group

OXFORDSHIRE SPORTS PARTNERSHIP

Appendix (7)

Student Invitation Letter

Project Title: Exploring the impact and feasibility of a pathway to sport and long-term participation in young people

Dear (student name),

You recently participated in a in a fitness session in your PE lesson organized and run by Oxford Brookes University. Your results suggest you have the potential to improve your scores and we would like to help you do this by inviting you to our EPIC training club.

What is EPIC Club?

A fun and exciting environment to improve your fitness, make new friends, and build up your confidence and skills needed to be involved in a range of activities and sports. The EPIC Club will be arranged to be held at the school's gym or at the Oxford Brookes University Clear Unit Gym to make
it as convenient as possible for you.

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What would it involve?

Over the course of 6 weeks, you will have the opportunity to work with personal trainers in a gym setting, meet new peers and train to get fitter and healthier. Types of training include aerobic exercise and resistance/strength training 2-3 times weekly (45 min each session) during or after school.

Before you start the program, we would run an initial fitness assessment and then again following the completed training to see how much fitter you have got. We would then contact you again after 6 months we will send you a few questions to let us know how you are doing.

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Along the way, we will offer 'Have a go" Sports Taster days inviting local sports coaches/clubs to hold sessions for you to come along and try.

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Further details regarding the pathway and training program are attached to this letter in the Participant Information Sheet. Hopefully the fitter you get, the more confident you will be to try out some different sports and activities.

It would be great if you and your parent could decide together if you would like to take part in EPIC Club. If you and your parent have any questions or concerns, please feel free to contact us. We look forward to hearing from you and we hope you will support the pathway by attending regular sessions with us!

An information session will be held for you on Friday the 12th February at 11 am. This will be a great opportunity for us to meet you and for you to ask questions you may have. Looking forward to seeing you

Kind regards,

Movement Science Group

Headington Campus, Gipsy Lane, Oxford OX3 0BP

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Appendix (8)

Factor Analysis: Correlation Matrix

		VO2 max	Dropping ball	Dribbling Ball	Push ups	sit ups	Shuttle run	Balance Beam	Penny transfer	Hand grip	Tennis wall Toss	Hopping	Broad Jump CM	Medicine Ball(m)	paper Folding	Copying (Star)	Copying square	Maze
Correlation	VO2 max	1.00	-0.06	0.05	0.10	0.04	-0.06	0.05	0.18	0.01	0.02	0.08	0.07	-0.04	0.03	0.01	0.07	-0.03
	Dropping ball	-0.06	1.00	0.09	0.01	0.14	-0.14	-0.11	0.04	-0.01	0.14	-0.08	0.07	0.00	0.11	-0.01	0.00	-0.24
	Dribbling Ball	0.05	0.09	1.00	-0.04	0.07	-0.13	-0.05	0.11	0.07	0.28	-0.08	0.17	0.18	-0.06	-0.02	-0.01	-0.24
	Push ups	0.10	0.01	-0.04	1.00	0.22	-0.28	0.30	0.21	0.14	0.17	0.34	0.25	0.14	0.00	-0.01	0.10	0.09
	sit ups	0.04	0.14	0.07	0.22	1.00	-0.42	0.07	0.02	0.18	0.33	-0.04	0.41	0.26	0.32	-0.12	0.04	-0.23
	Shuttle run	-0.06	-0.14	-0.13	-0.28	-0.42	1.00	-0.08	-0.14	-0.29	-0.39	-0.07	-0.63	-0.36	-0.13	0.01	-0.01	0.24
	Balance Beam	0.05	-0.11	-0.05	0.30	0.07	-0.08	1.00	0.17	-0.08	0.11	0.31	0.16	-0.02	0.00	0.12	0.01	0.18
	Penny transfer	0.18	0.04	0.11	0.21	0.02	-0.14	0.17	1.00	-0.01	0.12	0.22	0.21	-0.02	-0.06	0.08	0.21	0.02
	Hand grip	0.01	-0.01	0.07	0.14	0.18	-0.29	-0.08	-0.01	1.00	0.15	-0.03	0.38	0.62	0.06	-0.03	-0.02	-0.01
	Tennis wall Toss	0.02	0.14	0.28	0.17	0.33	-0.39	0.11	0.12	0.15	1.00	0.06	0.34	0.30	0.03	-0.08	0.09	-0.03
	Hopping	0.08	-0.08	-0.08	0.34	-0.04	-0.07	0.31	0.22	-0.03	0.06	1.00	0.06	-0.05	-0.05	0.15	0.09	0.15
	Broad Jump CM	0.07	0.07	0.17	0.25	0.41	-0.63	0.16	0.21	0.38	0.34	0.06	1.00	0.51	0.04	-0.11	0.03	-0.07
	Medicine Ball(m)	-0.04	0.00	0.18	0.14	0.26	-0.36	-0.02	-0.02	0.62	0.30	-0.05	0.51	1.00	-0.03	-0.04	-0.02	-0.14
	paper Folding	0.03	0.11	-0.06	0.00	0.32	-0.13	0.00	-0.06	0.06	0.03	-0.05	0.04	-0.03	1.00	0.08	0.05	-0.25
	Copying (Star)	0.01	-0.01	-0.02	-0.01	-0.12	0.01	0.12	0.08	-0.03	-0.08	0.15	-0.11	-0.04	0.08	1.00	0.22	-0.06
	Copying square	0.07	0.00	-0.01	0.10	0.04	-0.01	0.01	0.21	-0.02	0.09	0.09	0.03	-0.02	0.05	0.22	1.00	-0.05
	Maze	-0.03	-0.24	-0.24	0.09	-0.23	0.24	0.18	0.02	-0.01	-0.03	0.15	-0.07	-0.14	-0.25	-0.06	-0.05	1.00
Sig.	VO2 max		0.24	0.25	0.11	0.31	0.21	0.26	0.01	0.46	0.41	0.17	0.20	0.32	0.37	0.43	0.20	0.38
	Dropping ball	0.24		0.09	0.47	0.02	0.02	0.06	0.29	0.47	0.02	0.15	0.15	0.47	0.06	0.43	0.49	0.00
	Dribbling Ball	0.25	0.09		0.29	0.17	0.03	0.23	0.06	0.16	0.00	0.13	0.01	0.00	0.21	0.40	0.46	0.00
	Push ups	0.11	0.47	0.29		0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.00	0.03	0.47	0.47	0.09	0.10
	sit ups	0.31	0.02	0.17	0.00		0.00	0.16	0.41	0.01	0.00	0.27	0.00	0.00	0.00	0.05	0.27	0.00
	Shuttle run	0.21	0.02	0.03	0.00	0.00		0.11	0.02	0.00	0.00	0.17	0.00	0.00	0.03	0.42	0.43	0.00
	Balance Beam	0.26	0.06	0.23	0.00	0.16	0.11		0.01	0.13	0.06	0.00	0.01	0.37	0.48	0.04	0.45	0.00
	Penny transfer	0.01	0.29	0.06	0.00	0.41	0.02	0.01		0.43	0.04	0.00	0.00	0.37	0.21	0.12	0.00	0.40
	Hand grip	0.46	0.47	0.16	0.02	0.01	0.00	0.13	0.43		0.01	0.35	0.00	0.00	0.18	0.34	0.39	0.42
	Tennis wall Toss	0.41	0.02	0.00	0.01	0.00	0.00	0.06	0.04	0.01		0.19	0.00	0.00	0.36	0.14	0.10	0.31
	Hopping	0.17	0.15	0.13	0.00	0.27	0.17	0.00	0.00	0.35	0.19		0.18	0.26	0.27	0.02	0.12	0.02
	Broad Jump CM	0.20	0.15	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.18		0.00	0.27	0.05	0.34	0.15
	Medicine Ball(m)	0.32	0.47	0.00	0.03	0.00	0.00	0.37	0.37	0.00	0.00	0.26	0.00		0.33	0.28	0.40	0.02
	paper Folding	0.37	0.06	0.21	0.47	0.00	0.03	0.48	0.21	0.18	0.36	0.27	0.27	0.33		0.12	0.24	0.00
	Copying (Star)	0.43	0.43	0.40	0.47	0.05	0.42	0.04	0.12	0.34	0.14	0.02	0.05	0.28	0.12		0.00	0.20
	Copying square	0.20	0.49	0.46	0.09	0.27	0.43	0.45	0.00	0.39	0.10	0.12	0.34	0.40	0.24	0.00		0.24
	Maze	0.38	0.00	0.00	0.10	0.00	0.00	0.00	0.40	0.42	0.31	0.02	0.15	0.02	0.00	0.20	0.24	

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