The Impact of Exercise in Children and Adolescents with Movement Impairment

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Abstract

The relationship between level of movement skill and fitness in children and adolescents plays an important role in improving physical activity (PA) and health. Children with poor motor proficiency and coordination categorised as having movement impairment (MI) often choose a more sedentary lifestyle as a consequence of their movement difficulties and inefficient movement patterns. The literature has highlighted the association between movement difficulties and disengagement with sport and play; citing physiological and psychosocial aspects as limiting factors. Furthermore, children with MI who do engage in PA often participate at lower intensities and fail to attain recommended levels. Consequently, there is limited knowledge regarding how youth respond to various exercise intensities in relationship to MI. Additional research is warranted to fully understand the neurophysiological mechanisms (underpinnings) and limitations that may explain the association between PA and movement skills in MI. Therefore, the aim of this thesis is to better understand the physiological and perceptual responses during and following exercise of different intensities for exercise prescription in children and adolescents with movement impairment (MI).

A comprehensive, systematic literature review was conducted of the recent available studies on interventions focused on PA and fitness in children and adolescents with MI (Chapter 2). This review provided the background for the other three studies included in this thesis and evaluated the efficacy of interventions on physical fitness and psychosocial outcomes. The findings highlighted the range of intervention designs that have the potential for improving physical fitness and performance, however, larger RCT studies with follow-up periods are needed. In Chapter 3, a review of the common methods used to describe and measure components of fitness was summarised. The primary focus of this chapter was to review the background literature validating and providing a rationale for the methods used throughout this thesis. In Chapter 4, the physiological and perceptual responses during and following an acute bout of high and low-intensity exercise was explored in a randomized crossover design (study 1).

Participants were categorized as MI (n=17) and no movement impairment (NMI) (n=21) on the Bruininks-Oseretsky Test of Motor Proficiency 2 Short Form (BOT-2 SF) and performed an incremental bike test to establish aerobic capacity. Heart rate (HR), rating of perceived exertion (RPE), muscle strength (torque) and fatigue (EMG) was assessed pre-and post-exercise in the following two sessions. Significant differences in maximal oxygen uptake ($\dot{V}O_{2peak}$) (MI: 31.5±9.2 vs. NMI: 40.0±9.5 ml·kg·min1), PPO (MI: 157±61 vs. NMI: 216±57 watts, p<.05) and LI workload (MI: 85±38 and NMI: 121±29 watts, p<.05) was observed. Average HR during HI cycling was reduced in MI compared to NMI (140±18 and 157±14, p<.05), but not for LI (133±18 and 143±17 bpm, p>.05) or RPE at either intensity for legs (MI: 8±2 vs. NMI: 7±2, p>.05) and overall (MI: 7±3 vs. NMI: 6±2, p>.05). The results highlighted a reduced exercise capacity in MI compared to NMI and potentially suggest central (i.e., motivation and perceived adequacy) rather than peripheral factors may limit exercise performance in MI.

In Chapter 5, the criterion validity of the Åstrand-Rhyming (A-R) cycle test and the Chester Step Test (CST) for assessment of $\dot{V}O_{2peak}$ in field settings was conducted (study 2). The first part of this study established the criterion validation (n=18) and reliability (n=8) of the Åstrand cycle test to measure and estimate aerobic capacity in children and adolescents. The second part consisted of validating the CST for mass screening purposes (n=20) utilised in Chapter 6. The A-R cycle test overestimated $\dot{V}O_{2peak}$ by 10-15% and demonstrated a moderate reliability (R=0.84) when repeated. Similarly, the CST overestimated $\dot{V}O_{2peak}$ by 10% confirming that submaximal data should be interpreted with caution but are a feasible option for measuring aerobic fitness across varying levels of MI. To further build upon the findings in study 1 and 2 (Chapter 4 and 5), the final study aimed to provide a pathway for identifying adolescents (13-14 year olds) with MI and lower fitness levels based on an adapted screening process within Year 9 students (n=522). Individuals performing in the $\leq 25^{th}$ percentile of their class were invited to join the EPIC (Engagement, Participation, Inclusion and Confidence in sport and play) feasibility study, a 6-week gym intervention (EPIC Club) offered twice weekly consisting of cardiovascular and strength training elements. Out of the 155 adolescents identified and recruited to join EPIC, 31 participants enrolled in the

study. Pre- and post-intervention assessments were performed to monitor changes in fitness outcomes. The intervention pilot period had a high attendance rate (~90%) with participants reaching target exercise intensities between 65-95% HR_{max} during the sessions. However, no significant changes were observed pre- and post-intervention.

Collectively, these studies provide novel insight on the physiological underpinnings and perceptual factors contributing to exercise tolerance in MI. Furthermore, the screening process and targeted recruitment approach for the EPIC study intervention served as a feasible pathway for identifying adolescents with MI and lower fitness levels in school settings. Strategies that increase fitness parameters and development of movement skills in childhood may be a vital target for improving PA and play in youth with MI.

Keywords: Movement impairment, movement difficulties, motor coordination, developmental coordination disorder, fitness, physical activity, randomised controlled trial, feasibility, exercise, intensity

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Declarations

I declare that unless otherwise stated, all work presented in this thesis is my own.

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Abbreviations

ADL	Activities of daily living
A-R	Åstrand-Rhyming Cycle Test
BF	Biceps femoris
BOTMP	Bruininks-Oseretsky Test of Motor Proficiency
BOT-2 SF	Bruininks-Oseretsky Test of Motor Proficiency, Version 2, Short Form
BMI	Body mass index
CI	Confidence interval
cm	Centimetre
CNS	Central nervous system
CP	Cerebral palsy
CST	Chester Step Test
CT	Continuous training
DCD	Developmental Coordination Disorder
EMG	Electromyography
EPIC	Engagement, participation, inclusion and confidence in sport and play
FI (%)	Fatigue index
HI	High-intensity
HIT	High-intensity training
HR [bpm]	Heart rate [beats per minute]
HR_{avg}	Heart rate average
HR_{max}	Percentage of maximum heart rate
HRR [%]	Percentage of heart rate reserve
Hz	Hertz
ICC	Intraclass correlation coefficient

IT	Interval training
Kg	Kilogram
L	Litre
LI	Low-intensity
L/min	Litres per minute
LMM	Linear mixed model
LoA	Limits of agreement
LT	Lactate threshold
m	Metre
MABC	Movement Assessment Battery for Children- 2
MD	Movement difficulties
MF/ Med_{freq}	Median frequency
MI	Movement impairment
ml/kg·min	Millilitres per kilogram per minute
MPF	Median power frequency
MVIC	Maximal voluntary isometric contraction
MVPA	Moderate-vigorous physical activity
NCD	Non Communicable Disease
N·m	Newton-metre
NMI	No movement impairment
P0	Immediately post-exercise
P1	1-min post-exercise
P3	3-min post-exercise
P5	5-min post-exercise
P7	7-min post-exercise

PA	Physical activity
pDCD	Probable developmental coordination disorder
PP	Peak power
PP_{100}	100% peak power
PP_{50}	50% peak power
PPO	Peak power output
QoL	Quality of life
RCT	Randomised-controlled trial
RER	Respiratory exchange ratio
RM	Repetition max
RMS	Root mean square
RMS_{BF}	Max root mean square for biceps femoris
RMS_{M}	Root mean square of the maximum (peak) MVIC
RMS_{VL}	Max root mean square for vastus lateralis
RPE	Rating of perceived exertion
rpm	Revolutions per minute
s	Seconds
SD	Standard deviation
T [N·m]	Torque
VL	Vastus lateralis
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}O_2$	Oxygen consumption
$\dot{V}_E$	Ventilation
$\dot{V}O_{2peak}$	Peak oxygen uptake
$\dot{V}O_{2max}$	Maximal oxygen consumption

VT	Ventilatory threshold
W	Watts
WAnT	Wingate anaerobic test
WHO	World Health Organisation
%△	Percent change

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Introduction

1.1 Introduction

Over the past decades, the body of evidence in human movement science and applied paediatric physiology on children characterised with clumsiness and marked impairment in movement/motor coordination, has grown steadily. The increase in youth presenting with movement impairment (MI) and movement difficulties (MD) have resulted in research and advancements in understanding the physiological performance and psychological consequences associated with inefficient movement. Prevalence estimates are definition dependent due to the continuous nature of the problem (Gomez & Sirigu, 2015), however, studies have projected that nearly 5-6% of school-aged children in the UK (American Psychiatric Association, 2000; Gubbay, 1975; Henderson & Sugden, 1992; Magalhaes et al., 2011) and 15-16% in Greece and Singapore (Asonitou et al., 2012) experience considerable difficulties coordinating and controlling their body movements (American Psychiatric Association, 1994, 2000). These impairments affect the performance of age-appropriate motor tasks and daily activities that vary and range from fine motor to gross motor skills (Green et al., 2008; Hoare, 1994; Polatajko & Cantin, 2005; Rivilis et al., 2011).

Although some population studies imply an equal distribution of MD observed in males and females (Gubbay, 1975; Taylor, 1990), teacher and clinical referrals have reported a 3:1 ratio of males to females identified with poor coordination and clumsiness between 6 to 12 years of age (Missiuna et al., 2003); citing a 13-18% delay in reaching motor milestones for their age (Gubbay, 1978; Johnston et al., 1987). In addition, a higher incidence of MI may be found among children with a history of prenatal or perinatal difficulties (i.e. pre-term/low-birth weight) (Marlow et al., 2007; van Baar et al., 2005; Zwicker et al., 2013). Subsequently, school-aged children with MI have consistently demonstrated lower fitness levels and participation in physical activity (PA) in comparison to typically developing (TD) peers (Bloemen et al., 2015; Haga, 2008; Kolehmainen et al., 2011; Morris et al., 2013). Globally, 81% of children aged 11-17 years fail to meet the recommended PA guidelines and attain sufficient levels of PA (World Health Organization, 2010). Provided that, the percentage of inactivity and rise in obesity (Cairney et al., 2005; Wagner et al., 2011; Zhu et al., 2011) may be even more predominant in children with MI. Of added concern is that movement impairments are known to represent a continuous disorder, persisting throughout adolescence and adulthood (Cermak & Larkin, 2002; Kirby et al., 2010) thus, further impacting the ability of these individuals to develop and achieve a physically active lifestyle (Morris et al., 2013).

1.2 Definition and diagnosis

The first description of individuals exhibiting clumsiness and awkwardness syndrome occurred in the 1930s (Orton, 1937) and was later referred to as "clumsy child syndrome" in 1975 (Dewey & Tupper, 2004; Gubbay, 1975). Since then, the literature has encompassed a variety of terms to describe these children including but not limited to: 'movement difficulties', 'clumsy', 'low motor competency/proficiency', 'motor learning difficulties', 'dyspraxia' and most commonly 'developmental coordination disorder (DCD)' (American Psychiatric Assocation, 1994; American Psychiatric Association, 2000; Bouffard et al., 1996; Cairney et al., 2005; Cantell et al., 2008; Cantell et al., 1994; Geuze et al., 2001; Haga, 2008; Hill & Barnett, 2011; Hoare, 1994; Sugden & Wright, 1998). Over time, the term DCD gained popularity in the literature and research community to better help identify children with MD and to standardise research efforts in the field (Missiuna et al., 1995). Furthermore, the Diagnostic Statistical Manual (DSM-IV, 1994) devised a criteria-based diagnostic approach to formally define and diagnose individuals with DCD. The International Classification of Disease (ICD-10) also recommends individually administered, norm-referenced standardised testing to diagnose developmental conditions (World Health Organization, 1996). These various screening measurement tools include the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978; Venetsanou et al., 2007), the Movement Assessment Battery for Children (MABC) (Henderson & Sugden, 1992) and the Developmental Coordination Disorder Questionnaire (DCDQ) (Wilson et al., 2007) further described in Chapter 3.4.1. A somewhat arbitrary cutoff point that ranges from the 5th to the 20th percentile across different assessments is typically used to categorise and define impairment (Gomez & Sirigu, 2015). Nonetheless, adherence to the selection criteria has been inconsistent (Geuze et al., 2001) and a complete explanation of atypical developmental phenomenon remains complex and open for interpretation (Gomez & Sirigu, 2015).

To briefly address the different terminology found in the literature, "motor disorder" and "motor impairment" imply more overt central nervous system (CNS) damage in the CNS sensory motor areas or corticospinal tract involving symptoms of spasticity and dystonia. However, from what is known about DCD and probable DCD (pDCD), the underlying mechanisms may involve more issues with white matter connectivity between other areas (Langevin et al., 2015), rather than simply overt damage. Thus, the term "movement disorder" would fundamentally rule out DCD since not all children with DCD will have difficulties with movement per se, but rather more related to the visual-spatial or planning elements. The terms "motor skill proficiency" and/or "motor competency" would only be considered appropriate if the study group was predefined to only those who have movement skills testing below a certain cut-off point on a battery assessment (Chapter 3.4.1.2). In effect, the studies comprised in this thesis did not follow a formal diagnosis of DCD, but utilised a norm-referenced movement battery assessment to categorise the varying degrees of MD and motor coordination abilities observed in children and adolescents. Therefore, the term movement impairment (MI) was used throughout the studies to describe the population group of interest.

1.3 Deficits and prognosis

Although the aetiology of MI is thought to be multifactorial, what remains undisputed is the heterogeneity of the impairment and difficulties experienced by each child, which are not due to a pervasive developmental disorder, any history of neurological disease (i.e., muscular dystrophy or cerebral palsy) or intellectual impairments (American Psychiatric Association, 1994; Haga, 2008). These difficulties and challenges significantly affect activities of daily living (ADL) (i.e., functional mobility, self-care), academic performance and PA and play (Blank et al., 2012; Green et al., 2011; Jarus et al., 2011). To further, children with MI and MD often have coexisting conditions including attention deficit hyperactivity disorder (Baerg et al., 2011; Blank et al., 2012), learning difficulties (i.e., cognition, automisation, working memory) (Biotteau et al., 2015; Chen et al., 2015; Crova et al., 2014) and visuospatial deficits (Cantin et al., 2014; Tsai et al., 2012). Consequently, it is generally believed that the deficits and challenges including cognitive and learning problems, poor self-esteem and lower physical activity (PA) participation and fitness levels continue into adulthood if not addressed earlier on (Barnett et al., 2013; Cantell et al., 1994; Green et al., 2008; Hoare, 1994; Piek et al., 2010). Given the importance of movement development and the vicious cycle of physiological, psychological and environmental factors influencing the day-to-day life experiences of children with MI (Hill & Barnett, 2011), more research on the morphological and fitness components impacted by movement deficits is required (Ferguson et al., 2014; Summers, 1992). Moreover, greater attention to the limitations and underlying mechanisms including central and peripheral components (Farhat et al., 2014) of poor fitness, exercise intolerance and movement inefficiencies in MI is further warranted.

1.4 Fitness, physical activity and movement impairment

The development of adequate motor control and coordination plays an important role in growth and development; emerging early on to allow an infant to interact with and learn about their environment and eventually advancing to performing everyday activities during childhood (Hill & Barnett, 2011). Specific movement skills are needed for the development of health-related fitness components such as strength, power, muscular endurance, cardiorespiratory endurance and skill-related ones (i.e., balance, coordination, agility, reaction time) (Cantell et al., 2008; O'Beirne et al., 1994; Okely et al., 2010; Stodden et al., 2008). Consequently youth with MI and MD have consistently demonstrated lower fitness levels and decreased participation in PA compared to TD children (Bloemen et al., 2015; Haga, 2008; Kolehmainen et al., 2011; Morris et al., 2013). Children with poor coordination and MD demonstrate an increased risk for obesity (Cairney et al., 2005; Cantell et al., 2008), cardiovascular disease (CVD) (Faught et al., 2005) and compromised fitness (Morris et al., 2013) and PA levels (Barnett et al., 2009; Hands & Larkin, 2006).

More recently, numerous studies have emphasised the emerging relationship between movement skills, physical fitness, PA outcomes and exercise tolerance (Faught et al., 2013; Lubans et al., 2010; Morris et al., 2013; O'Beirne et al., 1994). Previous findings have revealed a negative relationship between degree of MI and fitness, as a result of inefficient movement patterns and reduced movement economy (Cantell et al., 2008; Morris et al., 2013). Whether measured in children or adults, individuals with MI have exhibited a reduced exercise capacity; failing to exercise hard enough to maximally tax the cardiovascular system (Cantell et al., 2008; Faught et al., 2013; Morris et al., 2013). Correspondingly, they have demonstrated lower maximal oxygen uptake ($\dot{V}O_{2max}$) and a reduced aerobic capacity on laboratory- and field-based testing (Faught et al., 2013; Morris et al., 2013; O'Beirne et al., 1994). During these assessments, children with MI also reported experiencing earlier fatigue compared to their well-coordinated peers (Farhat et al., 2014; Faught et al., 2013). To further, there is evidence to support that perceived adequacy toward PA and self-efficacy to perform tasks may contribute to the differences in fitness between children with and without MI (Cairney et al., 2005; Farhat et al., 2014). The decreased self-efficacy, perceived competence and motivation in MI may not only impact their performance on a particular task (i.e., riding a bicycle, catching a ball or running), but may also be detrimental to long-term participation in PA and play (Cairney et al., 2005; Cantell et al., 2008; Cantell et al., 2003). Individual factors such as physical difficulties and psychological aspects of an individual with movement difficulties may impact engagement in PA and exercise (Poulsen & Ziviani, 2004). In addition, Poulsen and Ziviani (2004) proposed that external factors such as social, cultural and environment may further act as facilitators or constraints/barriers to participation in PA (Barnett et al., 2013). Consequently, more interventions and programmes incorporating multiple dimensions alongside peer, teacher and family involvement are warranted to develop better models in youth with MI. Strategies targeting how children with MI perceive and enjoy exercise/activities are equally important for designing and implementing interventions to promote a physically active lifestyle.

Wasteful and inefficient movement patterns have also been attributed to the diminished fitness capacity alongside decreased muscle strength and power in MI (Farhat et al., 2015; Faught et al., 2013; Morris et al., 2013; Raynor, 2001). To this regard, a challenge in studies assessing fitness parameters often include using appropriate equipment and administering tests that can be suitably performed by individuals with poorer movement skills (Chapter 5) (Cantell et al., 2008; Faught et al., 2013). In contrast, the limitations to exercise in MI have strong physiological underpinnings (Morris et al., 2013) and may be influenced from both central and peripheral factors. For example, the reduced strength of major locomotor muscles in MI has been hypothesised to be ascribed to increased cocontraction, fatigue and generally underdeveloped strength (Morris et al., 2013; Raynor, 1998, 2001). However, despite their willingness to exert themselves maximally, children with MI also perceive exercise to be more strenuous (Barnett et al., 2013; Faught et al., 2013). From this standpoint, prospective studies should evaluate how children and adolescents with MI perform and tolerate different exercise intensities; including higher-intensity exercises which have shown to feasibly reduce cardiovascular risk and improve muscle function in healthy children (Buchan et al., 2013). Nevertheless, there remains a paucity of research examining the underlying mechanisms to exercise performance, particularly to various exercise intensities and further research is therefore required to identify novel and sustainable approaches to improve fitness and health in children with MI.

1.5 Organisation of the thesis

The aim of this thesis was to explore the physiological and perceptual responses to acute and chronic longer-term exercise in children and adolescents with MI. A unique opportunity to address this objective and extend the findings from previous work arose from (1) an evaluation of the gaps in the literature and (2) a collaboration with Sport England to implement and evaluate a pathway to sport and PA in MI. A systematic review of the literature was first conducted to provide insight on the types of interventions focused on physical fitness and activity in MI (Chapter 2) while presenting a platform to address the primary research question in the subsequent experimental chapters. A review of the methodology and techniques used to investigate components of fitness throughout the studies was addressed in Chapter 3. From there, the first experimental chapter (Chapter 4) explored the physiological and perceptual responses during and following an acute bout of high-intensity (HI) and low-intensity (LI) exercise in a range of children and adolescents with and without MI (NMI). In Chapter 5, the reliability and validity of submaximal exercise tests (Åstrand-Rhyming and Chester Step Test) to measure aerobic fitness for mass screening purposes was conducted to identify children and adolescents with MI in school settings (Chapter 6). Correspondingly, Chapter 6 extends the findings from the previous chapters by incorporating the fitness measures and testing paradigms to develop and assess the feasibility of a longer-term intervention (EPIC Club) designed to improve PA participation and fitness in adolescents with MI. Finally, Chapter 7 summarises and concludes the results and findings from Chapters 2-6 and provides recommendations for future research.

2

Systematic Literature Review

2.1 Abstract

Objectives: To systematically review and summarize the existing literature on the effectiveness of physical activity (PA) and exercise interventions on fitness, physical performance and psychosocial well-being in children and adolescents with movement impairment (MI). **Data sources**: Literature search using EMBASE, BNI, CINAHL, Cochrane Library, Ovid MEDLINE and Scopus from Jan 2005 to July 2015. **Review methods**: Two independent reviewers performed a systematic search of electronic databases and included studies for full-text review using the following inclusion criteria: all types of PA and exercise interventions reporting on fitness components in children and adolescents (average ≥6 years old) with MI. Inclusion of a different intervention or non-physical activity intervention in a control group was included. Data extraction was completed on the intervention study characteristics including: type of study design, sample size, protocol and outcome results. Methodological quality was also assessed using a 10-item scale. Levels of evidence were assessed for four types of intervention and four settings. **Results**: The literature search identified 14 studies meeting the inclusion criteria: 7 of high methodological quality (7/10 score), including 5 randomised controlled trials of high quality. Five studies used the Nintendo Wii

Fit and other virtual-reality (VR) videogame console, four studies incorporated fitness and exercise training, three studies on specific sports training/riding therapy and two studies featuring task/goal-based skill development. The fitness outcomes varied from each study however, movement skill proficiency/motor coordination and function were the most commonly measured with significant improvements shown post-intervention. Inconclusive and limited evidence for an effect was found for school and community settings, yet moderate effectiveness was shown for primary care facilities. Furthermore, moderate evidence was found for sports training/therapy and skill development intervention designs for improving one or more fitness parameter in MI. **Conclusion**: Some evidence ranging from limited to moderate was found for potentially effective intervention strategies to increase PA and fitness in youth with MI. These included but were not limited to sports training and skill development methods. Movement/motor proficiency was most commonly assessed across the different interventions employed, highlighting the importance of incorporating PA and exercise strategies targeting development of motor skills and functional movement. Although implementation within clinical settings showed promise, a lack of high quality evaluations with sufficient sample sizes resulted in limited effectiveness on fitness. Larger RCT studies with follow-up periods within school-based and community settings may better elucidate intervention effectiveness on fitness in MI.

2.2 Introduction

In light of the global burden and profound rise in non-communicable diseases, physical inactivity has been identified as the fourth leading risk factor for mortality, causing an estimated 3.2 million deaths worldwide (World Health Organization, 2001, 2010). Physical activity (PA) is defined as any body movement produced by skeletal muscles that require energy expenditure (EE) (World Health Organization, 2010). Comparatively, exercise refers to planned structured activities involving repeated movement of skeletal muscles that result in EE and seeks to improve or maintain levels of fitness above the intensity of activities of daily living (ADL) (Caspersen et al., 1985; Verschuren et al., 2008). Adequate exercise and PA in youth improves strength (Lloyd et al., 2013), cardiorespiratory fitness

(Armstrong et al., 2008; Ortega et al., 2008), and body composition (Ruiz et al., 2006; Spolidoro et al., 2013) thereby decreasing cardiovascular risk factors (Dunn et al., 1999; Fox et al., 1971; Sallis, 1993) and development of metabolic conditions (Chaput et al., 2013; Nelson et al., 2013). Current guidelines suggest that children and adolescents aged 5-18 years should engage in moderate-to-vigorous physical activity (MVPA) for 60 min or more per day and incorporate muscle and bone-strengthening activities three or more times per week (Dobbins et al., 2013; Janssen & Leblanc, 2010; Landry & Driscoll, 2012; WHO, 2004a). Despite these recommendations, globally 81% of children between 11-17 years old fail to attain sufficient levels of PA (World Health Organization, 2010), while increasingly engaging in sedentary behavior. These estimations may be even more prevalent in youth with movement difficulties and physical disabilities. Nonetheless, the pandemic of physical inactivity remains one of the greatest global challenges of our time and a major public health concern (Kohl III et al., 2012).

Regular PA and exercise is essential for optimal function of the human body and physical fitness (Malina, 2001). Correspondingly, fitness including health-related and skill-related components, is a powerful marker of health (Ortega et al., 2008) and is positively associated with movement proficiency and coordination (Hands et al., 2009; Lubans et al., 2010; Morris et al., 2013; Rivilis et al., 2011). Over the past decades, a surge of interest and concern for children presenting with clumsy movement and poor motor coordination has identified a relationship between PA and fitness parameters in children with movement difficulties (MD) (Haga, 2008; Rivilis et al., 2011) . As a result, youth with movement impairment (MI) and MD have demonstrated lower fitness levels and participation in PA compared to typically developing (TD) peers (Bloemen et al., 2015; Haga, 2008; Kolehmainen et al., 2011; Morris et al., 2013). To further complicate the matter, the literature encompasses a variety of terms to describe MI including but not limited to: ‘movement difficulties’, ‘clumsiness’, ‘motor impairment’, ‘motor learning difficulties’, ‘dyspraxia’ and most commonly ‘developmental coordination disorder’ (DCD). These terms are often used to refer to children who lack the motor coordination necessary to perform age-appropriate motor tasks, but who have adequate general intelligence (IQ>70) and no history of neurological disease (American Psychiatric Association, 1994; Haga, 2008).

Nearly 5-6% of school-aged children and adolescents in the UK (American Psychiatric Association, 2000; Magalhaes et al., 2011) and 15-16% in Greece and Singapore (Asonitou et al., 2012) experience considerable difficulties coordinating and controlling their body movements (American Psychiatric Association, 1994, 2000). These marked impairments have been reported to impact ADL, leisure activities, sports and academic performance (Cairney et al., 2007; Cairney et al., 2005; Cantell et al., 2008; Polatajko & Cantin, 2006; Summers et al., 2008) and has become a prominent area of research in paediatric healthcare within recent years. Studies exploring the leisure time and PA patterns of children with MI (Raz-Silbiger et al., 2015) have illustrated an alarming risk profile for metabolic syndrome (Cantell et al., 2008; Morris et al., 2013; Wahi et al., 2011) and cardiovascular disease (Faught et al., 2005; Rivilis et al., 2011) due to a higher percentage of body fat (Cairney et al., 2005; Joshi et al., 2015; Wrotniak et al., 2006), reduced aerobic capacity and generally decreased participation in PA and play (Cairney et al., 2007; Cairney et al., 2005; Rivilis et al., 2011; Schott et al., 2007; Wrotniak et al., 2006). In addition, lower PA levels often persist into adulthood and further impact healthy living and quality of life. Therefore, the combination of the health risks associated with physical inactivity and obesity presents a serious health concern and serves as an important target for PA promotion and interventions in this population.

The literature is replete with research studies highlighting the benefits of PA among healthy children (Armstrong 1994; Brown 2009; CDC 1997; CDC 1999; McMurray 2002; Thakor 2004; Tolfrey 2000; Whitt-Glover 2009; Zahner 2006; Dobbins et al., 2013) demonstrating the efficacy of school-based approaches to improving participation in PA, fitness, self-efficacy and measures of health and well-being (Dobbins et al., 2013; Dudley et al., 2011; Kriemler et al., 2011; Lonsdale et al., 2013; Naylor et al., 2015; Parrish et al., 2013; van Sluijs et al., 2007). Findings from these studies emphasised the need for fostering positive attitudes toward PA within schools and assessing the barriers and facilitators of PA (i.e., socioeconomic status, ethnicity) to devise interventions (Dobbins et al., 2009; Dobbins et al., 2013). In contrast, one of the most important challenges for paediatric rehabilitation and healthcare professionals is finding ways to increase and maintain PA and fitness among youth with MI (Buffart et al., 2010; Green et al., 2011). Regular provision for these children was conducted through a paediatrician via occupational therapy or physiotherapy (Sugden & Chambers, 2003, 2006). However, resource implications mean that most time is spent in assessment and advice. Due to the heterogeneity of functional abilities and motor deficits presented in MI, the type of effective interventions may vary from child to child. Albeit a small amount of research on interventions aimed at improving fitness in youth with poor movement and coordination, the majority of these studies are conducted in clinical settings where most or all of the common barriers (Barnett et al., 2013) to participation are eliminated (e.g. transportation, lack of knowledgeable staff, adaptation of programmes and/or facilities to child's needs) (Rimmer & Rowland, 2008). To date, there has been no real world delivery and subsequent evaluation for such interventions, yet ecological intervention models and group programme designs are gaining prominence (Cacola et al., 2016; Sugden, 2007).

Systematic reviews and studies have been conducted to summarise the barriers/constraints and facilitators to participation in PA in children and adolescents with physical disabilities (Bloemen et al., 2015; Ullenhag et al., 2014) and DCD (Barnett et al., 2013; Magalhaes et al., 2011; Rivilis et al., 2011). A common theme from these studies indicate the significance of increasing self-efficacy as well as the availability of appropriate equipment/facilities to foster environmental opportunities for PA (Bloemen et al., 2015). These studies not only stress the importance of exploring the fitness parameters and patterns of PA in MI, but also warrant the need for designing interventions to help improve these outcomes. For example, previous reports have concluded that the intensity, frequency and duration of PA contribute to overall public health status and suggest that a ‘threshold’ must be maintained in order to produce positive health effects (Cacola et al., 2016; Dobbins et al., 2013; Ruiz et al., 2006). However, few studies have measured intensity level and thus, the minimal and optimal doses of PA required for positive health benefits in youth remain unclear (Janssen & Leblanc, 2010).

Correspondingly, there are gaps in the literature regarding the impact of interventions due to methodological challenges like type of fitness and PA outcomes quantified and the measurement tools used across studies (Naylor et al., 2015; Rivilis et al., 2011). Better insight on the impact of exercise and training interventions on fitness measures are further required to address exercise prescription in children and adolescents with MI. Equally important is the quality of study and intervention design. According to a review by Verschuren et al. (2008), RCTs represent the ideal method to ensure that any differences in outcome are attributed to the treatment and not due to other factors, thereby determining the efficacy of a treatment. However, numerous studies in the literature often employ less-well-controlled research designs, making it difficult to confidently evaluate and grade the evidence of the results. In addition to conducting higher quality trials and longitudinal studies, more empirical evidence may provide a better understanding of the multidimensional factors related to participation in MI (Haga, 2008; Sugden & Chambers, 1998), while critically informing the design of appropriate activity-based interventions (Rivilis et al., 2011) .

To date, no review has evaluated the wide-range of interventions available or the quality of these studies targeting PA in MI, particularly on fitness parameters. Therefore, the aim of this review was to systematically describe and summarize the existing literature on the effectiveness of physical activity and exercise interventions on fitness, physical performance and psychosocial well-being in children and adolescents with MI. This review sought to address the following questions: (1) What types of exercise and training interventions focus on increasing PA or fitness in children and adolescents with MI? (2) What are the outcome measures that were used to assess and evaluate the effects of the interventions? and (3) What is the methodological quality of these studies?

2.3 Methods

A literature search of papers on PA and exercise interventions in young people with MI and DCD was employed using six electronic databases (EMBASE, BNI, CINAHL, Cochrane Library, Ovid MEDLINE, Scopus) for publications between Jan 2005 to July 2015. The search strategy focused on four key elements: population (i.e., children, adolescents, youth with MI); study design (i.e. randomised controlled trials (RCTs), case-controlled trials (CCTs), pre/post); interventions (i.e., PA promotion, exercise training, physical therapy, behaviour change) and outcome (i.e., fitness components, PA levels/skills and/or markers of health and well-being). The search strategies for the different electronic databases and the keywords used to perform the search are shown in Appendix A, with assistance by the Oxford Health NHS Foundation Trust (KC). Furthermore, other potential papers for inclusion were identified through a search of the reference lists from included papers and published relevant reviews. Duplicate article citations were identified and screened by hand.

2.3.1 Inclusion/Exclusion Criteria

We restricted the review to published study trials, applying the following inclusion criteria: (i) children and adolescents (i.e., teens, youth, students, boys or girls) ≥6 years old, based on either the minimum age or average combined with; (ii) diagnosed or described movement impairment/movement difficulty via norm-referenced tests/criterion measures (≥50% of total included participants must be categorised with MI/MD and excluding cerebral palsy and neuromuscular diseases); (iii) interventions in which the main component or one of the components aimed to promote PA and fitness components (inclusion of a different intervention or non-physical activity intervention for control group); (iv) a reported outcome measure of interest relating to any validated or defined fitness parameters (i.e., cardiorespiratory fitness (CRF), muscle strength/endurance, motor skill, agility, flexibility, energy expenditure (EE), physical activity level (PAL) and time spent active). For example, CRF could be expressed as maximal oxygen uptake ($\dot{V}O_{2max}$) and assessed using the incremental bike test or via field-testing as long as the author defines the outcome. Secondary outcomes of interest included: fatigue, self-efficacy/self-esteem, adherence/attendance, cognition and behaviour, enjoyment and quality of life (QoL). For a typical search of one database see Appendix A.

Two reviewers (FL and GB) independently reviewed the results from the initial search based on the title and abstract. Eligible studies meeting the inclusion criteria were obtained in full text after discussion and agreement on the included titles/abstracts. When appropriateness of the title/abstract could not be determined, the full text was retrieved and discussed for further consideration. From there, both reviewers checked the full text papers and upon 100% agreement the papers were included for data extraction.

2.3.2 Data extraction

Data extraction was performed using standardised forms (Appendix B) and transferred onto a spreadsheet database with information regarding the study design, randomisation and blinding procedure, participant and control group characteristics, diagnostic criteria for categorising MI/MD, description of intervention(s) and control conditions, duration of intervention, length of follow-up, losses to follow-up, main outcome measures, secondary outcome measures, and results (Appendix B). In order to categorise results across studies so that they were comparable for synthesis and evidence assessment, studies were grouped by study design, type of intervention programme and fitness measure. Similar to the methods endorsed in van Sluijs et al. (2007), the size of the study was given a positive (+) if there were more than 250 participants or if a power calculation was provided justifying the sample size (large) and as negative (-) if there were ≤250 participants (small).

2.3.3 Assessment of methodological quality

For each of the included studies, methodological quality assessment was performed using a 10-item quality assessment scale (Table 2.1) used in recent reviews on child and adolescent PA interventions (van Sluijs et al., 2007) and the effect of school recess PA interventions (Parrish et al., 2013). Two reviewers (FL and GB) independently assessed for the quality of each study using scoring items A-J and indicated whether an item was “positive”, “negative” or “not/insufficiently described” (Table 2.1). In cases of disagreement, consensus was reached by discussion. Methodological quality was defined as high when a RCT scored ≥6 or a controlled trial scored ≥5 or more on the scale. The level of agreement between the two reviewers (FL and GB) was evaluated using Cohen's k, with agreement determined as "positive" or "negative and not described" assessments.

Table 2.1 Criteria for assessment of methodological quality adapted from van Sluijs et al. (2007)

Item	Description (10-items)
A	Groups comparable at baseline on key characteristics—positive if stratified baseline characteristics were presented for age, sex, and at least one relevant outcome measure; for cluster randomized controlled trials and controlled trials, positive if this was statistically tested; and for all studies only positive when differences observed were controlled for in analyses.
B	Randomisation procedure clearly described and adequately carried out.
C	Unit of analysis was individual—negative if unit of analysis was school level, or school level randomisation not accounted for in individual-level analyses
D	Validated outcome measures used—positive if validation of outcome measures was reported or referred to
E	Dropout described and not more than 20% for studies with a follow-up of 6 months or shorter, and not more than 30% for studies with a follow-up longer than 6 months.
F	Timing of measurements comparable between intervention and control groups
G	Blinding outcome assessment—positive if those responsible for assessing outcome were blinded to group allocation of individual participants
H	Participants followed up for a minimum of 6 months
I	Intention-to-treat analysis used
J	Potential confounders accounted for in analyses

** Future physical activity intervention studies might usefully do within study risk group analyses to examine whether the intervention does indeed achieve the intended response in those children who stand to benefit the most

2.3.4 Evidence assessment

In many systematic reviews, a meta-analysis is performed by statistically combining and integrating the results of the various included studies into a single estimated effect size (ES) (Stroup et al., 2000). However, a meta-analysis has been described specifically for RCTs (Verschuren et al., 2008). Several of the studies included for review consisted of CCTs, observational and pre/post design, a complexity in which the use of meta-analysis is generally not recommended (Egger et al., 1998). Due to the heterogeneity of the intervention types, settings and outcome measures used, we intended to use a rating system of levels of evidence to help evaluate diverse studies and to determine the degree of confidence on the effectiveness of an intervention (Engbers et al., 2005; van Sluijs et al., 2004; van Sluijs et al., 2007). This rating system consists of five levels including study design, methodological quality and sample size: strong, moderate, limited, inconclusive, or no evidence for effect, and conclusions drawn based on the consistency of results from studies demonstrating the highest available level of quality. Scores were used to indicate intervention 'effectiveness' with the following scoring: no difference in effect between control and intervention group (0 score), a positive or negative trend (+ or −), or a statistically significant difference ($p<0.05$) in favour of the intervention or control (++ or ––, respectively) (van Sluijs et al., 2007). In effect, if at least two thirds (66%) of the relevant studies were reported to have significant results in the same direction, then overall results were considered to be consistent.

2.4 Results

The search yielded 150 potentially relevant publications based on titles (BNI, n=7; CINAHL, n=43; EMBASE, n=25; Cochrane Library, n=3; OVID Medline, n=36; Scopus, n=36). On the basis of information retrieved in the abstracts, 117 articles were excluded and 33 met the inclusion criteria for full paper retrieval. Of the 33 articles included for full text data extraction and evidence synthesis, nineteen papers were excluded based on further analysis (Figure 2.1). Overviews of the literature, comparisons of interventions or systematic reviews were also excluded. Other reasons for exclusion were no diagnostic tools used to categorise population group, main outcome measure did not involve fitness parameters and study design described with no results presented. In total, fourteen studies were included and the intervention study characteristics are presented in Table 2.2.

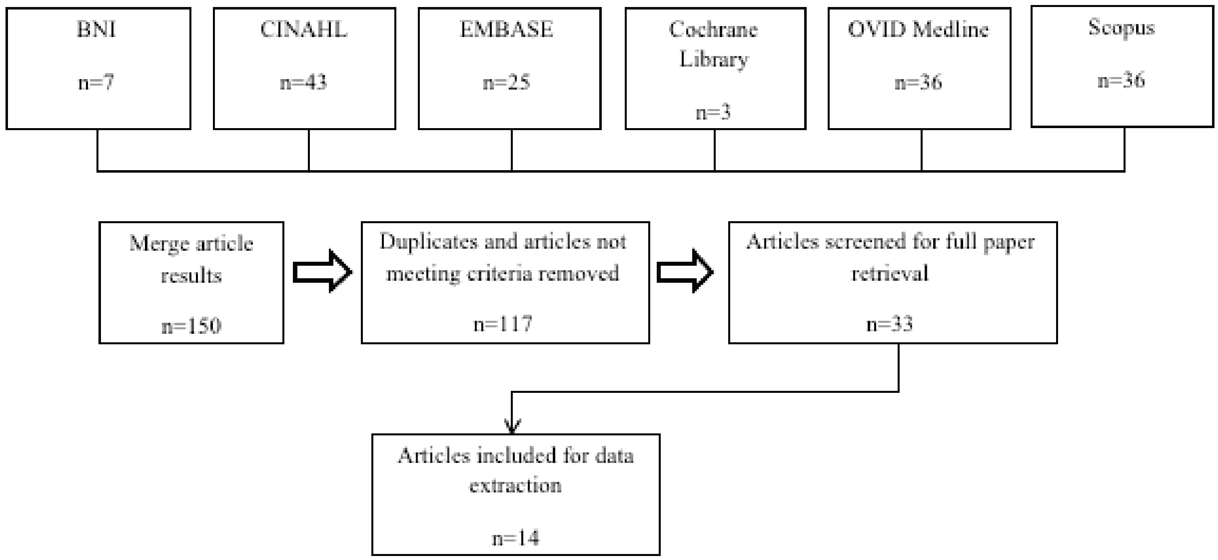


Figure 2.1 Identification of included studies

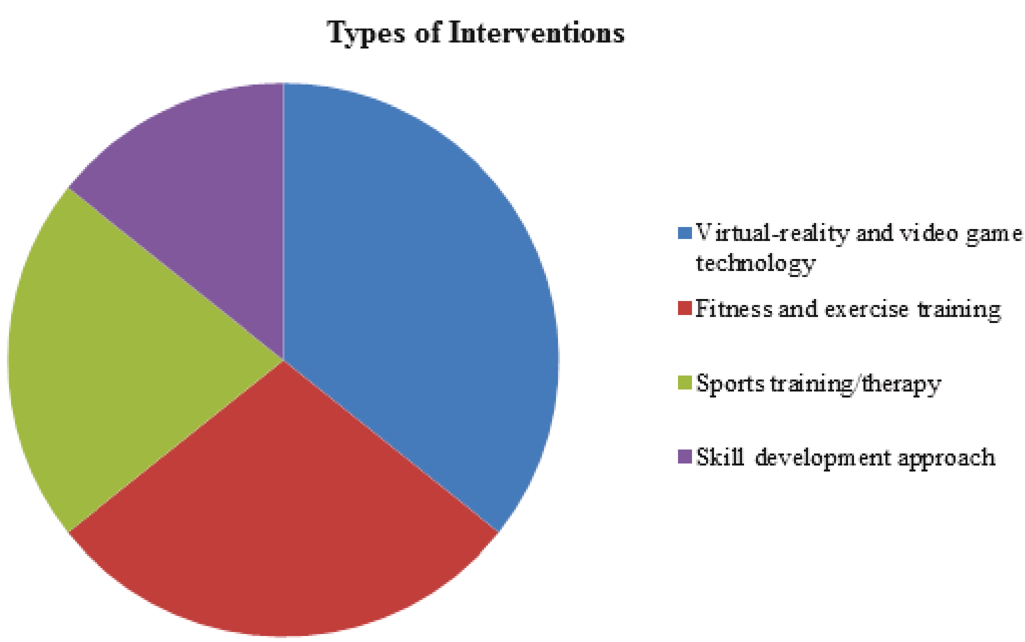


Figure 2.2 Breakdown of intervention type

Table 2.2 Intervention characteristics of included studies aimed at improving fitness and increasing physical activity in children and adolescents

Study	Design	Movement impairment assessment tool	Participants	Intervention description and intensity	Outcome measures
(Hammond et al., 2014)[1]	Randomised cross-over trial (pilot study) (UK)	Participants were recruited from two primary schools in Mid-Sussex, UK following a two stage recruitment process. Stage 1: senior members of staff at each school identified children who were in 'Jump-Ahead', a local school-run motor intervention program for children with movement difficulties, including some formal diagnosis of DCD. Stage 2: each child's teacher completed the Developmental Coordination Disorder Questionnaire (DCDQ) (5^{th}-15^{th} percentile cut-off)	Children with DCD aged 7-10 years and those considered to be at risk of movement difficulties (scoring within the bottom quintile on the DCDQ) and/or had a diagnosis of DCD. N=10 assigned to intervention and n=8 in comparison group (did not specify M/F numbers)	This was a cross-over intervention study consisting of two phases, each lasting four weeks for a total of eight weeks. In Phase 1, children were randomly divided into two groups: Group A (n=10) and Group B (n=8). School-based supervised play for 10 min on Wii Fit was offered three times weekly for 1 month during lunch break for the intervention group while, the comparison group took part in their regular 'Jump Ahead' programme. The Wii Fit games focused on balance and coordination. It was administered at the discretion of the schools, during lunchtime. Phase 2 commenced 2.5 months after the end of Phase 1 and the groups participated in the alternative intervention for the following four weeks	Motor proficiency was measured using the BOT-2 SF and self-perceived ability and satisfaction with motor tasks via the 10-item questionnaire called the Coordination Skills Questionnaire (CSQ). Lastly, the emotional and behavioural development of the participant was assessed via a 25-item parental report using the Strengths and Difficulties Questionnaire (SDQ)
(Au et al., 2014)[2]	RCT (Hong Kong)	Diagnosis of DCD according to criteria described in Diagnostic and Statistical Manual	Children aged 6-12 years with DCD. N = 26 (15M/7F)	A 8-week pilot of the Core stability program (using physioball Fitball) vs. Task-oriented program (training on functional tasks including those involving body stability and those	The outcome measures of interest include the BOT-2 SF (with a possible score ranging from 20 to 80, mean = 50 and SD = 10) and postural control via the Sensory Organisation Test using the Balance Master System.

		for Mental Disorders, 4th Edition (DSM-IV); MABC and BOT-2 SF. MABC ≤ 15th% percentile and/or demonstrating two or more subtests on BOT-2 SF < 1.5 SD		required for body transport) run by a physiotherapist once per week for 60 min. Level of difficulty was increased by increasing the complexity of the tasks, number of repetitions and duration of each exercise/activity and reducing the level of assistance or guidance	Attendance was also measured.
(Jelsma et al., 2014)[3]	Mixed methods: combined interventional and nested case control study (The Netherlands)	The MABC-2 was used to identify pDCD. Balance score (static and dynamic and IQ>70 was also determined. MABC2 ≤ 16th% and ≤ 16th% score on the component score for balance (static and dynamic balance)	Children between 6-12 years old with pDCD, balance problems (BP) and typically developing children (TD). N = 28 (14M/4F) and 20 TD children	Technology-based intervention consisting of 30 min practicing the Wii Fit plus balancing games with intervention given by 4th year students of a Sports Academy or Medical Pedagogy under supervision of first author. Sessions were offered 3 times per week for 6 weeks total. Children could choose from 18 Wii balancing games and played each game twice before being allowed to continue to one of the other games to allow for variety of training and equal time spent training	Motor performance was assessed with the MABC-2 and three subtests of the BOT-2 SF (i.e., bilateral coordination, balance and running speed and agility). A Wii Fit ski slalom test was also administered
(Kane & Bell, 2009)[4]	CCT (Canada)	Participants met the criteria outlined by the Diagnostic and Statistical Manual of Mental Disorders Fourth Edition criteria for DCD (DSM-IV) and referred by a developmental paediatrician. DCDQ, BOT2-SF and CSAPPA administered at baseline. Initial scores seen: DCDQ	Children 9-11 years old with DCD (Case report study documenting the response to a 6-week group exercise intervention program). N=3 (1M/2F)	Six-week group program held twice weekly in a gymnasium at a rehabilitation center with a PT. Each session consisted of a 20 min aerobic warm-up, 15 min of core stability exercises and 20 min of task-specific intervention and sport skills training based on the child's chosen goals. Eight home exercises were also promoted based on classic Pilates and core stability exercises graded to match the abilities of the children provided in a home manual. A task-specific intervention whereby an individualized approach focuses on problem solving and direct teaching of specific functional, meaningful skills,	Core stability screen and rating of self-chosen goal measures are highlighted here with the child-chosen goals. Baseline and post-intervention assessment of the DCDQ, Canadian occupational and performance model and the BOT-2 SF.

		37-40/85; BOTMP-SF below 1st% to 15th%; CSAPPA 66-68		with the goal of optimising movement efficiency and performance, given the individual's abilities was used to teach sport skills including floor hockey, basketball and soccer	
Fragala-Pinkham et al. (2006)[5]	Quasi-experimental using a single group pre-test and post-test design to examine feasibility (USA)	Participants classified using criteria from the Gross Motor Function Classification System (GMFCS). Level I: ability to walk without restrictions but had limitations in advanced gross motor skills; Level II: walked without assistive devices but had difficulty with walking outdoors and in the community; Level III: walked with and assistive device and had limitations in walking outdoors and in the community	School-aged children between 6-14 years of age with neuromuscular and developmental disabilities. N=28 (17M/11F)	16-week community-based fitness group fitness program held twice weekly at YMCA sites consisting of strengthening, aerobic conditioning and flexibility exercises. Each 60 min sessions was run by a paediatric physical therapist.	Outcome measures of interest include: isometric muscle strength of the knee extensors, hip abductors, and ankle plantarflexors, walking energy expenditure index (EEI), functional mobility and fitness. Falls and injury data and program attendance was also reported
(Ferguson et al., 2013)[6]	Pragmatic, single-blinded, quasi-experimental design (South Africa)	Classified using the MABC-2 ($\leq 16^{th}$ percentile) and teacher report of functional motor problem	Children 6-10 years old with DCD attending mainstream schools in low-income setting. School A and B (n = 27) and school C	Task-based intervention approach via neuromotor task training (NTT) and Nintendo Wii Fit Training (Wii training) designed to examined the efficacy of this intervention approach improve motor performance. Children attending schools A and B identified with DCD automatically allocated to NTT	Motor performance measures including isometric strength (handheld dynamometer), Functional Strength Measures (FSM) and cardiorespiratory fitness (aerobic and anaerobic capacity) (20 Metre Shuttle Run test; 20mSRT and Muscle Power Sprint Test)

			(n = 19) (15M/12F NTT and 9M/10F Wii training)	intervention and those at school C allocated to Wii training programme conducted at school or after school with therapist. 2x45 and 60 min sessions per week (9 weeks total) for NTT and 30 min Wii Fit intervention twice weekly for 6 weeks total.	
(Menz et al., 2013)[7]	Single-case study (USA)	Medical diagnosis of apraxia and hypotonia with BOT-2 SF scores 1.5 to 2 SDs below the mean	One girl aged 6 years 11 months with apraxia and hypotonia and demonstrating motor delays consistent with DCD	A strength training program taking place twice a week over a period of 12 weeks (60 min treatment), was implemented using a Universal Exercise Unit (UEU) supervised by a PT. The UEU provided resistance through a pulley weight system. The exercises were supervised by a physical therapist who focused the training on performing a high number of repetitions and a moderate load to facilitate motor learning; starting with 30 repetitions with no load and increasing 0.5 kg once 3 sets of 30 repetitions were successfully completed.	Functional Strength Tests: Heel raises, posterior pelvic tilt, bridging, plank, trunk extension and hang from bar. Self-assessment of current function was also measured post-intervention via the Canadian Occupational Performance Measure (COPM). Activity was further assessed using 3 standard assessments: 1.) The Developmental Coordination Disorder Questionnaire-Revised 2007 (DCDQ'07) measure parent perception of participant's motor skills; 2.) Test of Gross Motor Development and 3.) BOT-2 SF
(Giagazoglou et al., 2015)[8]	Intervention-control group (Greece)	Body Coordination Test for Children (BCTC) and the Körperkoordinations test für Kinder (KTK) was used to categorize motor competence.	Greek children age 8-9 years old from various elementary schools in Thessaloniki. Out of 200 children assessed using the KTK, 20 exhibited motor difficulties suggestive of pDCD. N=20 (13M/7F)	A 12-week balance training intervention program with the use of a trampoline in improving motor coordination and balance ability. PE teachers instructed the training program. Sessions took place 3 times per week, lasting 45 min each. The participants in the intervention followed circuit training format consisting of various portable or stable gym equipment. The trampoline was used for at least 15 min during each 45 min session. The 20 students diagnosed with DCD were equally separated into two groups whereby each individual of the experimental group were paired with an individual of the control group. The control group adhered to their regular	Evaluation of overall body coordination and control was assessed using the BCTC. Furthermore, aspects of motor ability and body co-ordination based on video analysis while performing jumps on the trampoline was measured using the Trampoline Body Coordination Test (TBCT) consisting of 33 items in 9 different motor domains

				school schedule, which included participation in physical education activity three times per week for 40-45 min	
(Ashkenazi et al., 2013)[9]	Feasibility intervention with pre- and post-intervention assessments (Israel)	Each child demonstrated difficulties with activities of daily living and categorized on the MABC-2 (scoring ≤15th percentile) and were considered at risk for DCD or pDCD	Children 4-6 years old with pDCD as referred by a pediatrician specialist in developmental disorders. Referrals were based on complaints and observations of gross and/or fine motor delay, clumsiness, balance problems or difficulties participating in classroom and playground activities. N=9 (7M/2F)	The intervention consisted of 10x60 min sessions conducted each week over a total of 12 weeks to accommodate for missed sessions. The VR-based intervention incorporated the Sony PlayStation 2 EyeToy with a web camera video capture interface using 2-dimensional gesture recognition and encouraged trunk activity while performing stability exercises on different surfaces. Furthermore, the children had an individual intervention plan that took into account personal priorities related to their specific motor skill abilities and limitations defined in the first session. From there on, the last 15 min of each session was devoted to developing the goal-directed task (i.e., riding bicycles, playing ball games or putting on and taking off their clothes). The intervention and assessments were conducted by trained PTs.	MABC-2, DCDQ, Parents' subjective report, walking and talking test covering a distance of 10-m as quickly as they could and with various tasks and the six-minute walk test (6MWT)
(Hession et al., 2014)[10]	Randomised before/after study design (UK)	Children with a primary diagnosis of dyspraxia from Dyspraxia Ireland and social media for recruited	Children with a primary diagnosis of dyspraxia ranging from ages 6-15 years old were selected to join this study in Ireland. N=40 (28M/12F)	The study was conducted over an 8-week period whereby children were randomly divided into eight groups of five and were assessed over a two-day period. The riding therapy sessions took place at the Fettercairn Youth Horse Project Center with a certified riding instructor and a first-aid responder present during all sessions. At week 1, initial assessments evaluating cognition, mood arousal and gait analysis using standard assessment tools described	This study set out to investigate the effects of physical motion of a horse (equine riding therapy) and the audiovisual perception of this motion on measures of cognition, mood arousal and gait variability using the Standard Progressive Matrices, the Childhood Depression Inventory, and GAITRite Pressure Mapping System were used to quantitatively capture the results

				below were followed by 30 min of an audiovisual screening of equine motion and behaviour. From week 2-7, the sessions consisted of a weekly 30 min horse-riding session	
(Pesce et al., 2013)[11]	Ecological validity study (Italy)	The MABC-2 was used to assess motor coordination performance with the sample indicating TD: 67.6%; borderline 18.4% and DCD 14.8%. Cut-off threshold is <15th% threshold for borderline and 5th% threshold for DCD	Two classes of children aged 3-5 years and five classes of 1st to 5th grade children aged 6-10 years of TD and atypical motor development. N = 250 (127M/123F). Mean age groups were 7.0±1.6 (G-led); 6.8±1.5 (S-led); 7.1±1.3 (ceS-led)	Each school was randomly allocated to receive two of the three interventions (first school: three G-led (Generalist) and four S-led (Specialist) classes; second school: four G-led and three ceS-led (Cognitively enriched specialist) classes; third school: three S-led and four ceS-led classes) for 6 months. The teacher-student ratio was about 1:25 and the PE session was offered once/weekly for 60 min each. The two specialist-led PE programs differed from one another in that the Ces-led intervention incorporated a higher amount of mental engagement and were specifically tailored to challenge executive function. For the intervention, games were altered during PE lessons in a way that children's roles were no longer fixed, but fluctuated along the game or hold a rule in mind while inhibiting a habitual response	The intervention outcomes may depend on PE content and the delivery skills of the teachers as well as on intensity and duration of physically active time in PE. Therefore, PE sessions were monitored with videotape to observe and monitor the characteristics of the sessions over two randomly selected classes. Furthermore, exercise intensity was monitored using heart rate (HR) monitors on a subsample of children (n=12 for each school) once a month. Outcome measures of interest included cognitive assessment using the Cognitive Assessment System (CAS) alongside the Planning Scale and Attention scale composed of subtests requiring the child to use focal attention to detect target stimuli and avoid distractions. Furthermore, manual dexterity and ball skills were assessed via the MABC-2
(Tsai et al., 2012)[12]	RCT (Taiwan)	MABC was used whereby the total impairment core (TIS) was presented as < 5th% percentile then examined with a brief behaviour rating scale based on DSM-IV criteria	Children with DCD 9-10 years old. N = 368 total; n = 259 normal; n = 75 borderline DCD; n = 34 DCD. N = 16 (DCD training) (9M/7F) and n = 14 (DCD non-training) (9M/4F)	The 10-week exercise training program took place five times per week for 50 min each. The DCD-training group focused on playing soccer with the structure of: warm-up, the main part of soccer training, playing a soccer game with partners, and cooling down at the end. The training program was aimed at improving general skills, and on lower-extremity exercises, soccer-specific technical skills, short intermittent sprint,	The MABC mean total impairment score (TIS) was measured pre- and post-intervention. Target-evoked P3 component of the electrophysiological (ERP) testing with the visuospatial attention paradigm looking at changes in the patterns of brain activation due to training

				comprehensive practice and a soccer match. The intensity was incorporated increasing complexity over the 10-weeks. For instance, after 2 weeks, more task specific training was added to the main program based on the theory of constraint-induced movement therapy, which proposes that the forced-use technique might also undercover latent motor potential while repetition is known to be crucial for improved performance	
(Zwicker et al., 2015)[13]	Mixed methods to evaluate intervention effectiveness (Canada)	Clinical referral based on DSM-IV criteria for DCD diagnosis. The MABC-2 and the Developmental Coordination Disorder Questionnaire (DCDQ) was also administered. Cut-off values were <15th percentile on MABC-2 or <5th percentile on one domain of the MABC-2 regardless of total score	Children with DCD between 7-12 years who were clinically referred. N=11 (9M/2F) in first camp and N=3 (2M/1F) in second	The summer camp ran for 2 weeks on two occasions with occupational therapy students and instructors. Four sessions were run over the 2 weeks lasting 1.5 hours per session to work on their chosen goal with a staff member who guided the child to utilise 'Goal-Plan-Do-Check' to problem solve through performance and skill execution difficulties. Some of the goal-based activities included baking, dragon boating, hiking, crafts, rock climbing, and self-esteem games	The quantitative phase of the study utilised a pretest-posttest design that examined changes in performance and satisfaction with child-chosen goals, as well as self-efficacy and participation in PA via the Perceived Efficacy and Goal Setting System (PEGS) following the intervention. The qualitative phase consisted of an online exit survey completed by parents. The primary outcome measure was the COMP, which measured changes in performance and satisfaction of child-chosen goals before and after the intervention using a visual analog scale of 1-10. Furthermore, the Children’s Self-Perception and Adequacy in Predilection for Physical Activity (CSAPPA) was administered as a comprehensive measure of participation

(Fong et al., 2013)[14]	RCT (Hong Kong)	Formal diagnosis of DCD according to DSM-IV	Children 6-12 years old with and without DCD. N = 21 (17M/4F) in intervention group and N = 23 (18M/5F) (DCD control group) and N = 18 (14M/4F)(normal control group)	Tae Kwon Do (TKD) training sessions were held at the administering institute for 12 consecutive weeks; 60 min session once per week. Participants were instructed to perform these TKD exercises daily (excluding TKD days) throughout the 3- month study period. The training protocol was produced for the participants motor abilities by an experienced pediatric PT and a skilled TKD instructor	Isokinetic quadriceps and hamstring muscle strength was assessed using Cybex Norm isokinetic dynamometer. In addition, static balance, single-leg standing and reactive balance control was measured by the motor control test (MCT)

Abbreviations: 6MWT, Six-minute walk test; 20mSRT, 20 Metre Shuttle Run test; BCTC, Body Coordination Test for Children; BOTMP, Bruininks-Oseretsky Test of Motor Proficiency; BOT-2 SF, Bruininks-Oseretsky Test of Motor Proficiency Short Form; CAS, Cognitive Assessment System; CCT, Case-Controlled Trial; COMP, Canadian Occupational Performance Measure; CSAPPA, Children's Self-Perception and Adequacy in Predilection for Physical Activity; CSQ, Coordination Skills Questionnaire; DCDQ, Developmental Coordination Disorder Questionnaire; DSM-IV, Diagnostic and Statistical Manual of Mental Disorders Fourth Edition criteria for DCD; EEI, Energy Expenditure Index; FSM, Functional Strength Measures; HR, heart rate; KTK, Körperkoordinations test für Kinder, MABC, Movement Assessment Battery for Children; MD; Movement Difficulties; MCT, Motor control test; NTT, Neuromotor Task Training; PA, Physical Activity; pDCD, probable DCD; PEGS, Perceived Efficacy and Goal Setting System; PT, Physical Therapist/Physiotherapist; RCT, Randomised-Controlled Trial; SD, standard deviation; SDQ, Strengths and Difficulties Questionnaire; TKD, Tae Kwon Do; TBCT, Trampoline Body Coordination Test

2.4.1 Evidence of effect

Out of the 14 included studies, seven reported a positive intervention effect in favour of treatment and achieved statistical significance (7/14 studies) (50%). Three studies had no effectiveness (3/14 studies) (21%) and four studies illustrated a positive trend of effect (4/14 studies) (28%). Furthermore, significant improvements in motor proficiency/performance (79%) were shown in participants scoring in the normal range or average on total standard score (i.e., MABC, BOT-2 SF) following intervention period. Balance coordination/postural control was the most popular fitness component measured (43%) with a positive effect on composite scores post-intervention. No studies directly focused on the effectiveness of PA. Table 2.3 summarises the stratified levels of evidence across the different interventions targeting PA an fitness in children adolescents. Level of evidence based on five levels: Strong, moderate, limited, inconclusive and no evidence.

Table 2.3 Summary of levels of evidence for effectiveness of interventions to promote PA and exercise in children and adolescents stratified by setting, intervention characteristics and diagnostic tool to categorise group (van Sluijs et al., 2007)

	Children and adolescents	
Variables	**No of studies (/14)**	**Level of evidence**
Intervention type:		
Virtual-reality (VR) and video game consoles	5	Inconclusive
Fitness and exercise training	4	Limited
Sports training/therapy	3	Moderate
Skill development	2	Moderate
Setting:		
School	4	Inconclusive
School plus community or family	2	Inconclusive
Community	5	Limited
Primary care	5	Moderate

2.4.2 Study intervention characteristics

Two of the 14 studies were conducted in the UK[1,10], three in Europe[3,8,11], four from North America[4,5,7,13], three in Asia[2,12,14] and the remainder from other parts of the world[6,9]. In total, five studies were RCTs[1,2,10,12,14], one CCT[4], one single case study[7], two quasi-experimental[5,6], one ecological validity study[11], two pre-/post-intervention[8,9] and two mixed methods design[3,13]. Table 2.2 shows the intervention characteristics of the included studies aimed at improving fitness and physical and non-physical outcomes in children and adolescents ranging from 6 to 15 years old. Among the studies presented in the systematic review: five studies used the Nintendo Wii Fit[1,2,3,6] and other virtual-reality (VR) videogame consoles[9], two studies focused on balance and strength training[7,8,], two studies included fitness and exercise training[4,5], three studies on specific sports training/riding therapy[10,12,14], one study featuring goal-based skill development[13] and one study intervention incorporating cognitive skills into PE lessons[11]. Details of the interventions were described above in Table 2.2. Most studies incorporated comparison groups including children with definite movement difficulties versus TD peers, or a mixed sample of children with varying movement skills and conditions.

Of the 14 reviewed studies, two were case studies[4,7] and three studies implemented a pre-and post-test design[2,5,9] and therefore did not utilise comparison groups. Although no articles were excluded based on sample size, studies varied from single case report[7] to a sample of 368 children[12]. Intervention time frames ranged from 2 weeks[13] up to 24 weeks[11] with most interventions averaging 6-12 weeks[1-10,12,14] in duration. Exercise frequency ranged from once per week[2,10,11,14] to 2-3 times weekly[1,3,4,5,6,7,8], 4-5 times weekly[12,13] and a maximum frequency of 10 sessions per week[9]. On average, intervention sessions ran for 45-60 min[2,4-9,11,12,14] whereas one study incorporated 10 min[1] sessions, three studies ran for 30 min[3,6,10] and one study devised 90 min sessions[13] due to a short intervention period. The sessions were supervised by trained physical therapists/physiotherapists[2,4-7,9,14], PE Teachers[1,8,11], trained instructors[10,14,13] and sports students[3]. As part of the criteria for inclusion, level of MI or MD had to be ascertained using a standardised battery test/assessment. One study utilised both the MABC and BOT-2 SF[2], six studies used the MABC/MABC-2[3,6,9,11-13], three studies used the BOT-2 SF[1,4,7] and the remaining studies used other instruments and/or formal diagnoses of dyspraxia/DCD[1,4,5,8,10,13,14].

2.4.3 Outcome measures

All studies reported on at least one fitness/physical outcome of interest including the following: functional strength/mobility[5,6,7,8], muscle strength[5,6,14], CRF/aerobic fitness[3,5,6], balance and coordination/postural control[1,2,3,8,11,14], speed and agility[3,6], gait/walking[9,10], core stability[4] and intensity[7,11,12]. No studies directly focused on the measurement of physical activity (i.e., PAL). For secondary outcome measures of interest, the most common non-physical outcomes include: self-perceived ability/self-efficacy[1,4,13], cognition[10,11,12], audio/visuo-spatial attention[10,12], self-chosen goals[4,13], DCDQ[7,9], parent questionnaires[2,7,13], attendance[2,5] and energy expenditure[5]. Moreover, motor proficiency/motor performance was a key outcome in most of the intervention trials[1-4,7-9,11,12], except in five studies[5,6,0,13,14]. When motor proficiency/performance was assessed, the MABC/MABC-2[3,9,11,12] or BOT-2 SF[1-4,7] were the primary battery tests used.

2.4.3.1 Fitness measures

Balance and coordination

Seven studies measured balance, coordination and/or postural control[1,2,3,7,8,11,14]. To measure this, subtests via the BOT-2 SF (i.e., bilateral coordination and balance)[1,2,3], the Test of Gross Motor Development-Second Edition (TGMD-2)[7] and the MABC[11] were used. In another study, static balance control tasks while standing on an EPS pressure platform, the Body Coordination Test for Children (BCTC) and the Trampoline body coordination test (TBC) was used[8]. Conversely, Fong et al. (2013) assessed static balance control using an isokinetic machine, a motor control test (MCT) and a unilateral stance test (UST)[14]. Furthermore, core stability was examined with an assessment tool created by the authors, which consisted of 6 items ranging from sit-ups, push-ups, timed holds of plank, hip bridge, and "bird dog" positions and timed single-leg stance as a functional measure of postural stability and balance[4].

Cardiorespiratory and aerobic fitness

To measure CRF and aerobic fitness, [3,5,6], the Presidential Physical Fitness Test (PFT) composed of five subtests including the one-mile walk/run was used to measure changes in fitness[5] alongside the Wii Fit Ski Slalom Test[3] and the 20-m shuttle run[6].

Speed and agility

Speed and agility was measured in two studies [3,6] via the Muscle Power Sprint Test at baseline and post-intervention[6] and the Running Speed and Agility component of the BOT-2 SF[3].

Muscle strength

To measure muscle strength (i.e., peak isometric strength), a hand held dynamometer (i.e., grip strength)[5,6] and an isokinetic machine with low, moderate and high movement velocities[14].

Movement/Motor proficiency

Across studies, movement/motor proficiency was assessed using standardised battery tests including the MABC/MABC-2[3,9,11,12] or BOT-2 SF[1-4,7] pre- and post-intervention.

Functional strength and mobility

Functional strength was measured using the Functional Strength Measure (FSM)[6] and functional outcomes were assessed across nine different motor domains on the TBCT test[8]. In one study, examination of impairments focused on motor control components by assessing muscle activation, maintenance of muscle contraction and the ability to produce power on the BOT-2 SF[7]. Additionally, the Pompe-Pediatric Evaluation of Disability Inventory (Pompe-PEDI) and the Functional Skills Mobility scale was used to measure mobility and gross motor function[5]. To measure gait and walking, the 6-minunte walk test and the 10-m walk test was incorporated[10]. One study used the GAITRite Pressure

Mapping System to analyse foot function and gait variability by assessing single and double support, cycle time, cadence, toe in/out and stride length post-intervention[9].

Intensity

To measure intensity, incremental gains in resistance and increases in repetition were documented throughout the intervention period in one study[7]. Exercise intensity was also monitored using heart rate (HR) monitors and quantified during sessions as time spent in the MVPA (e.g., HR>139 bpm)[11]. In Tsai et al., (2012), the soccer training sessions were comprised of technical and tactical drills focused on the participant's agility and task-specific training that increased in intensity during the study period. However, no specific tool was described for measuring intensity[12] aside from HR monitors and increases in repetitions/time duration.

2.4.3.2 Non-physical measures

The secondary outcome measures in the reviewed studies included non-physical measures ranging from psychosocial aspects to cognition and attendance. In two studies, self-perceived ability[1] and self-efficacy[4,13] was assessed using the Children's Self-Perception and Adequacy in Predilection for Physical Activity (CSAPPA; (Hay, 1992)), the Coordination Skills Questionnaire (CSQ; (Green & Wilson, 2008)) and the Perceived Efficacy and Goal Setting system (PEGS; (Missiuna et al., 2006)), which is a self-report of the child's performance in 24 everyday tasks in home, school and community environments. The Canadian Occupational Performance Measure (COMP; (Law et al., 1998)) was also used to assess performance on self-chosen goals via a 10-point visual analogue scale[13]. To measure self-chosen goals, the study by Kane and Bell (2009), had the participants rate their ability to perform their chosen tasks on a 5-point facial hedonic scale[4] whereas CAPE questionnaire was administered pre- and post-testing to capture perceived improvements on the child's chosen goal[13]. Moreover, participation was also assessed using the standardised Children's Assessment of Participation and Enjoyment (CAPE; (King et al., 2007))[13]. Correspondingly, attendance was measured in three studies[2,5,6] with one study reporting a mean attendance rate of 75% during the intervention[5] and another noting 98% attendance in the Neuromotor Task Training (NTT) group and 96% in the Wii Fit group[6]. Parent questionnaires were administered in a few studies to obtain their views and feedback regarding the programme and intervention[2]. Three studies used the Developmental Coordination Disorder Questionnaire-Revised 2007 (DCDQ'07; (Wilson et al., 2007)) to evaluate parent perception of changes in their child's motor skills and coordination difficulties[7,9,13].

Other notable secondary measures assessed were cognition[10,11,12] and audio/visuo-spatial attention[10,12]. For instance, cognitive performance was assessed via objective measures obtained from laboratory-based performance data[12] whereas another study measured the optimal challenge point in PA using the Cognitive Assessment System (CAS; (Naglieri & Das, 1997)) consisting of 12 subtests that assessed four aspects of cognition (i.e., Planning, Attention, Simultaneous and Successive processes)[11]. In Hession et al. (2014), the Ravens test ((Raven et al., 2003)) was used to measure two complementary aspects of general intelligence and the Childhood Depression Inventories (CDI; (Ivarsson et al., 2006)) self-report questionnaire was used to assess cognitive, affective and behavioural signs of depression[10]. One study measured visuo-spatial attention with concomitant electrophysiological recordings while a stimulus was displayed on a laptop[12] and another utilised beat-based rhythms of equine motion and audiovisual stimulation to promote memory, attention, cognition and movement pattern synchronisation[10].

2.4.4 Methodological quality

Overall seven studies (50%) exhibited high methodological quality receiving a score of 7 across the 10-items assessed[1,2,6,9,12,1314]. According to Table 2.3, five of the studies (35%) demonstrated the highest methodological quality as an RCT and received a score ≥6[1,2,12,13,14]. Furthermore, two studies (14%) had more than 250 participants or a sample size justified to be large for the trial design[12,14]. The study by Kane and Bell (2009)[4] was the only CCT demonstrating high methodological quality with an overall score of 6 (Table 2.4). Over nine of the studies obtained a negative score for sample size due to smaller participant numbers in the feasibility or pilot study.

Table 2.4 Methodological quality score

Study reference	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**Score§**	**Size±**	**Effect‡**
Ashkenazi et al (2013)[9]	·	·	+	+	+	+	+	−	+	+	7*	–	++
Au et al. (2014)[2]	+	+	+	+	+	?	+	−	+	−	7	–	––
Ferguson et al. (2013)[6]	+	−	+	+	+	+	+	?	+	−	7*	–	++
Fong et al. (2013)[14]	+	+	+	+	−	+	+	−	+	−	7	+	++
Fragala-Pinkham et al. (2006)[5]	·	·	+	+	?	+	−	−	+	−	4*	+	++
Giagazoglou et al. (2015)[8]	+	−	+	+	?	+	?	−	+	−	5*	+	++
Hammond et al. (2014)[1]	+	?	+	+	+	+	−	−	+	+	7	–	––
Hession (2014)[10]	·	·	+	−	+	+	−	−	+	−	4*	–	++
Jelsma et al. (2014)[3]	−	·	+	+	−	+	−	−	+	+	5*	–	+
Kane and Bell (2009)[4]	·	·	+	+	+	+	−	−	+	+	6*	–	+
Menz et al. (2013)[7]	·	·	+	+	+	+	−	−	·	−	4*	–	––
Pesce (2013)[11]	+	·	+	+	?	+	−	−	+	+	6*	+	+
Tsai (2012)[12]	+	+	+	+	?	+	+	−	+	−	7	+	+
Zwicker et al. (2015)[13]	·	·	+	+	+	+	+	−	+	+	7	–	++
Key:	A: Groups comparable	B: Randomisation	C: Unit of analysis	D: Outcome measure	E: Drop out	F: Timing	G: Blinding	H: follow-up	I: Intention-to-treat	J: Confounders	Possible values: + Positive ? Not, or insufficiently, described − Negative · Not applicable Score§: total number of positives (+) Size±: ≥250 participants or power calculation provided justifying sample size as large (+) and ≤250 participants as small (–) Effect‡: No difference between control and intervention group (score =0); positive or negative trend (+ or –); statistically significant (p<0.05) in favour of intervention or control (++ or ––) * Non RCT		

Six out of the 14 studies reported blinding personnel and/or participants during the intervention period whereas 7/14 did not blind and one study was insufficiently described. Randomisation was not applicable in 8/14 studies while two studies did not randomise and one was not described. Although more studies utilised non-RCT designs, those trials often reported a positive trend on improvements in outcome measures despite smaller participant numbers. Four out of the five RCTs demonstrated intervention effectiveness on motor skill proficiency and improvements on impairment score[1,2,13], performance on self-chosen goals[12], static balance and muscle strength[14]

2.5 Summary of study results and discussion

The aim of this study was to systematically review and summarise the literature on the types of interventions targeting fitness outcomes in youth with MI. As delineated in the introduction, a novelty of conducting this systematic review was to address gaps in the literature surrounding the impact of exercise and PA interventions targeting fitness parameters in MI. Although previous reviews have focused on the barriers/constraints and school-based approaches in healthy individuals and children with physical disabilities, this is the first systematic review to date highlighting the different types of interventions and the efficacy of these treatments in relationship to fitness in MI. Due to the heterogeneity of the intervention designs, settings and outcome measures used, a narrative synthesis approach was taken (Popay et al., 2006; Rivilis et al., 2011; Tan et al., 2014; van Sluijs et al., 2007). In agreement with previous findings by Rivilis et al. (2011), this systematic review confirmed that children with MI and MD generally had lower performance than TD peers on measures of physical fitness. In addition, an improvement in movement/motor skill proficiency was a key outcome measure observed throughout the studies reviewed, irrespective of the type of intervention implemented. This was an instrumental finding considering the relationship between motor skill proficiency and fitness reported in MI (Morris et al., 2013). Overall, there were only five RCTs that focused on the efficacy of physical training/exercise therapy interventions on some aspect of a physical performance outcome and the remaining studies were considered less well-controlled and described. These findings highlight the need for sufficiently powered RCTs with follow-up periods to better monitor the impact and sustainability of the intervention on physical fitness and performance in MI.

2.5.1 Intervention characteristics

The reviewed intervention studies involving children and adolescents with MI/MD varied in program design, population and evaluation. The setting in which the interventions were conducted ranged from laboratory-based settings, rehabilitation facilities, the community and school-and home-based settings. Furthermore, the delivery of the intervention programmes differed in each study with physical therapists/physiotherapists, PE teachers, instructors and parents involved throughout the intervention period. Thus far, there is little evidence based on the reviewed studies regarding the optimal mode, frequency, intensity, setting and duration of activity in the intervention programmes. Of all the studies, 5/14 were RCTs with motor skill proficiency and balance/coordination being the most common fitness outcome measured. Only three studies assessed activity intensity[7,11,12] with an average methodological score of 6 (Table 2.4), which may have important implications for exercise prescription.

Intervention duration

Overall, most intervention periods lasted between 6-12 weeks[1-10,12,14] with the exception of one study which was incorporated within PE lessons and therefore, ran for 24 weeks[11] while another study offered sessions over a two weeks summer camp[13]. Numerous studies in the literature implemented physical exercise training interventions lasting a minimum of 12 weeks and on average, 2-3 sessions per week for 45-60 min each to show improvements of measures of fitness in children and young adults (Buchan et al., 2013; Dobbins et al., 2009; Duppen et al., 2013; Verschuren et al., 2008). The results from this review support these recommendations with many of the intervention sessions running for 45-60 min each[2,4-9,11,12,14] . Interventions offering one session per week demonstrated improvements in the main outcomes of interest, however, significant improvements in motor proficiency and[1,3,6,7,8] and functional performance and impairment dimensions[5] pre- to post-intervention were only noted with sessions offered 2-3 times/week.

For the studies incorporating 4-5 times sessions per week, no measurable changes in self-efficacy and participation were observed[13] although beneficial effects in inhibitory control were reported specifically with soccer-based skills training[12]. Recent evidence by Cacola et al. (2016), suggests a minimum of two sessions per week over 12 weeks was more effective than once a week over 10 weeks. Factors that may also contribute to the effectiveness of interventions include levels of exposure, adherence and the sustainability of developed skills (van Sluijs et al., 2007). Previous papers emphasised problems in these areas with only 5% of participants attending at least half of the sessions offered or insufficient description of attendance rates reported (Pate et al., 1995). Only three out of the 14 reviewed studies reported on mean attendance and/or adherence rates as secondary goals with a 75% attendance rate observed in Fragala-Pinkham et al. (2006)[5], 96-98% for Wii Fit group[6] and compliance with the home program in the task-oriented training group positively correlated with change in motor proficiency. Similar to the findings in Linke et al. (2011), some studies may have considered participants retained if they attended the post-intervention and/or follow-up testing or completed a minimum number of sessions, however, most studies did not necessarily measure this component (13/14 studies reported no follow-up) (Table 2.4). Before pursuing intervention strategies further, it is necessary for researchers to identify and learn from the limitations of the presented studies and to evaluate the evidence/feasibility of recommended programmes (van Sluijs et al., 2007).

Intensity

Only three studies measured intensity[7,11,12], however the mixture of the outcome measures highlights the need for more quantitative measures such as accelerometry or HR monitoring to capture intensity level and PA patterns for comparison. Importantly, interventions should monitor whether the specific "dose" of the training or treatment (i.e., exercise training or PA) is adequate to create any net impact on overall physical performance and PA (Reilly et al., 2006). In Fragala-Pinkham et al. (2006)[5], the authors noted that differences in program intensity and duration might have influenced the outcomes despite improvements in functional mobility. This is particularly important considering that children with MD and DCD were not necessarily less active, but were significantly less aerobically fit and often participated at lower intensities (Hands et al., 2009; Rivilis et al., 2011). Correspondingly, a previous study observed significant differences in exercise intensity between children with low vs. high movement competency (Cantell et al., 2008). The current recommendations for achieving ≥60 min per day of MVPA may be an intimidating goal for children with MI (Janssen & Leblanc, 2010). Therefore, different strategies for accumulating sufficient PA, including shorter bouts of higher intensity and sporadic type activity are warranted.

Virtual-reality and video game consoles

Five studies utilised VR/video game technology but the level of evidence remained inconclusive. Although there is preliminary evidence to support the use of the Wii Fit and VR technology within therapeutic exercise programmes for children with MI/MD, it was not possible to conclude which children are most likely to benefit from using the Wii Fit and specifically what the optimal dose and duration should be[1,6]. Interestingly, not only did VR interventions improve motor function and balance, but the children also appeared to be engaged and motivated with the interaction of the VR game[3,9]. Interventions using VR can enable users with more awareness of their movements by providing opportunities to perform tasks they may not be able to execute in the 'real-world' but offering experimental, active learning within a safe and controlled environment (Green & Wilson, 2012; Hammond et al., 2014). When compared to NTT, greater gains in motor performance, functional strength, impairment dimensions and CRF were cited in the NTT group whereas greater improvements in anaerobic performance was shown in the Wii training group[6]. Children with MI/MD including DCD represent a heterogenous group who exhibit a range of impairments in body functioning that may negatively impact their ability to perform daily tasks and participate in PA (Ferguson et al., 2014). Overall, an advantage of this study was the attempt to examine the impact of interventions across a broad spectrum of the International Classification of Function, Disability and Health (ICF) framework for the description of health, more commonly applied to studies in children with CP (Verschuren et al., 2008). Using the ICF framework (2001) and the Ecological Intervention (EI) model (Sugden, 2007) to understand the underlying impairments and limitations (contextual and environmental) remains an important aspect for devising appropriate interventions and programmes.

In general, limitations of VR intervention studies include small sample sizes and hence, larger blinded RCTs are required to further investigate the benefits of VR interventions on physical fitness. Only 6/10 studies reported blinding in their studies[2,6,9,12,13,14] with the remainder insufficiently described or not performed. Short-term changes in PA can be achieved during a brief intervention, however, evidence of long-term effects is weak and other strategies including the community and family support may further promote sustainable change and PA among young people (Ortega-Sanchez et al., 2004; Patrick et al., 2006; Patrick et al., 2001; Salmon et al., 2007).

School, parental and community settings

Parental factors and the home environment are believed to influence PA behaviour (Dowda et al., 2007; Gustafson & Rhodes, 2006; van Sluijs et al., 2007), yet only two studies incorporated home exercises and practice in this review[2,4]. According to Kane and Bell (2009), the intervention programme may have a successful impact within community settings to facilitate the development of diverse skills and task-specific self-efficacy[4]. Another study focused on a community-based group fitness programme and demonstrated success in improving functional mobility, fitness parameters while providing a feasible template for fostering participation and play in children with disabilities[5]. Based on the published evidence by van Sluijs et al. (2007), a multilevel approach to promoting PA and fitness within school-based and family/community designed interventions were likely to be effective in adolescents, but more research is warranted in both TD and atypically developed children.

Only one study investigated the efficacy of cognitive engagement in PA during school PE lessons for promoting attention development in children with MI/MD[11]. This type of intervention was more ecological and the results showed that the cognitively enriched PA environment may have an added value for TD children, but specialist-led PE lessons focused on variability of practice while challenging motor control was more useful for children with MD. A notable finding in this study was that the cognitively-enriched lessons group (ceS-led)[11] reported spending an average 53.6% of time in the MVPA intensity domain with improvements in their MABC score and outdoor play time. These findings contribute to qualitative and quantitative PA prescription within school settings and highlight the importance of fine-tuning movement-based executive function in relation to movement skill level. The aims of that study corroborated with the early work of Henderson and Sugden (1992), who developed the cognitive motor approach emphasising the planning and execution of movement with the use of cognitive skills (Sugden, 2007). More recently, the cognitive motor approach has been updated and renamed the ecological intervention (EI) and incorporates all the principles and practices of the cognitive approach but devises the intervention within a more family, community and ecological setting and lifelong participation as a goal (Sugden, 2007). In addition, Sugden (2007) notes that the child's active involvement in an intervention is key, however priority should also be given to functional activities and specific skills relevant to the child while fostering generalisability and stressing aggregate of marginal gains.

Task-based and goal-based approach

Correspondingly, a recent review of the most effective interventions for treating DCD suggests that task-based approaches (e.g., addressing problems in motor learning, motor control and cognitive processes) (Wilson, 2004) yield stronger effects in improving functional outcomes compared to process-oriented approaches emphasising impairments and deficits in body structure and function (Ferguson et al., 2013; Polatajko & Cantin, 2006; Smits-Engelsman et al., 2013). In this review, two studies incorporated task-specific conditions with balance training [2,4] and one study focused on goal-based skill development [13].

Such approaches resulted in significant improvements in movement proficiency and satisfaction in activity performance, but whether these gains are sustained following the study period remains unknown. More research on ecological models that include a dynamic interaction of both internal/personal and external/environmental factors (Barnett et al., 2013) in longer-term studies would better inform exercise and PA promotion programmes.

In addition to performing ADL, children with MI often find dynamic activities such as running, walking and jumping challenging as a consequence of their poor movement proficiency and coordination. Adequate muscle strength and endurance are vital fitness components for performing daily activities and participating in sports (Rivilis et al., 2011) , yet children with MI and DCD often demonstrate poor muscle strength, muscle cocontraction, low muscle tone and fatigue (Faught et al., 2013; Johnston et al., 2004; Unnithan et al., 1996). A recent systematic review concluded that body composition, CRF, muscle strength and endurance, anaerobic capacity, power and PA were negatively associated with poor movement proficiency (Rivilis et al., 2011). Although this review emphasised PA and fitness in youth with DCD, only two intervention studies were included and most of the publications consisted of observational and descriptive studies. Therefore, this systematic review sought to specifically address the different types of interventions featured in MI and their impact on fitness parameters. Of the 14 studies included, only two studies focused on balance and strength training [7,8,] while two others incorporated mixed exercise training (i.e., aerobic, strength and self-chosen goals)[4,5]. Through the practice of isolated, simple joint movements during the strength training sessions in Menz et al. (2013), positive changes in improved function and gains in balance and coordination were observed. The findings support the need for a larger RCT study focused on strength training and possibly followed by a functional intervention compared to solely strength training[7]. Furthermore, improved functional mobility and balance from trampoline-type exercise and mixed fitness programmes may be due to the incorporation of functional activities into aspects of the intervention design[5,8]. To further, three studies focused on specific sports training/riding therapy[10,12,14] and saw benefits in movement proficiency[10,14], balance/control[14] and visuo-spatial attention[12]. Future work should focus on comparing specific exercise training to mixed training programmes to better assess the impact on physical fitness outcomes and barriers and constraints to maintain an active lifestyle.

2.5.2 Outcome measures

Throughout the studies, movement/motor proficiency was a primary outcome measure with children demonstrating improvements in one or more areas of movement and motor skill (i.e., increased time on single-leg, balance, coordination)[1-4,7-9,11,12]. This is a crucial finding considering that reduced levels of participation in PA exhibited in children with MI/MD may result as a consequence of mechanically inefficient movement patterns, leading to earlier fatigue compared to well-coordinated individuals (Hands & Larkin, 2006; Rivilis et al., 2011). No studies in this review directly measured mechanical efficiency, however significant gains in movement and motor proficiency post-interventions were a common theme presented. For instance, through the practice of isolated, simple joint movements during the strength training sessions in one case-study, positive changes in improved function, balance and coordination were detected[7]. An individual's movement skills is positively associated with PA and inversely linked with sedentary activity (Wrotniak et al., 2006). Therefore, strategies to increase movement skills and motor proficiency in childhood may be an important target for increasing PA and health in youth, and particularly in children with MI.

It has been suggested that hypoactivity is often seen in children with poorer movement proficiency including DCD and is associated with lower self-perception and self-adequacy (Hay, 1992; Wrotniak et al., 2006). Perceptions of poorer coordination and general physical ability not only negatively impacts performance, but may also lead to reduced enjoyment in the activity (Cairney et al., 2005; Rivilis et al., 2011). Thus, psychosocial outcomes including self-efficacy, self-perception and emotional well-being are also important for evaluating the efficacy of an intervention [1,4,10,13]. Whether, obtained directly from the participants or via questionnaires from parents and teachers, outcome measures should also provide insight on the satisfaction with the intervention and perceptions of improvements for the child and the research design. For example, parents and children reported positive benefits to camp participation including confidence to try new activities and interacting with other children with DCD[13]. However, the short two-week duration of the summer camp intervention may not necessarily demonstrate that benefits will be maintained over the long run. For instance, functional strength and mobility was measured in several studies[5,8] before and after the intervention, yet no follow-up assessments were included to evaluate changes to impairment.

Instruments and tests used to measure the intervention effects on physical fitness components and functional mobility/balance varied across the studies. Studies targeting muscle strength mostly used dynamometers to assess pre-and post-intervention changes in peak isometric strength[5,6]. One study concluded that 77.7% of the participants scored in the normal range on the Muscle Power Sprint Test after NTT compared to 31.6% in the Wii training group[6]. Although improvements were seen, children with MI/MD are often characterised with poorer muscle strength and endurance compared to TD peers, which may negatively impact participation in PA (Morris et al., 2013; Rivilis et al., 2011). The decreased muscle strength and power of children with DCD may be due to increased levels of coactivation and inefficient muscular activation as a consequence of their limited movement experiences (Raynor, 2001). Nevertheless, interventions incorporating strength and resistance training with outcome measures examining underlying deficits like strength, power and muscular organisation may enhance the results supported by task-oriented approaches in children with MI/MD (Hall, 1988; Henderson & Sugden, 1992; Raynor, 2001). Moreover, few studies assessed CRF and aerobic fitness in the interventions reviewed[3,5,6]. Approximately 43% of participants in the study by Fragala-Pinkham et al. (2006) showed a positive effect on the PFT including the one-mile walk/run, post-intervention. In addition, improvements on 20-m shuttle run performance was observed in the NTT group but significant increases in anaerobic sprinting was found in the Wii training group[6]. Because many of the daily childhood activities consist of short-intermittent bursts of intense activity, anaerobic fitness is thought to be an important measure of functional capacity in children with MI (Verschuren et al., 2008). According to Morris et al. (2013), children with greater MI demonstrated a reduced exercise capacity and failed to tax their cardiovascular system maximally. Research has shown that exercise interventions play a potential role in improving movement skills in children with MD (Hung & Pang, 2010), however, how these changes relate to alterations in markers of cardiovascular and muscular health alongside long-term involvement in PA have yet to be elucidated (Morris et al., 2013). Correspondingly, no studies specifically measured exercise intensity except one study using HR monitors to capture time spent in MVPA[11] and as such, this is an important outcome for identifying PA levels and tracking fitness and health changes over time.

2.6 Conclusion

In general, the methodological quality of the included intervention studies was considered moderate. Only five RCTs were included out of the 14 studies. Seven of the studies demonstrated a significant effect from the intervention treatment: functional mobility, motor skill, muscle strength, balance/coordination with a high methodological quality grade. More RCTs with appropriately powered sample sizes and blinding are required to better determine the efficacy of intervention designs on outcomes measures. Based on critical evaluation of the types of interventions reviewed and the physical/non-physical outcome measures, children and adolescents with MI/MD may benefit from both VR training and exercise programmes for improving movement/motor proficiency. However, the level of evidence on effectiveness was limited compared to the moderate results of sports training/goal-based skill development interventions. The outcome measures of interest and measurement tools varied across studies, which made it difficult to make comparisons and assess the level of evidence. However, each study demonstrated an improvement on some physical fitness outcome whether the design was more individually focused versus group-based programmes. A limitation of this systematic review was only studies in English were considered and no follow-up testing was administered. Strategies that increase parameters of fitness including intensity level and movement skills in childhood may be a vital target for improving participation in PA and play in youth with MI. Additional research is warranted to fully understand the fitness capacity, neurophysiological mechanisms, and limitations to exercise in children with MI for designing long-term, sustainable interventions. Furthermore, it is imperative that interventions also focuses on facilitating personal attributes associated with PA and play including fitness capacity (Maltais et al., 2005; Shapiro & Martin, 2010) and fundamental movement skills in MI (Capio et al., 2015). Overall, moderate evidence was found for sports training/therapy and skill-based development intervention designs on fitness outcomes in children and adolescents with MI and demonstrates promise for incorporation into future intervention studies.

3

Measurement of fitness methods and exercise response in paediatric populations

3.1 Abstract

Introduction: This chapter highlights the common methods used to measure the physiological and metabolic responses to exercise and developed fitness markers in paediatric exercise populations. **Purpose/Methods:** The primary focus was to initially review the background literature of exercise responses and supporting the use of different fitness measures to provide a rationale for the methods to be implemented in the subsequent studies conducted. **Discussion:** The methods were discussed in relation to the tests and techniques used to assess the impact of exercise and measures of fitness and fitness testing methods to be used in the thesis outlined. This chapter aimed to review the different methods and techniques used to measure components of fitness in children and adolescents. The different types of physiological measures utilised in this thesis include: categorisation of motor skill level by the Bruininks-Oseretsky Test of Motor Proficiency 2 Short Form (BOT-2 SF), ratings of perceived exertion (RPE) via the CALER scale, maximal and submaximal assessment of aerobic capacity (Chapter 4 and 5), power and agility (Chapter 6) and measures of muscle strength using an isometric maximal voluntary isometric contractions (MVIC) protocol with surface electromyography (sEMG) and handgrip dynamometer

(Chapter 4 and 6). Importantly, workload and heart rate (HR) will be used to monitor exercise responses and to quantify exercise intensity throughout this thesis in young people presenting with varying degrees of movement impairment/difficulties.

3.2 Components of fitness

Children and adolescents with movement impairment (MI) and movement difficulties including low motor competence, poor coordination and/or diminished motor skills demonstrate poor physical fitness outcomes and a reduced level of physical activity (PA) (Haga, 2009; Hay et al., 2003) compared to their typically developing (TD) peers. Physical fitness can be described as an integrated measure of most, if not all, the body functions (i.e., cardiorespiratory, skeletomuscular, haemato-circulatory, psycho-neurological and endocrine-metabolic) which, enable an individual to perform PA and exercise (Ortega et al., 2008). Thus, when physical fitness is assessed, the functional status of all these systems should be determined. Moreover, physical fitness serves as an indicator of important health markers, as well as a predictor of mortality (Myers et al., 2002) and modifiable risk factors for cardiovascular disease (CVD) (Blair et al., 1989; Ortega et al., 2008). Although both genetic and environmental factors influence physical fitness, the growth and development stages during childhood and throughout adolescence mark crucial periods of physiological and psychological changes (Armstrong, 2007). Moreover PA, exercise and lifestyle patterns are usually established during these years (Ortega et al., 2008), which are likely to influence adult behaviour and health status later in life. Therefore, measuring physical fitness parameters can help researchers to identify children and adolescents with MI and to gain a better understanding of the physical limitations and barriers to PA and exercise in this group. The components of fitness can be separated into health-related fitness and skill-related fitness as listed in Table 3.1. However, both health-related and skill-related fitness components will be used to define the term “fitness” throughout this thesis. This chapter will review the literature on the different methods used to measure fitness in children and adolescents with MI and provide a rationale for the specific assessments selected in this population group.

Table 3.1 Components of fitness (Baechle et al., 2008)

Health-related fitness	Skill-related fitness
▪ Cardiovascular endurance, exercise capacity, aerobic fitness level (how efficiently the body can take in, transport and utilise oxygen) ▪ Muscular strength (e.g. 1-rep max) ▪ Muscular endurance (the ability of a muscle or group of muscles to perform repetitive contractions over a period of time) ▪ Flexibility (range of motion of joints/stretching of muscles) ▪ Body Composition (i.e., fat and lean muscle mass)	▪ Coordination (the ability to change the position of the body quickly and move limbs accurately) ▪ Balance (the ability to maintain stability during stationary and/or dynamic movements) ▪ Agility (the rate at which an individual is able to perform a movement or cover a distance in a period of time) ▪ Power (an explosive movement involving a rapid application of muscular force) ▪ Speed (the maximum rate at which a person can move over a specific distance) ▪ Reaction time (the time taken from the start of the stimulus to the start of the response)

3.3 Physiological measures of fitness

Fitness testing is prominent among sporting, school and research purposes to measure physiological parameters, which are essential for the valid interpretation of human performance and health status. Standard measures associated with exercise capacity and aerobic fitness levels such as maximal oxygen uptake ($\dot{V}O_{2max}$), serve as an important indicator of successful PA interventions and participation levels (Dobbins et al., 2009). Thus, fitness assessment and evaluation play a vital role in the cornerstone of PA and health promotion strategies and exercise prescription. Within school settings, fitness testing purposes include (Harris & Cale, 2006):

- programme evaluation
- motivation
- identification of children in need of improvement
- identification of children with potential screening diagnosis of fitness needs for individual exercise prescription and improvement
- the promotion of PA, goal setting, self-monitoring and self-assessing skills

In terms of research, fitness testing is considered important for the following reasons:

- to achieve a better understanding of fitness phenomena and their demography
- to investigate the effects of training on children's fitness in the public health context, to survey the fitness levels of children on a large scale in order to provide baseline measures from which to analyse the health-related fitness of a population (Fox and Biddle, 1986).

Working with children requires modification of measurement tools (Bar-Or, 1984). Consequently, equipment and protocols designed for use with adults cannot automatically be applied to paediatric research, whether due to differences in body size, muscle strength, motor coordination, attention span, and/or motivation. Although research has expanded since the 1960s on age-related differences in physiological responses to exercise, how children, distinctively presenting with varying motor skill abilities and MI, respond to acute exercise and to chronic, longer-term training is still limited. Therefore, introspective consideration for the types of protocols and methodologies suitable for measuring components of fitness in youth with MI are described throughout this chapter.

3.4 Coordination and balance

Children and adolescents with MI often, but not always, exhibit difficulties with performing a variety of motor tasks that directly affects everyday activities including balance and coordination. For example, children with developmental coordination disorder (DCD) are frequently characterised as having considerable difficulties coordinating and controlling their body movements (Farhat et al., 2014). As a consequence of their "clumsiness" and coordination difficulties, children with MI are less physically active (Bouffard et al., 1996; Cairney et al., 2005) and more likely to engage in excessive sedentary time (Li et al., 2011) compared to their TD peers. Whether it involves fine motor skills (i.e., drawing, writing, buttoning a coat, tying shoes) which are essential for basic self-help skills, or gross motor skills (i.e., running, hopping, catching, throwing), the competency to perform tasks and ADL plays an important role in the emerging relationship between fundamental movement skills (FMS) and PA (Cantell et al., 2008; Hands & Larkin, 2006). Research in the area of movement skill development has primarily focused on MI and motor deficits in children who exhibit inefficient movement behaviour and dysfunctions (Davies, 2003). In these children, withdrawal from PA and poor physical fitness due to motor skill deficits can lead to a vicious cycle of poorer physical tolerance, lower physical fitness and increased physical inactivity (Barnett et al., 2013; Silman et al., 2011).

3.4.1 Movement skill proficiency

In the literature, movement skill and motor skill proficiency are commonly referred to as movement performance, motor competence, motor development and/or movement/motor coordination. Specifically, "motor disorder" and "motor impairment" imply more overt central nervous system (CNS) damage in the CNS sensory motor areas or corticospinal tract with symptoms of spasticity and dystonia. However, from what is known about Developmental Coordination Disorder (DCD) and probable DCD (pDCD), the underlying mechanisms may involve more issues with white matter (WM) connectivity between other areas (Langevin et al., 2015) rather than simply overt damage. The term "movement disorder" would essentially rule out DCD since not all children with DCD will have difficulties with movement per se, but perhaps more related to the visual-spatial or planning elements. With regards to "motor skill proficiency" and/or "motor competency", these terms would only be deemed appropriate if the study group is predefined to only those who have movement skills testing below a certain cut-off point on a battery assessment which will be described in further detail in Chapter 3.4.1.2. Thus, to keep in line with the aims of this thesis exploring the impact of exercise and fitness in relationship to varying degrees of movement difficulties in children and adolescents, the term "movement impairment" (MI) will be used to describe the mixed population group of interest.

Individuals with MI experience significant difficulties with fine and gross motor control, the planning and execution of movement and in some cases visuo-spatial skills (Hill & Barnett, 2011). At an early age, gross movement skills are necessary to move, stabilise and control the body and objects while exploring the surrounding environment. The development of motor skill competence is considered an important fitness component and the primary underlying mechanism that promotes engagement in PA. Given the importance of movement development, Wilson (2004) emphasised that in addition to conventional (validated) screening tools, methods drawn from other perspectives should be used to not only provide leverage for multimodal treatment, but also to broaden the research views on motor assessment of children. The normative functional skills approach draws from traditional developmental theory and remains the cornerstone of motor assessment. Such assessment is descriptive and is concerned with the acquisition of fundamental motor skills and functional skills as referenced against age norms. To enumerate, a norm-referenced test compares the child's performance to that of a normative group, quantifying the child's movement skill competence. One of the first steps for categorising level of impairment and diagnosis of DCD requires identification that the child has 'significant movement difficulties for their age' (DSM-IV) as performed using a norm-referenced test (Hill & Barnett, 2011). In contrast, a criterion-referenced test compares the child's performance to pre-determined criteria ultimately taking into account the qualitative aspects of the movements required to perform the movement skill task (Cools, 2009). Numerous movement skill assessment tools have been featured in the literature including the Motoriktest für vier-bis sechsjährige Kinder (MOT 4-6), the Peabody Developmental Motor Scales-Second Edition (PDMS-2), the Körperkoordinationstest für Kinder (KTK) and the Maastrichtse Motoriek Test (MMT) (Vles et al., 2004; Kiphard and Schilling, 1974; Folio and Fewell, 1983; Zimmer and Volkamer, 1987). The most commonly used tests of motor skills include the Movement Assessment

Battery for Children (MABC or MABC-2), the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) and the Test for Gross Motor Development (TGMD-2). Irrespective of the type of movement skill proficiency assessment selected, the heterogeneity of individuals with lower movement skill abilities and poorer coordination must be considered.

3.4.1.1 Test of Gross Motor Development

The Test of Gross Motor Development, Second Edition (TGDM-2) (Ulrich, 2000), a revision of the original Test of Gross Motor Development (TGMD) (Ulrich, 1985), measures gross movement performance based on qualitative aspects of movement skills (Cools et al., 2009). According to Ulrich (1985), the test can be used to assess and identify children (3-10 years old) with a significantly reduced gross motor performance compared to their peers. In addition, the TGMD provides therapists and researchers with the information to measure gross motor development and plan programs to improve skills observed in children demonstrating delays. The TGMD-2 requires 15-20 minutes to administer per child with 12 gross motor skills divided into two subtests: 1) Locomotor (i.e., run, hop, leap, gallop, horizontal jump and slide) and 2) Object control (i.e., ball skills, stationary dribble, catch, kick, overhand throw and underhand roll) (Ulrich, 2000). Each item is performed twice and a score of either 1 for correct and 0 for incorrect is added to produce a standard score for both subtests. Next, a gross motor quotient (GMQ) score is calculated and matched to a percentile rank and descriptive rating ranging from "very poor " = <70 GMG (<1%), "average" = 90-110 GMQ (25-75th%) to "very superior" = >130 GMQ (99th%). According to Ulrich (2000), the revised TGMD-2 has included improvements on reliability and validity alongside new normative data from USA for each half-year periods. Notably, Flemish children significantly underperformed on the TGMD-2 compared to American children potentially due to cultural differences in taught object control skills and therefore should be taken into consideration when interpreting the results. Overall, the TGMD-2 is a suitable test to assess motor abilities and fundamental motor skills but does not evaluate fine motor or stability movement skills (Burton & Miller, 1998).

3.4.1.2 The Movement Assessment Battery for Children (MABC)

The Movement Assessment Battery for Children (MABC) is one of the many standardised motor competence tests developed to assess both gross and fine motor coordination in children (Cairney et al., 2009; Henderson & Sugden, 1992; Henderson et al., 2007). It is an extended version of the Test of Motor Impairment (Stott & Moyes, 1985) and is recognised as the most reliable and valid (Kaplan et al., 1998; Tan et al., 2001) test to identify and describe impairments of motor function in children. Moreover the MABC is widely used as a screening tool for children aged 3-16 years old with DCD. The MABC provides both quantitative and qualitative measures to evaluate the motor competence children experience in daily life and provides an outcome of movement as a total impairment score (TIS) based on the accuracy and speed of eight items performed by the child (Farhat et al., 2014) covering the following areas: manual dexterity, ball skills, and static and dynamic balance. The TIS ranges from 0 to 40 with a lower score representing better task performance. The raw score is then converted into a percentage with an individual score below the 5^{th} percentile as having a definite motor problem or motor impairment and those scoring at or below the 15^{th} percentile as a clinical risk range and should therefore be monitored (Henderson & Sugden, 1992).

The MABC has a test-retest reliability of 0.75 and an inter-rater reliability of 0.70 (Henderson & Sugden, 1992; Johnston & Watter, 2006). In addition, the MABC has demonstrated an 80% agreement with the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978) with regards to validity (Crawford et al., 2001). However, unlike the BOTMP which measures the child's strengths and weaknesses over a range of skills, the MABC is limited to movement skills of a certain age group and may introduce a ceiling effect (Cools et al., 2009). Alternatively, the BOTMP involves a full range of fine and gross motor skill tasks used to assess the motor proficiency of children and young persons (4-21 years old), ranging from typically developing (TD) to individuals with moderate motor-skill deficits. Furthermore, the BOTMP can be used for developing and evaluating training programmes.

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

The Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978) is one of the most popular motor assessment batteries for children between 4 years 6 months to 14 years 5 months used for identifying children with movement difficulties (Venetsanou et al., 2007). In addition to the complete form, several versions of the battery exist with the complete, long form (LF) and the adapted short form (SF) version (Verderber & Payne, 1987). The LF of the battery provides ‘a comprehensive index of motor proficiency as well as separate measures of both gross and fine motor skills’ whereas the SF (Bruininks-Oseretsky Test of Motor Proficiency 2, Short Form; BOT-2 SF) consists of 14 items from the LF that provides a brief survey of general motor proficiency. Moreover, the SF requires 20 min to administer compared to 45 min with the LF and encompasses both fine and gross motor skill elements (Verderber & Payne, 1987). The eight subtests assess fine motor precision, fine motor integration, manual dexterity, bilateral coordination, balance, running speed and agility, upper-limb coordination and strength. Based on the LF scores as a criterion, only a few studies to date has compared the classifications indicated by the two forms of the BOTMP to identify motor impairment in children (Venetsanou et al., 2007; Verderber & Payne, 1987). According to Venetsanou et al. (2007), the two forms demonstrated a high Pearson’s product-moment coefficients correlation (r=0.85) for the composite scores. However, the SF total scores were significantly higher than the LF and therefore, indicated lower discriminative accuracy compared to the LF and thus should be kept in mind when interpreting results. The BOT-2 SF is suitable for children and young people 4-21 years old and evaluates both fine and gross motor skills including areas of fine manual control, manual coordination, body coordination, and strength and agility (Deitz et al., 2007). Thus, both the MABC and the BOT-2 SF have been piloted prior to implementation in the study methods. However, due to the wide age range assessed and time limitations requiring ease of administration, the BOT-2 SF was the preferred motor proficiency test to categorise level of MI.

Depending on which battery assessment, various criteria have been used across studies to determine the performance level at which motor skill can be considered impaired with cut-off values set at the 5th and

15th percentile (Riggen et al., 1990; Tan et al., 2001) as definite and borderline motor impairment for the MABC and between the 7th (Verderber & Payne, 1987) and the 23rd percentile (Venetsanou et al., 2007) on the BOTMP. Taking this into consideration, deciding which cut-off value to use is likely to influence the classification of motor skill proficiency and serve as an indicator of MI level. Therefore, due to the variability of cut-off percentages in the literature, the studies conducted in this thesis will use the 17th percentile cut-off point to establish level of MI as based on the BOT-2 SF manual of normative reference values (Bruininks & Bruininks, 2005).

3.5 Cardiovascular endurance, exercise capacity and aerobic fitness level

Another important component of fitness that has received widespread attention in relationship to level of MI and movement difficulties is endurance. Among children and adolescents, endurance or aerobic capacity (cardiorespiratory fitness (CRF)/aerobic fitness) has been reported to be an important marker of health, with higher aerobic capacity associated with lower total adiposity (Lee and Arslanian, 2007) and inversely associated with cardiovascular risk factors (Hurtig-Wennlof et al., 2007). Previous studies examining the relationship between movement problems and children with lower CRF have suggested that children with MI and motor coordination problems are less aerobically fit than children without (Hands & Larkin, 2006; Hay et al., 2003). The measurement of maximal oxygen uptake ($\dot{V}O_{2max}$) or peak oxygen uptake ($\dot{V}O_{2peak}$) when performing maximal physical exertion is the most widely used indicator of cardiorespiratory fitness (Cairney et al., 2010) and is regarded as the gold standard (Chia et al., 2010). It is defined as the highest rate that the body can take up and use oxygen during exercise (Krahenbuhl et al., 1985). Moreover, the measurement of $\dot{V}O_{2max}$ can be used in a variety of different settings: elite athlete, healthy individuals in a fitness setting, individuals with disabilities, chronic conditions, diseases or even individuals classified as higher risk (i.e., heart disease and obesity) (Astrand, 1952; Fletcher et al., 1990). This section will highlight $\dot{V}O_{2max}$ and $\dot{V}O_{2peak}$ as a measure of aerobic fitness and exercise capacity in children and adolescents with MI. Additionally, a summary of the maximal and submaximal protocols used to assess exercise capacity in a variety of settings will be provided.

3.5.1 Maximal oxygen uptake

Maximal oxygen uptake ($\dot{V}O_{2max}$) represents the greatest amount of oxygen an individual can take up and consume from inspired air while performing dynamic exercise involving a large part of total muscle mass (Astrand et al., 1986; Bassett & Howley, 2000). It is considered to be the best measure of cardiovascular fitness and the gold standard for assessing exercise capacity (Fletcher et al., 2001). Traditionally, $\dot{V}O_{2max}$ is defined by reaching a plateau where oxygen consumption fails to increase despite an increase in workload (American College of Sports Medicine, 2000). However, because children and young individuals often do not demonstrate a plateau in $\dot{V}O_2$ as exhibited in the criteria of a true $\dot{V}O_{2max}$, the point of highest oxygen uptake attained during a graded maximal exercise to volitional exhaustion or peak oxygen uptake ($\dot{V}O_{2peak}$) is used to represent aerobic fitness (Shepard, 1968). Additionally, $\dot{V}O_{2peak}$ is the only index that encompasses the pulmonary, circulatory and muscular function into a quantitative value (Figure 3.1).

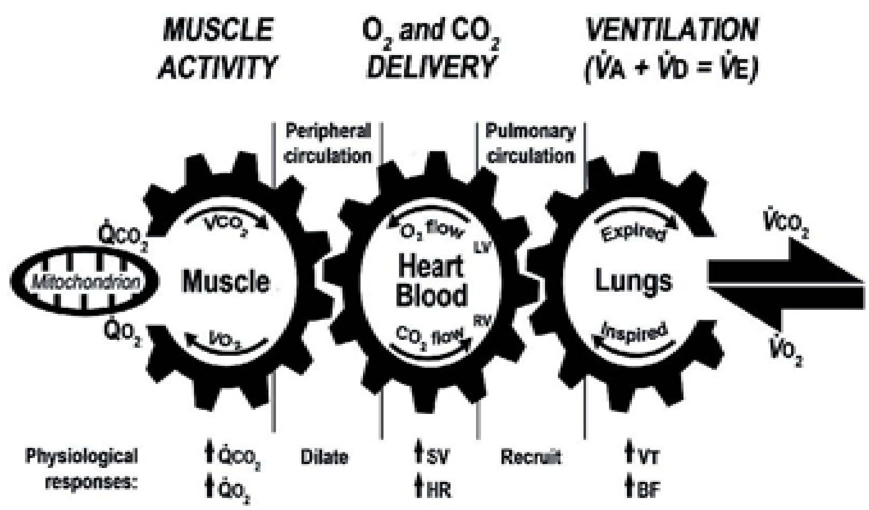


Figure 3.1 The pathway of oxygen in the human body. Inhaled oxygen (O_2) is bound in the lungs to the blood. The heart pumps the blood to the active muscles, where free fatty acids (FFA) and carbohydrates (CHO) are oxidised using O_2 in the mitochondria. Carbon dioxide (CO_2) is produced during this process, and bound to the blood and transported back to the lungs, where CO_2 is expired [printed with permission by Wasserman et al. (2005)].

A systematic review by Rivilis et al. (2011), reported that children with DCD had on average 11-22% lower peak aerobic power ($\dot{V}O_{2peak}$) using lab based assessments and 17-28% lower aerobic power in field based tests such as the 20-m shuttle run test. Furthermore, in comparison to their typically developing (TD) peers, it has been shown that children with poor movement patterns often demonstrate a compromised movement efficiency (Faught et al., 2013) and a more rapid decline in aerobic power over time (Rivilis et al., 2011). Therefore, targeting the aerobic fitness capacity of young persons with lower movement skill competency and difficulties can benefit health-related fitness and overall well-being. Correspondingly, it is important to select an appropriate test to measure aerobic fitness among children with poorer coordination as issues of motivation and testing environment is paramount.

Although $\dot{V}O_{2max}$ can be estimated using maximal or submaximal methodologies, via direct and indirect methods (e.g. submaximal bike test, shuttle run, step test), the suitability of which method to use depends on several factors including environment, testing group and feasibility. In particular, different protocols to assess $\dot{V}O_{2max}$ have been developed for youth with MI ranging from cycle ergometer and treadmill testing within laboratory settings to the shuttle run test for field-based assessments and population-based studies (Cairney et al., 2010). Moreover, in epidemiological studies the most common test for assessing cardiorespiratory fitness (CRF) is the multistage 20-m shuttle run test (Ruiz et al., 2006; Leger et al., 1988), which has demonstrated moderate validity ($r = 0.71$) to the cycle ergometer protocol (Cairney et al., 2010). Other types of testing for non-laboratory settings and mass testing include the Chester Step Test (Buckley, 2004) and the Astrand Cycle Ergometer Test (Astrand & Eyrich, 1952), which will be discussed in greater detail under methods for submaximal testing (Section 3.6).

3.5.2 Maximal exercise testing

Maximal exercise testing to measure or predict $\dot{V}O_{2max}$ has been accepted as the basis for determining fitness (Balke & Ware, 1959; Noonan & Dean, 2000; Patterson et al., 1972). Theoretically, a maximal test is demarcated by a plateau in $\dot{V}O_2$ with further increases in workload (McArdle et al., 1990). In children and adolescents, the highest $\dot{V}O_2$ achieved during a maximal exercise test ($\dot{V}O_{2peak}$), is often used to denote $\dot{V}O_{2max}$ due to the absence of a plateau in $\dot{V}O_2$ (Shepard, 1968). Thus, throughout this thesis, $\dot{V}O_{2peak}$ will be used to represent $\dot{V}O_{2max}$. As a result, other indices are also used as an assessment criteria for attaining maximal effort include: 1) Heart Rate (HR) >180 beats/min (Schulze-Neick et al., 1992), 2) Respiratory Exchange Ratio (RER) > 1.06 (Armstrong et al., 2008; Winter et al., 2007), and/or 3) subjective signs of exhaustion (Verschuren et al., 2006). In addition, a common sign of reaching volitional exhaustion during maximal testing on a cycle ergometer occurs when the participant is unable to maintain a cadence of 60 revolutions per minute (rpm) while pedaling.

3.5.2.1 Peak Oxygen Uptake

Paediatric exercise studies have indicated that only a minority of children demonstrate a $\dot{V}O_2$ plateau during progressive exercise testing (Rowland & Cunningham, 1992) and therefore, $\dot{V}O_{2peak}$ should be utilised for the purposes of testing a wide range of movement abilities. Numerous maximal graded exercise test (GXT) protocols are used for the measurement of $\dot{V}O_{2peak}$ and for clinical diagnostic purposes. Standardised exercise testing is often conducted to provide objective information about exercise capacity, to identify abnormal responses to exercise, for the management of treatment outcomes and to motivate children to engage in PA (Massin, 2014). The different methodologies to measure $\dot{V}O_{2peak}$ include incremental (step) and continuous ramp protocols for treadmill running and cycle ergometry. The Bruce treadmill test (Bruce, 1971) is suitable for children as young as age four years with a correlation coefficient of r=0.88 to r=0.94 for endurance time and $\dot{V}O_{2max}$ (Froelicher et al., 1975; Pollock et al., 1982). The Bruce protocol lasts for 21 min and consists of seven stages (3 min per stage) with speed increasing from 2.7 to 9.7 $km \cdot h^{-1}$ and an incline of 2% from 10-22%. Based on the normative values established for HRs at treadmill stages 1 to 3 and the endurance times, maximal endurance time may be used as a sole criterion of exercise capacity (Gumming et al., 1978). The Balke protocol (Balke & Ware, 1959) consists of nine stages lasting 1 min each at a constant velocity of 5.6 $km \cdot h^{-1}$ and increasing elevation from 6 to 22% in 2% increments. According to, the Balke protocol had a longer test duration

(21.7±0.6 min) and lower VO_2/kg (34.2±1.8 ml/kg^{-1}min^{-1}) than the Bruce protocol (14.9±1.1 min; 48.6±2.7 ml/kg^{-1}min^{-1}) due to the minimal workload increments (Marinov et al., 2003). Moreover, when considering the suitability and reliability of maximal treadmill exercise tests in children and adolescents, the Bruce test is symptom-limited (Marinov et al., 2003) and thus, may be ethically unacceptable for the evaluation of exercise capacity in young individuals.

As a consequence of poorer coordination and inefficient movement patterns observed in children with MI, cycle ergometer exercise tests may serve as an appropriate option for measuring aerobic fitness in a range of abilities and disabilities. In addition to participant characteristics, the length of the exercise test required to elicit maximal or $\dot{V}O_{2peak}$ and demonstrating good reproducibility of commonly measured exercise parameters (i.e., ventilatory threshold (VT)) should also be considered. Moreover, test durations of 10-12 min have been recommended to allow individuals to reach their limit of tolerance (Hulzebos et al., 2012; Paridon et al., 2006). Midgley et al. (2008) highlighted that cycle ergometer tests should last between 7 and 26 min with an emphasis on tolerable workload increments rather than test duration per se. Although no major differences were observed in maximal heart rate or $\dot{V}O_{2max}$ among the various treadmill or cycle ergometer protocols (Myers et al., 1991), measurements of gas exchange, blood pressure, and in some cases, echocardiogram (ECG) recordings are usually easier to perform on participants exercising on a cycle ergometer than on a treadmill. Furthermore, depending on the manner in which the imposed work rate is controlled mechanically braked or electronically braked cycle ergometers are selected. Essentially, mechanically braked cycle ergometers control external work rate with frictional bands, whereas electronically braked ergometers increase resistance to pedaling electromagnetically. The main advantage of an electronically braked cycle ergometer is that it provides a more accurate measurement of mechanical power output, thereby enabling straightforward determination of work efficiency when accompanied by gas exchange measurements (Paridon et al., 2006). However, the child's leg strength and motivational ability to maintain a standard pedaling cadence of 60-70 rpm during a cycling exercise test should also be contemplated.

The Godfrey protocol (Godfrey et al., 1971) is an incremental bike test designed for three groups of workload increments based on height. The incremental stages consist of 10W to 15W (<150 cm) and 20W (>150 cm) per min. In order to accommodate children, the seat height, handlebar position and pedal crank length may need to be adjusted when conducting cycle ergometer testing (Takken et al., 2009). Overall, the Godfrey protocol has been modified for an individualised workload increase and used extensively in clinical settings among children with chronic health conditions including cardiac and respiratory diseases, congenital heart disease, cerebral palsy, cystic fibrosis and asthma (Hulzebos et al., 2012; Karila et al., 2001). Due to ease of administration and familiarisation for participants with MI, the Godfrey protocol was selected as the baseline exercise test mode to assess aerobic fitness level and exercise capacity for each study. Correspondingly, submaximal tests and predictive/estimation techniques for $\dot{V}O_{2max}$ have been adapted for specific population groups and non-laboratory settings and will be briefly discussed. The remainder of this section will touch upon the physiological parameters that can be extracted from measurement of $\dot{V}O_{2max}$/ $\dot{V}O_{2peak}$.

3.5.2.2 Normalising data

Importantly, because $\dot{V}O_{2peak}$ is strongly correlated with body mass and is conventionally normalised in data to compare values across participants, which include both males and females ranging 11-17 years of age, $\dot{V}O_{2peak}$ (mL/min^{-1}) was divided by body mass (kg) to obtain a ratio of ml/kg/min (Armstrong & Welsman, 2001). According to Armstrong and Welsman, (2001), when $\dot{V}O_{2peak}$ is normalised to body mass, males' $\dot{V}O_{2peak}$ remained remarkably consistent from 6 to 18 years (approximately 48 ml/kg^{-1}min^{-1}) while females' values demonstrated a decline from approximately 45 to 35 ml/kg^{-1}min^{-1} (Armstrong, 2007; Armstrong & Welsman, 1994). Moreover, when considering absolute (L/min^{-1}) to relative (ml/kg^{-1}min^{-1}) values, children's aerobic capacity is much lower compared with adults (Table 3.2) and was significantly greater in Tanner stage 3 and stage 4/5 children versus stages 1 and 2, but not when expressed relative to body weight (Armstrong, 2013) (Figure 3.2). In conjunction, the relationship between the amount of oxygen utilised for a given work rate was calculated from the linear slope of the relationship between $\dot{V}O_2$ and Watts ($\dot{V}O_2$/W) and was used as a measure of muscular efficiency during maximal testing. Oxygen pulse (O_2 pulse), a non-invasive indicator of cardiac function, was calculated by

Table 3.2 Adapted example of comparing fitness measures (i.e., $\dot{V}O_{2max}$) using various ways to normalise data and its interpretation (Bar-Or, 1994)

Mode of comparison	**$\dot{V}O_{2max}$ observed or expected**		
	Child[a]	**Adult**	**Child's aerobic capacity compared with adult**
Absolute values l/min^{-1}	1.4	3.2	Much lower
Per kg body weight $ml/kg^{-1}min^{-1}$	50	50	Equal
Per height^2 l/m^2	0.83	1.20	Lower
Per height$^{2.46}$ l/m^2	0.73	0.81	Slightly lower

[a] The child weighed 28 kg and was 130 cm tall; respective values for the adult were 68 kg and 175 cm

dividing the $\dot{V}O_{2peak}$ by peak heart rate (HR_{peak}) ($\dot{V}O_{2peak}/HR_{peak}$) (Wasserman et al., 1999; Wasserman et al., 2011). Maximum O_2 pulse is one of the many indicators of stroke volume, arterial mixed venous oxygen differences and peak oxygen consumption in cardio-dynamic adaptations. Moreover, O_2 pulse serves as an important index of cardiovascular efficiency and is closely related to health and cardiopulmonary function (Abbasi & Tartibian, 2006). For instance, an exercise response with lower peak O_2 pulse represents low stroke volume and cardiac output, a decrease of oxygen delivery to tissues and, therefore, demonstrates a weak function of the cardiovascular system (Wasserman et al., 2011).

Furthermore, O_2 pulse has been utilised as a prognosis indicator in past studies (Astrand & Rodhal, 1988; Wasserman et al., 1999) and reported as an evaluation of cardiovascular fitness by others (Fellmann et al., 2003; Lehman & Kolling, 1996). Notably, Fellmann et al. (2003) introduced the maximum O_2 pulse as an index for the prediction of exercise intensity and energy expenditure following prolonged exercise. Correspondingly, Lehman and Kolling (1996) found that the O_2 pulse may be used to assess cardiovascular limitations and for the determination of anaerobic threshold (AT) (Abbasi & Tartibian, 2006). Although methodological constraints prohibit direct measurements of cellular metabolism in children (e.g., muscle biopsy samples), there is growing evidence that gas exchange measured indirectly via mouth reflects cellular function (Armon et al., 1991) and can provide great insight into the physiological capabilities and responses of an individual.

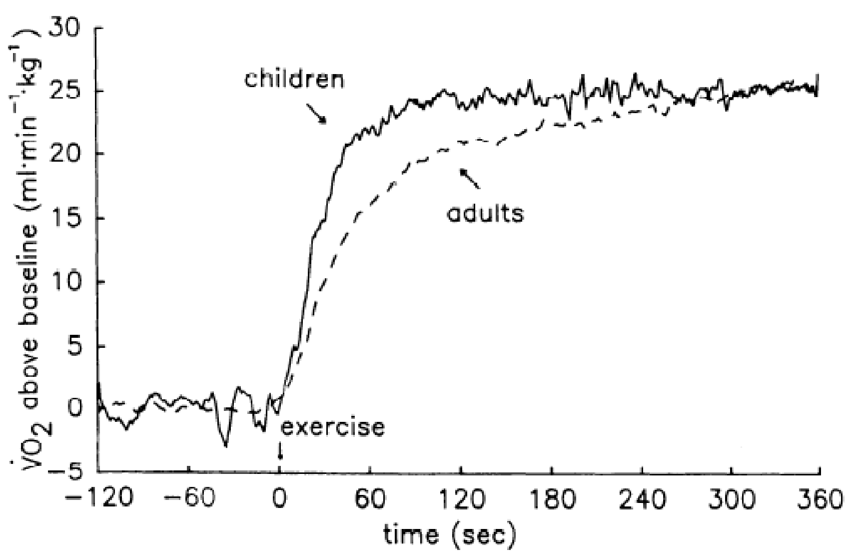


Figure 3.2 Group mean $\dot{V}O_2$ response (normalised to body weight above baseline) to the same work rate exercise (2W/kg) in children and adults. Note different $\dot{V}O_2$ kinetics in children and adults (Armon et al., 1991) [Printed with permission from author].

3.5.2.3 Respiratory exchange ratio

Another measure extracted from the $\dot{V}O_{2max}$ test includes the respiratory exchange ratio (RER), which is calculated from the ratio of $\dot{V}CO_2$ to $\dot{V}O_2$ (Krogh & Lindhard, 1920) at each workload level throughout the exercise test. During exercise, the amount of chemical energy released by each oxygen molecule is dependent on the fuel substrate used (Boisseau & Delamarche, 2000). The ratio is determined by comparing exhaled gasses to room air and can be used for estimating the respiratory quotient (RQ), which is an indicator of which fuel substrate (carbohydrate or fat) is being metabolised to supply the body with energy. At rest, the RER is about 0.8 but can exceed 1.0 (primarily carbohydrate utilised) during intense exercise as CO_2 production by the working muscles becomes greater and more of the inhaled O_2 gets used rather than being expelled (Krogh & Lindhard, 1920). During a $\dot{V}O_{2max}$ test, an RER >1.1 is often an indicator that participants are nearing the point of exhaustion.

The RER was calculated using the breath-by-breath measurements of $\dot{V}O_2$ and $\dot{V}CO_2$ (1) at each workload level throughout the exercise test via an online gas analyser (Cortex Metalyser 3B, Cortex, Leipzig, Germany). Maximal fat oxidation was also calculated using the Frayn equation (2) below:

$$RER = \dot{V}O_2 / \dot{V}CO_2 \qquad (1) \text{ (Krogh \& Lindhard, 1920)}$$

$$\text{Fat oxidation (g.min)} = 1.67 \times \dot{V}CO_2 \qquad (2) \text{ (Frayn, 1983)}$$

In a study by Morris et al. (2013), no differences were seen in RER when comparing $\dot{V}O_{2max}$ cycle tests in boys aged 12-15 years with high motor impairment (HMI) and no motor impairment (NMI). Key findings indicated that when considering the limits to exercise in people with HMI, their maximal RER and fat oxidation levels at test termination suggest that low levels of aerobic muscle performance and not a heightened perceived level of exertion were limiting factors to exercise performance. Therefore, a low level of aerobic muscle performance may be a contributor to the reduced exercise capacity in children with movement difficulties and poorer coordination. In conjunction, further evidence of children with DCD requiring a higher metabolic cost and working at a higher relative intensity compared to TD children was demonstrated by the significantly higher RER (suggesting increased reliance on carbohydrate oxidation) in response to different running speeds (Chia et al., 2013). Boys with DCD also experienced higher levels of sympathoadrenal medullary activity and were more sensitive to pain compared with their TD peers, which may be a deterring factor for engaging in physical activity (Chia et al., 2013). These findings provide a justification for potentially implementing training modalities focused on higher power output and mechanisms of exercise tolerance (Buchan et al., 2013).

3.5.3 Maximal aerobic power

Assessment of maximal power serves as a simple and adequate surrogate measure for $\dot{V}O_{2max}$, providing a simple method for determining aerobic fitness and anaerobic capacity in epidemiological studies (Dencker et al., 2008; Hawley & Noakes, 1992; Krahenbuhl et al., 1985). The power output during cycling at which $\dot{V}O_{2max}$ occurs is termed the maximal aerobic power or peak power output (PPO) and is represented as W_{peak}. Differences in maximal aerobic power between individuals have most often been attributed to central processes or processes involved in the uptake and transport of O_2 to the working muscle (Green & Patla, 1992). For the purposes of exploring different exercise intensities in this thesis, PPO (W_{peak}) was calculated as the average workload (Watts, W) attained in the final 30s completed during the $\dot{V}O_{2max}$ test. This was a critical value for establishing level of exercise intensity (i.e., high and low intensity) assigned to the study interventions comprised in this thesis.

Presently, to draw a connection between level of MI and exercise intensity, Morris et al. (2013), found that children with higher MI demonstrated lower maximum HRs (mean 176 bpm) compared to TD peers (mean 188 bpm) when performing maximal exercise testing. Subsequently, these findings suggest a decreased level of aerobic muscle performance was limiting the ability of children with higher MI to push them hard enough to maximally tax the cardiovascular system (Karila et al., 2001; Morris et al., 2013).

This was further supported in a study by Cantell et al. (2008), who concluded that exercise intensity differed between children with MI and NMI further emphasising that adults with lower movement skills also received ratings of either “needs improvement” or “fair” for metabolic equivalent of task (MET) levels during PA. Studies have shown that children with disabilities also tend to be engaged in less varied activities and often at lower intensities compared to children without disabilities (Law et al., 2006; Majnemer et al., 2008; Ullenhag et al., 2014). Therefore, as a picture emerges suggesting the negative physical fitness and health indices observed in children and adolescents with MI, it is crucial to consider level of exercise intensity achieved as supported by the findings in the systematic review (Chapter 2).

3.5.4 Heart rate (HR)

The measurement of heart rate (HR) as both a training tool and marker of physiological and metabolic stress represents the most common method of physiological monitoring in exercise training and exercise physiology research. Measurement of HR presents a number of distinct advantages; firstly the equipment required is cheap and easy to use, secondly measurement techniques are uncomplicated and non-invasive and finally interpretation of the measurement is simple. Exercise intensity can be prescribed or described according to HR as it relates to (percentage of) maximal heart rate (HR_{max}) or heart rate reserve (HRR). Calculating HRR (6) was not applicable due to time constraints and thus, HR_{max} was utilised, representing the highest HR attained of an individual. This is either directly measured during a mode specific incremental maximum exercise test or via a prediction equation:

The Fox-Haskell formula:	[220-age]	(3) (Fox et al., 1971)
The Tanaka formula:	[208-0.7·age]	(4) (Tanaka et al., 2001)
The Nes formula:	[211-0.64·age]	(5) (Nes et al., 2013)
HRR:	[HR_{max} – resting HR]	(6) (Morris et al., 2013)

The Fox-Haskell formula (3) over-predicted HR_{max} in boys 10-16 years old, whereas the Tanaka equation (4) demonstrated better validity and appropriateness for predicting HR_{max} (Machado & Denadai, 2011). Depending on the setting, direct or predicted measurement of HR_{max} was performed throughout the studies using HR monitors, finger pulse oximeters, and/or the Tanaka equation (4).

3.5.4.1 Measuring heart rate

In Chapters 4 and 5, HR was measured continuously using an online telemetry system (PE4000 Polar Sport Tester, Kempele, Finland). Rather than being estimated, HR_{max} was directly measured and taken as the peak HR recorded during the $\dot{V}O_{2max}$ test. The HR monitor was fitted with a chest strap around the participant and the back of the monitor was gently wetted for better conduction. Weippert et al. (2013), compared the Polar HR monitor to the gold standard ECG and calculated an ICC of 0.995 (95% CI is 0.993-0.991), demonstrating high reliability. In non-laboratory settings (Chapter 6), HR was monitored using pulse oximetry (Kamat, 2002), which is a non-invasive method for monitoring a person's O_2 saturation via fingertip. A device is placed on the fingertip and two wavelengths of light pass through the body part to a photodetector, measuring the changing absorbance of the pulsing arterial blood at each of the wavelengths (Choice med OxyWatch C20SM Pulse Oximeter, Concord, USA). This measure is useful among clinicians for evaluating if a child is receiving sufficient O_2 and effectively using it during breathing (Fouzas et al., 2011), which may be different in individuals with MI. In comparison to chest strap HR monitors, this technique was considered more practical during mass screening sessions. However, the accuracy was questionable during colder temperature settings and also with motion. Therefore, the use of wrist accelerometers with HR monitoring capabilities such as the TomTom Multi-Sport CardioWatch (TomTom International, B.V., Amsterdam, The Netherlands) and the Empatica E4 watch (Empatica S.R.L., Milano) may be an applicable option for assessing an individual's PA and intensity level in school and field-based settings.

3.5.5 Exercise intensity

An important aspect to consider when drawing a link between studies investigating the relationship between $\dot{V}O_{2max}$ and HR is exercise intensity. Exercise requires contributions from the cardiovascular, metabolic, muscular and neural systems in order to meet the increased energy demand and maintain homeostasis. Depending on the exercise intensity and modality, the relative importance and contribution from each of these systems can vary. In adults, PA of a certain form (i.e., endurance or sprints), duration (ranging 15-60 min), frequency (3-5 times per week) and intensity (~60-90% HR_{max}) are crucial elements to improving $\dot{V}O_{2max}$ with training (Rowland, 1985). However, there is conflicting data regarding the effect of endurance training in children with MI albeit research indicating that 8 weeks of endurance training incorporating continuous running for 10-30 min at 70-80% $\dot{V}O_{2max}$ and repeated intervals of 100-800 m at 90-100% $\dot{V}O_{2max}$ showed significant improvements in ventilatory threshold (VT) and aerobic capacity in healthy children (Mahon & Vaccaro, 1989). Notably, significant improvement in $\dot{V}O_{2peak}$ was reportedly independent of training frequency, duration and programme length (ranging 4-18 weeks) (Baquet et al., 2003). However, according to Baquet et al. (2003), achieving exercise intensities >80% HR_{max} is required to elucidate significant increases in $\dot{V}O_{2peak}$. Furthermore, the frequency, intensity and duration of exercise that can be tolerated in children and adolescents with MI to improve aerobic fitness with endurance training and/or high-intensity exercise, still remains unknown (Chapter 2). As previously delineated from the findings in the systematic review from Chapter 2, exercise intensity was infrequently monitored but may represent an important tool/marker for evaluating levels of activity achieved in MI. Therefore, in order to examine the mechanisms of fatigue, exercise tolerance and the effect of exercise interventions, exercise intensity should be quantified and prescribed as a proportion of an individual's $\dot{V}O_{2max,}$ W_{max}/PPO or HR_{max} (Chapter 3.5.3).

3.5.6 Rating of perceived exertion (RPE)

Rating of perceived exertion (RPE) has been used extensively as a subjective tool to quantify an individual's symptoms and perception of the physical demands of an activity (Ritchie, 2012). These scales offer a simple and inexpensive technique to estimate and regulate exercise intensity during exercise testing, for exercise prescription and in field studies (Barkley & Roemmich, 2008; Borg, 1982). The 'Borg Scale' is the most widely used psychophysical RPE scale ranging from 6 (no exertion at all) to 20 (maximal exertion) (American College of Sports Medicine, 2000; Borg, 1982). As such, research has shown that young adults are able to accurately produce power outputs proportional to their measured maximum when using the Borg Scale as a perceptual reference frame (Eston et al., 1987; Williams et al., 1991). Correspondingly, following the development of a simpler RPE scale ranging from 1-10 (Williams et al., 1991) proposed for use in children, several children's scales have been developed to tailor the cognitive ability and/or vocabulary level of the descriptors of exercise intensity based on adult RPE scales (Ritchie, 2012). To enumerate, the OMNI scale of perceived exertion (OMNI scale), which illustrates a child becoming more fatigued while cycling up a hill is a simple estimation-of-effort paradigm during cycling (Robertson et al., 2000) and widely employed for prescribing exercise intensity in children (Barkley & Roemmich, 2008; Robertson et al., 2002). In contrast, the Cart and Load Effort Rating (CALER) scale of perceived exertion (Figure 3.3) was also developed for use during cycle ergometer exercise and is an abridged version of the Children's Effort Rating Table (CERT) (Williams et al., 1994). The CALER has a scale from1 to 10 with 1 being classed as 'very easy' and 10 being 'so hard I'm going to stop'. Accompanying the scale is an illustration of a child pulling a cart behind their bicycle, which was progressively laden with bricks.

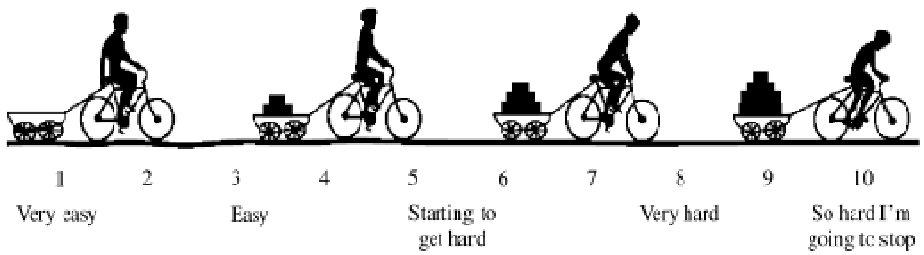


Figure 3.3 The Cart and Load Effort Rating (CALER) scale (Eston et al., 2000)

The concurrent validity of the CALER and OMNI bike scales were established by Barkley and Roenmich (2008) and demonstrated a significant linear relation ($p<0.001$, random effects model) with $\dot{V}O_2$ ($r=0.89$ and 0.88) and HR ($r=0.93$ and 0.92) across cycle ergometer test stages. The CALER scale is considered a valid and reliable measure of perceived exertion in children as young as 9 years old (Barkley & Roemmich, 2008) and hence, was used to record RPE during all exercise tests and interventions (Eston et al., 2000).

In addition to the contribution of local and central cues to effort during dynamic exercise, cognition and motivation/emotion are important factors to RPE (Pandolf, 1983; Robertson, 1982). More specifically, applied physiologists recognise that what individuals "think they are doing" is just as important as the actual metabolic costs of an activity for establishing appropriate exercise intensities (Rejeski, 1985). Within the context of participation in daily tasks and PAs, children with movement difficulties often express lower perceived adequacy and motivation compared to TD children (Silman et al., 2011).

3.6 Submaximal exercise testing

Although the criterion measurement of $\dot{V}O_{2max}$ via direct gas exchange during maximal exercise to volitional exhaustion is regarded as the gold standard for assessing aerobic capacity (Chia et al., 2010), advanced equipment/facilities and well-trained individuals are required to administer the test. In addition, maximal exercise testing can be unpleasant and burdensome for individuals with physical limitations such as pain, fatigue, abnormal gait or impaired balance that are often observed in special population groups. Among children with DCD who exhibit decreased cardiopulmonary function and altered peripheral muscle responses (van der Hoek et al., 2012), submaximal exercise testing may serve as a safe and practical method for establishing functional capacity and monitoring treatment effectiveness (Farhat et al., 2014). For instance, children with MI including pDCD and DCD may be particularly disposed to perform at a submaximal level due to the negative perceptions they feel regarding their physical abilities (Cairney et al., 2010; Cairney et al., 2005). However, clumsy and poorer coordinated children may find running exercise tests (i.e., Shuttle Run Test) difficult to perform in comparison to stationary cycling (Cairney et al., 2010) leading to invalid conclusions. Furthermore, direct measurement of $\dot{V}O_{2max}$ is generally not applicable for most public school settings, health promotion programs, or epidemiological field studies within paediatric research (Buono et al., 1991). Thus, indirect methods including predictive and performance tests (e.g., predictive submaximal exercise tests, shuttle run, step tests and walk tests) may be a more feasible method to assess aerobic fitness levels in non-laboratory settings and among clinical populations.

3.6.1 Predictive vs. performance tests

Predictive tests are submaximal tests that are used to predict maximal aerobic capacity whereas performance based tests measure responses to standardised PAs that are typically encountered in daily life

(Noonan & Dean, 2000). Typically, predictive tests including the modified Bruce Treadmill Test (Bruce et al., 1973), the Cooper Test, the 20-Meter Shuttle Test (Noonan & Dean, 2000; Sartor et al., 2013) and Åstrand Cycle Test (Astrand & Ryhming, 1954) utilise HR or oxygen consumption ($\dot{V}O_2$) measurements at two or more workloads to extrapolate a relationship to age-predicted maximal heart rate (HR_{max}). Notably, measures of exertion, pain, discomfort, breathlessness, fatigue and well-being in response to exercise are important parameters to capture among clinical population groups.

3.6.2 The 20-Meter Shuttle Run Test (20-MST) and 6-Minute Walk Test (6-MWT)

Another consideration for using submaximal exercise tests to assess aerobic fitness is due to the fact that children and young individuals often do not demonstrate a plateau in $\dot{V}O_2$ as exhibited in the criteria of obtaining a true $\dot{V}O_{2max}$. Thus, the point of highest oxygen uptake attained during a graded maximal exercise to volitional exhaustion ($\dot{V}O_{2peak}$) is often used to represent aerobic fitness among youth (Shepard, 1968). The 20-Meter Shuttle Run Test (20-MST) (Leger et al., 1982; Leger et al., 1988) assesses $\dot{V}O_{2max}$ and was designed for children and adults in PE and fitness class settings. With limited equipment involving only a cassette tape and cones to denote distance lines, the 20-MST requires participants to run between two lines spaced 20 m apart at a pace set by signals on the tape (Noonan & Dean, 2000). The starting speed is 8.5 km/h and the frequency of the signals is increased by 0.5 km/h per minute. Once the participant fails to maintain the set pace, the last completed speed (i.e., stage) is recorded and used to predict $\dot{V}O_{2max.}$ A previous study demonstrated a moderate-to-high correlation ($r=0.71$, $p<0.001$) between the 20-MST and a cycle ergometer test in children with pDCD and concluded that the shuttle run test is a reliable substitute in this population group when lab based assessments of $\dot{V}O_{2max}$ are not feasible (Cairney et al., 2010).

The relationship between body composition, physical fitness and exercise tolerance in children with and without DCD was examined using the 6-Minute Walk Test (6-MWT) (Farhat et al., 2015). Some investigators have reported a correlation between distance covered in the 6-MWT and $\dot{V}O_{2peak}$ ($r=0.64$)

(Cahalin et al., 1996) and (r=0.70) (Nixon et al., 1995). However, the authors noted the importance of conducting two practice tests and in the same testing environment to produce optimum results. Nonetheless, the 6-MWT is a simple and inexpensive submaximal test that corresponds to functional activities performed in daily activities. Moreover, standard time rather than a predetermined distance may provide a better indicator of endurance in children and operate as a measure for detecting change following an exercise intervention (Noonan & Dean, 2000). However, some main constraints may be due to coordination, timing and pacing, which remain problematic in youth with MI who often rely on the perception of timing and planning in relationship to running speed.

3.6.3 The Åstrand-Rhyming (A-R) cycle test

The Åstrand-Rhyming (A-R) method is perhaps the most commonly used submaximal test in adults and adolescents aged 15 years and older (Ekblom, 2014) (Figure 3.4). It is based on the relationship between steady-state HR during submaximal workloads and uses the nomogram technique (Åstrand and Rhyming, 1954) to predict $\dot{V}O_{2max}$. According to Åstrand and Rhyming (1954), the results were optimal for assessing aerobic capacity when the workload was at a severity level where HR attained during steady state ranged between 125 to 170 bpm (Astrand & Rhyming, 1954). Correspondingly, within these limits there is a linear increase in metabolism with HR. The accuracy of the A-R method to predict $\dot{V}O_{2max}$ was first studied in adults (Davies, 1968; Von Dobeln et al., 1967) with no age-correcting factors available at the time for individuals under 15 years of age (Ekblom, 2014). Studies conducted since then, have primarily observed children aged 11-12 years, noting the important training age in which most sports disciplines begin, thus leading to several regression models and age-correction factors (Ekblom, 2014; Olgun Binyildiz, 1980; Woynarowska, 1980). More recently, a study by Buono (1991) evaluated the A-R method with a correction factor in children 10-16 years old, which demonstrated moderate reliability (r=0.77) compared to a $\dot{V}O_{2max}$ treadmill test. However, the validity and reliability was only examined in TD individuals and may not necessarily be comparable due to the nature of the two tests (i.e. cycling vs.

running). Furthermore, few studies have failed to take into account the wide range of motor skill abilities and levels among youth when validating such methods.

In Chapters 5 and 6, participants completed the Åstrand-Rhyming (A-R) submaximal cycle test using the nomogram technique (Astrand & Rhyming, 1954) and age-correction factors (Buono et al., 1991) to predict $\dot{V}O_{2max.}$ The protocol methods are described in Chapter 5.2.1 and the criterion validity and reliability of the test in children and adolescents with MI is explored in Chapter 5.

Image removed from electronic version

Figure 3.4 Early contributions to exercise physiology depicted during development of the Åstrand bike test (Åstrand, 1952).

3.6.4 The Chester Step Test (CST)

The Chester Step Test (CST) is another submaximal test popularly used for commercial health and fitness assessment purposes and as a field test (Chapter 5.2.2). Prediction of $\dot{V}O_{2max}$ using the CST is based on the extrapolation of a "line of best fit", which passes through the submaximal HR responses for each stepping stage, up to a level which equals the participants' age-estimated HR_{max}. The cornerstone of the

CST is based on the assumption that a linear relation exists between each step stage (stages I-V) of the CST with HR and $\dot{V}O_2$; meaning HR_{max} and $\dot{V}O_{2max}$ are coinciding events and that HR_{max} is equal to 220 minus the participant's age (Buckley, 2004). Participants performed the CST in Chapter 5 to establish the criterion-validity of the CST against direct measurement of $\dot{V}O_{2max}$ for the purpose of assessing aerobic capacity within group settings. The CST was also utilised for group testing during screening sessions later described in Chapter 6. This stemmed from the idea that the CST may be a novel and appropriate method for capturing individuals with different levels of motor abilities whilst quantifying aerobic capacity for large settings.

3.7 Agility

Young individuals with MI may exhibit a range of motor competency skills with some children experiencing considerable difficulties coordinating and controlling their fine and gross body movements as characterised in DCD. Correspondingly, it is intuitive that atypical development of physical fitness and reduced PA may further restrict the opportunities for children with movement difficulties and MI to practice and develop fundamental movement skills (Barnett et al., 2008; Haga, 2008). As a result, another important fitness component to measure is agility, which is defined as the ability to change the direction of the body in an efficient and effective manner. In order to do so, an individual requires a combination of coordination, balance, strength and speed (McArdle et al., 2000), which are often less refined in children with MI and impact their engagement in sports and PA. Sports such as tennis, football, handball, basketball and rugby involve players to produce multidirectional movements: accelerate, decelerate and change direction throughout the game in response to a stimulus (i.e., movement of ball or opposing team player) (Sassi et al., 2014; Sheppard & Young, 2006). Thus, fitness assessments encapsulating agility can provide multifaceted information on preventative strategies or clinical treatments to improve health outcomes in children and adolescents.

As such, various agility tests have been developed for field-testing with the majority based on change of speed direction. These tests include the Illinois agility test (Cureton, 1951; Hastad & Lacy, 1994), the 505test (Deutsch et al., 1998), the L-run test (Meir et al., 2001) the zig-zag test (Little & Williams, 2005) and the T-test (Pauole et al., 2000), which is well accepted as the standard test of agility (Sassi et al., 2014). The T-test involves speed with four directional changes and more recently, a modified version of the agility T-Test (MAT) was tailored to replicate the movement pattern of field and court sports and reduce total test distance to 20 m. Overall, the MAT has demonstrated excellent reliability with an ICC of 0.92 and 0.95 in males and females. Moreover, Sassi et al. (2014) concluded that the complexity of motor control and coordination of muscle groups could influence the ability to the change of directional speed (Young et al., 1996). In addition, the 10-metre shuttle run test utilised in Chapter 6, which is an adapted version of the maximal multistage 20-MST (Leger & Lambert, 1982) to accommodate children with CP (Verschuren et al., 2006), is another inexpensive and easy agility test to facilitate for assessing speed, body control and changing directions. Two lines are marked using tape or cones to delineate the 10 m distance and participants are instructed to sprint to the opposite line, pick-up the sponge/sock and run back and place the item on the starting line. Then, without a rest, the participant repeats the protocol and picks up the second item and returns to the starting line again while timed (Leger & Lambert, 1982).

3.8 Power and speed

The assessment of power in children with DCD has also received limited attention, O'Beirne and colleagues (1994) reported lower levels of total anaerobic output, relative peak power (PP) and absolute and relative mean power based on the Wingate test (Bar-Or, 1987; Raynor, 2001). This was further evident by higher scores in the fatigue index demonstrating increased fatigue levels by uncoordinated children (O'Beirne et al., 1994) and inability to produce the power during an all-out cycling task. Within physiology, power is defined as the product of force and velocity whereby the maximum force of a muscle is determined by the number of sarcomeres arranged in parallel and is consequently proportional to the cross-sectional area of the muscle or the square of the linear dimensions (l^2) (Armstrong, 2013). The velocity of muscle shortening depends on the number of sarcomeres in series and is directly proportional to the length of the muscle. Power is accordingly related to (l^3) and best reflected by measurement of muscle volume (Armstrong, 2013). The greatest gains both in terms of strength and muscle size have been produced by those protocols whereby the product of load times duration was high and training at a high percentage of the individual's maximal strength (from 60% to 100% of one repetition maximum) has been shown to be most effective (MacDougall, 1986). Although not discussed too in-depth, power is considered a critical component among the target population group in this thesis for completing high-intensity intermittent exercise as presented in Chapter 4. Despite the importance of power, this fitness component was only assessed in Chapter 6 (EPIC Study) and the fitness tests predominantly comprised in the subsequent studies focused on elements of strength and aerobic capacity.

Muscle power and muscular endurance tests are commonly used to make inferences about anaerobic muscle capacity. Tests of explosive muscle power examine parameters such as distance covered (e.g., throwing a heavy ball or performing a standing-long-jump) whereas tests of anaerobic muscle endurance measure the maximal number of repetitions within a specific time constraint (e.g., number of sit-ups or push-ups executed in 30 s). While the extent to which motor coordination deficits influence performance on such test components is acknowledged (Raynor, 2001; Rivilis et al., 2011), only a few studies have examined the relationship between muscular fitness and task constraints within children with MI (Ferguson et al., 2014). More recently, Garber et al. (2011) introduced the term neuromotor fitness to describe skill-related fitness components such as balance, coordination, agility and proprioceptive ability important for performing functional skills and motor tasks. Standardised motor skill and movement proficiency battery assessments often evaluate measures of neuromotor fitness in the individual subtests. Poor balance and agility in children with MI plays an important role in motor control and movement efficiency. As a result, compensatory strategies including coactivation of muscles for motor control deficits are likely to influence physical fitness outcomes (Ferguson et al., 2014).

3.8.1 Wingate anaerobic test

Some data have also suggested that the anaerobic capacity of children who are poorly coordinated is well below average, as performances on tasks testing explosive power (e.g., sprinting, hopping and jumping) were diminished (O'Beirne et al., 1994). However, common field-based tests used to measure short-term power such as sprinting and jumping, require a high degree of coordination, which may be an ineffective method for capturing anaerobic power and anaerobic capacity in children with MI. The Wingate anaerobic test (WAnT), which allows for the determination of cycling peak anaerobic power (PP) over a one or five second period and mean power (MP) over a 30 second period, is the most popular test of short term, high-intensity power output (PO) in children and adolescents (Armstrong et al., 2001). In O'Beirne et al. (1994), the PP of the poorly coordinated children during the WAnT were 9.7% below that of the controls (mean 177 W vs. 196 W) and the mean PO during the 30-s test was significantly lower for the poorly coordinated children (mean 129 W) compared to coordinated controls (mean 161 W). Consequently, such a performance decrement may relate to reduced anaerobic PO resulting from less intensive activity and decreased muscle force and strength. Although the WAnT was piloted in a small sample of children during the early phases of this PhD, the main emphasis remained focused on strength. However, in conjunction with generating force, individuals with MI may have difficulty coordinating throwing and jumping movements (Ferguson et al., 2014) and therefore, power represents a critical measure and is briefly measured in Chapter 6.

3.8.2 Vertical jump

The vertical jump (VJ) is a fundamental movement skill that is used to train and test the power output of an individual (Ostojić et al., 2010); most commonly representing explosive power. Participants are instructed to jump from a 90° knee squat position with the hands on the hips and with a jump meter/mat to record height distance and flight time (Tsiotra et al., 2009). Different variations of the jump include counter-movement jump using the legs and squat position (CMJ) as well as arm swinging prior to take-off to increase the body's center of mass (COM) rise. A study by Williams (2008) explored differences in VJ performance between TD children and DCD to identify the possible mechanisms in movement complications and impairment in DCD. The results illustrated that the DCD group had lower VJs than their TD peers and interestingly, their peak vertical COM occurred earlier and took a longer elapsed time from instant peak to take-off. Furthermore, these findings suggest that the earlier occurrence of peak vertical COM may be attributed to coordination error and/or difficulty in automating movements, highlighting the importance of developing these skills in children with MI (Williams, 2008).

3.9 Muscle strength

Another aspect of health-related fitness and the acquisition of fundamental motor skills (FMS) is the development of muscular strength. The main health-related muscular fitness components (i.e., the capacity to carry out work against a resistance) are maximal strength (isometric and dynamic), explosive strength, endurance strength and isokinetic strength (Ortega et al., 2008). Importantly, the ability to produce and modulate force output is an essential aspect of motor control and execution of movement that depends on both peripheral (i.e., muscle anatomy and fibre type composition) and central (i.e., central motor commands) factors (Perrey, 2013). According to Stodden et al. (2008), the three fundamental aspects involved in the development of neuromuscular adaptations and muscular strength include (a) the ability to effectively recruit motor units, (b) the ability to increase motor-firing rates, and (c) a decreased level of coactivation of muscle agonists and antagonists (i.e., coordinated muscle recruitment/muscle activation). The following sections will elaborate on the different techniques and types of strength measures utilised in paediatric studies.

3.9.1 Measuring maximum force

The increased ability to produce maximum voluntary force as children grow up, has been well documented (Raynor, 2001). According to Lloyd et al. (2013), as children reach the onset of puberty, they experience rapid growth along with observable non-linear gains in muscle strength . However, there exists a paucity of empirical evidence supporting such normal gains in strength and power in children with DCD or physical impairment (Parker et al., 1990). As such, the difficulties experienced by children with DCD when performing everyday fundamental movement skills (FMS) including throwing, catching and hopping have been associated with strength and power deficits (Knuttgen & Komi, 1992; Larkin & Hoare, 1991). Muscular strength is an essential aspect of motor skill performance (Behringer et al., 2011; Malina et al., 2004; Tveter & Holm, 2010), and therefore, developing confidence and competence to perform muscle bearing resistance exercise during growth may have important long-term implications for fitness and health. The ACSM has further recommended performing strength and resistance training exercise for at least three times weekly for bone and muscle health (ACSM, 2000). Furthermore, it is imperative that coaches and health professionals teaching and training children and adolescents are aware of paediatric scientific principles to ensure that an exercise prescription is planned according to the unique demands of the individual inclusive of baseline fitness levels, motor skill development, movement competencies and health or medical issues (Lloyd et al., 2013). Comparatively, the reduced exercise capacity and muscular performance demonstrated by participants with higher MI highlight the need for exercise interventions to target the development of muscular function in MI (Morris et al., 2013).

There are several factors to consider when measuring the generation of maximum force, including the type of muscle fibres, the size and number of muscles involved along with the proportion of muscle fibres and the coordination of muscle groups. Notably, the production of voluntary muscle force is the consequence of a number of processes that start in the brain. After a command from the supra-cortical structures, the descending drive from the motor cortical structures activates the spinal motor-neurons, which in turn activate muscle fibres (motor-neurons) to produce muscle force (Dum and Strick, 1996). In children with cerebral palsy (CP), coactivation of antagonists and reduced muscle activation during movement, have been associated to spasticity and impairment of voluntary movement (Leunkeu et al., 2010). Increased levels of coactivation are an indicator of motor coordination problems and often relate to the lack of movement experience (Bouffard et al., 1996) and programming problems associated with

DCD (Raynor, 2001). To gain a better understanding of muscle force production in children with MI, studies have investigated strength, power, coactivation and muscle fatigue measures during isometric and isokinetic tasks (Morris et al., 2013; Raynor, 2001).

3.9.1.1 Isokinetic strength

Isokinetic strength testing has been less widely used with children compared to isometric testing, however it is advantageous in assessing a muscle at its maximal potential throughout the joints' full range of motion and in the absence of fixed resistance (Raynor, 2001). The dynamic nature of isokinetic testing makes it applicable to many fundamental movements (Leunkeu et al., 2010) and numerous studies have indicated that children including TD and CP (Eken et al., 2013; Moreau et al., 2008) can be reliably assessed isokinetically using both concentric and eccentric actions (De Ste Croix et al., 2003). Conversely, the mechanisms associated with the increase in isokinetic strength with age in children are still not well understood. Therefore, researchers have become increasingly interested in exploring the motor deficits (e.g., muscle spasticity, increased coactivation, motor control problems) responsible for impaired movement patterns and decreased muscle strength in children with MI (Eken et al., 2013).

An isokinetic muscle contraction can be defined as a muscle that contracts and shortens at a constant rate of speed (Osternig, 1986; Spennewyn, 2008), thus, taking velocity into account. When children performed strength testing under isokinetic conditions on a Biodex dynamometer, peak torque and power was decreased in the DCD group and even more so at higher velocities (Raynor, 2001). Furthermore, a lower flexor-extensor percentage was recorded for children with DCD under isokinetic conditions; suggesting increased levels of coactivation (Raynor, 2001). The coactivation ratio (i.e., agonist:antagonist ratio) is used as a measure of an individual's muscular organisation with lower levels of coactivation representing a more effective method of muscular activation for the production of maximum force. Correspondingly, the increased levels of coactivation observed in DCD has been previously associated with unskilled movements (Basmajian & De Luca, 1985) thereby affecting neural factors associated with producing sufficient strength and power to perform activities of daily living (ADL) (Eken et al., 2013; Ramsay et al., 1990).

3.9.1.2 Isometric strength

Given its static nature, isometric strength testing has been reliably and favourably used to assess populations with movement difficulties, as the strength factor is less likely to be confounded by the movement problem (Morris et al., 2013; Raynor, 2001). Isometric strength is defined as the capacity to produce force or torque with a voluntary isometric contraction, meaning, that muscle(s) maintain a constant length in the absence of body movement during the measurement period (Chaffin, 1975; Stobbe & Plummer, 1984). Although isometric strength may be a more suitable measure in children with MI, there are limitations regarding its applicability to "real life" actions, especially since youth are constantly playing and moving and everyday movements seldom involve pure forms of isolated muscle action. Conversely, isometric leg muscle strength has been moderately related to mobility capacity in children with CP compared to TD, demonstrating reduced isometric strength ranging from 36-82% across different muscle groups and assessments (Dallmeijer et al., 2015). Moreover, children may not produce maximum force during isometric actions as attributed to inhibitory mechanisms that preclude children from exerting maximal effort as a consequence of experiencing discomfort caused by a rapid development of force. Whole motor pools may not be activated due to a reduction in the neural drive under high tension loading conditions. Nonetheless, measurement of isometric strength has the potential to not only evaluate strength and muscle structure/composition, but also provide insight on the muscle fatigue experienced in MI (Barnett et al., 2013).

3.9.2 Muscle fatigue

Despite the acknowledged factors (e.g., reduced muscle activation and increased muscle coactivation) associated with impairment of voluntary movement in children with DCD (Raynor, 2001) and CP (Leunkeu et al., 2010), there remains a paucity of research examining muscle fatigue. Previous research on the measurement of mechanical force or power output profiles during sustained isometric maximal contractions and/or repeated bouts of high-intensity exercise, have shown that children demonstrated better resistance to fatigue in comparison to adults (Ratel et al., 2006) and children with MI (Eken et al., 2013; Leunkeu et al., 2010; Raynor, 2001). However, the lack of agreement on defining 'fatigue' and what it represents in the literature has influenced the complexity of investigating muscle fatigue. Throughout the literature, muscle fatigue is not only characterised by reductions in maximal force output or performance (Asmussen and Mazin, 1978; Degens and Veerkamp, 1994; Fitts and Metzger, 1993), but also has been defined as in increase in the perceived effort needed to exert a desired force (Enoka and Stuart, 1992). Throughout this thesis, muscle fatigue will be defined as 'the failure to maintain a required or expected force," (Edwards, 1983; Raynor, 2001) and is further defined and explored in Chapter 4.

Despite the dearth of information regarding mechanisms related to children recovering more rapidly, there is still little known about the neuromuscular mechanisms with respect to exercise-induced fatigue in children. Recovery interval studies conducted in children have utilised isometric (Armatas et al., 2010) or isokinetic (Zafeiridis et al., 2005) and isotonic contractions (Faigenbaum, 2008), which are most predominant in activities of daily living (ADL) (Murphy et al. 2014). Furthermore, there is evidence of children recovering as quickly as 1-min post exercise (Faigenbaum et al., 2008) whereas adults have reported fatigue or performance decrements approximately 3-min into recovery (Behm et al., 2002). When performing maximal isometric (Halin et al., 2003) or isokinetic contractions (Paraschos et al., 2007), pre-adolescent children were less fatigued than adults. This has also been observed during dynamic actions, such as maximal cycling (Ratel et al., 2002) and short running bouts (Ratel et al., 2006).

Current evidence suggests that young children fatigue less during high-intensity exercise compared to adults. The mechanisms related to the greater fatigue resistance in TD children are thought to be due to the lower ability to activate type II (fast twitch) muscle fibres and the lower accumulation of muscle by-products (Halin et al., 2003; Ratel et al., 2006). Additionally, the ability of children to recover faster following exercise compared to adults has been linked to factors including: faster phosphocreatine (PCr) resynthesis; greater oxidative capacity; better acid-base regulation; speedier return to baseline CRF and higher removal of metabolic by products (Ratel et al., 2006). Moreover, factors such as motivation, muscle mass, fibre-type distribution and neuromuscular activation may further explain the greater muscle fatigue and exercise intolerance observed in children with MI and across age/maturation-related differences (Falgairette et al., 1991; Ratel et al., 2006). It has been highlighted that poor performance on anaerobic tasks, requiring more explosive power, may be explained by the inefficient movement patterns and deficient motor fibre recruitment in children with MI (Keller et al., 2000; Rivilis et al., 2011). This reduction in anaerobic performance was further confirmed in O'Beirne et al. (1994) who observed that poorly coordinated subjects were unable to maintain as great a percentage of PO and reported greater local muscle fatigue.

3.9.2.1 Central and peripheral fatigue

The potential factors involved in fatigue development (i.e., decrement in muscular performance) can be classified into two categories: (i) central factors involving the CNS and nervous pathways (Enoka, 1995; Ratel et al., 2006); and (ii) peripheral factors occurring within the muscle itself (Fitts, 1994; Westerblad et al., 1991). Although there remains a discrepancy on the relative contributions of central and peripheral factors in the development of fatigue it has been established that during sustained maximal voluntary isometric contractions (MVICs) (Kent-Braun, 1999; Schillings et al., 2003) or high-intensity dynamic exercise (James et al., 1995), ~80% of fatigue is peripherally influenced (Ratel et al., 2006). In order to quantify the ability of the CNS to fully drive the muscle, the level of voluntary activation or the ability of the muscle to recruit motor units voluntarily, is determined during a maximal voluntary contraction (MVC) (Gandevia et al., 1996; Gandevia et al., 1998; Herbert & Gandevia, 1999). Such methods employed to examine this have included the twitch interpolation technique (Behm et al., 1996; Shield & Zhou, 2004) in which an external stimulus (i.e., electrical or magnetic) is applied to the muscle activates any motor units not recruited or not recruited at maximum firing rates to elicit a true maximal force

(Gandevia et al., 1998). If an increase in force is evoked, then the voluntary activation is submaximal (Stackhouse et al., 2001; Todd et al., 2003) however, if no increase occurs the force is considered a MVC (Gandevia et al., 1998). In addition, the contribution of peripheral and central mechanisms is exercise mode specific. For example, running induces more central fatigue than cycling due to muscle damage (Lepers et al., 2002), which was taken into consideration when deciding on the type of exercise to implement in examining responses to different exercise intensities in Chapter 4.

3.9.2.2 Muscle-fibre type

During fatiguing protocols involving several repeated bouts of MVICs, it has been suggested that fatigue resistance differed between individuals with contrasting fibre type composition. In particular, during high-intensity intermittent exercise, adults with a higher content of type II fibre composition (Colliander et al., 1988; Hamada et al., 2003) demonstrated greater muscle fatigue and decrements in peak torque compared to individuals with a high type I (slow twitch) fibre composition (du Plessis et al., 1985), which have less mitochondria. Consequently, fatigue during high intensity exercise relates to the inability of type II muscle fibres to maintain the high rate of ATP resynthesis required. The complexity of understanding the underlying mechanisms and factors involved in muscle fatigue is influenced not only by the action of the muscle group examined but also by the morphological muscle characteristics and age differences in fatigability. Specifically, Lexell et al. (1992) noted that the proportion of type I fibres in the vastus lateralis muscle decreased from around 65% at 5 years of age to less than 50% at 20 years of age (Ortel, 1988). Accordingly, this decrease in the proportion of type I fibres is hypothesised to be due to a transformation of type I fibres to type II fibres throughout growth and adolescence (Lexell et al., 1992; Ratel et al., 2006). Muscle biopsies of children with MI, in particular with CP, have demonstrated abnormal variation in the size of fibres and also altered distribution of fibre types in the affected muscle groups (Rose et al., 1994). More specifically, both hypertrophy and atrophy of type I and type II fibres were observed in CP (Castle et al., 1979) alongside concurrent contraction of agonist and antagonist muscles during movement (Leunkeu et al., 2010). These factors may influence the balance deficits, impaired motor control and gait abnormalities detected in children with CP (Rose et al., 1994) and DCD (Raynor, 2001), resulting in metabolic inefficiency and fatigue.

3.9.2.3 Coactivation/ Cocontraction

Coactivation, also known as cocontraction, is a result of simultaneous activation of agonist and antagonist muscle groups during voluntary contractions (Soares et al., 1996) and has an important link to the central theories of fatigue (Ratel et al., 2006). For example, increased levels of coactivation have been highlighted in children with DCD and CP (Leunkeu et al., 2010; Raynor, 2001), in which the decline in force can essentially be related to a decline in 'motor drive' and therefore, an inability to maintain muscle activation (Ratel et al., 2006). Prior conclusions on muscle fatigability in children with CP focused on the observed differences in torque decline during a series of maximal contractions (Eken et al., 2013). Consequently, it has been postulated that if coactivation increased during acute exercise, this could add to the loss of the force-generating capacity linked to fatigue in children (Ratel et al., 2006). More recently however, the use of surface electromyography (sEMG) has gained popularity as a non-invasive method to evaluate coactivation and muscle fatigue (Chapter 4.3.4.1). The use of sEMG in conjunction with assessment of muscle strength and fatigue of the major locomotor muscles (i.e., quadriceps) may further elucidate the underlying deficits of strength, power and muscular organisation in individuals with MI (Disselhorst-Klug et al., 2009; Leunkeu et al., 2010). Accordingly, during isometric exercise in healthy participants, muscle fatigue is associated with an increase in the sEMG signal amplitude and with a shift of the EMG activity toward lower frequencies (i.e., 70-125 Hz). Therefore, a decrease in the median frequency (MF) of the power spectral density generated from an EMG signal may serve as an index of fatigue (Knaflitz and De Luca, 1990), in which a spectral shift to the left or towards lower frequencies occurs as fatigue progresses. These trends will be explored in greater depth in Chapter 3.9.3.3 and Chapter 4.

3.9.3 Maximal voluntary isometric contraction (MVIC)

As previously mentioned, isometric strength assessments are a feasible method to perform in both MI and TD youth. Throughout the studies presented in this thesis, participants were asked to perform a 1 repetition max (RM) maximal voluntary isometric contraction (MVIC) (leg extensor strength test) on a specially designed isometric strength-testing chair before and following exercise. Participants were asked to relax for 30 s, perform and hold a maximum knee extension for approximately 3 s followed by relaxing for 30 s repeated three times. Verbal encouragement was provided throughout the test to attain maximum force and visual feedback of the torque output was provided during the tests (O'Leary et al., 2015). The highest torque value was marked on the monitor and set as a target to overcome for the pending MVICs (Morris et al., 2012). This test was performed at each of the three visits and repeated three times within each session. Maximum output was determined as the 1RM at baseline and immediately after (P0) and five min post-exercise cycling bout (P5) for all visits conducted in Chapter 4. Electrical signals from the torque transducer was amplified (Digitimer Neurolog NL107 Recorder Amplifier) and digitised (Cambridge Electronic Design, micro1401) for further analysis later (see Chapter 4.3.4). In Chapter 6, the same MVIC protocol was used during pre-and post-assessments. However, a portable torque transducer was used to ensure ease of administration in non-laboratory settings.

In order to calculate the MVIC force in Newtons (N) and torque in Newton metres (N·m), electrical output from the strain gauge was converted by calibrating the specially designed isometric strength-testing chair with weights of a known mass on a pulley system. With the leg lever placed perpendicular to the floor, mass was applied to a cable that produced force in a direction parallel to the floor. The electrical output in volts (V) was then converted to N by multiplying the known loaded mass in kg by 9.81 and to N·m by multiplying the force in N by the distance in metres from the centre of rotation that the pulley was applied. This relationship was confirmed as linear ($r^2 > 0.99$).

3.9.3.1 Handgrip dynamometer

Reliable muscle strength measurement of different muscle groups may not always be feasible outside laboratory and clinical settings. Alternatively, a simple and quick measurement such as grip strength, may provide a good indication of general muscle strength as commonly associated with arm, back and leg strength in adults (Davies et al., 1988; Fricke & Schoenau, 2005; Wang et al., 2005; Wind et al., 2010). Grip strength is also an important indicator of sarcopenia and loss of muscle strength and function in elderly populations and may be a useful measure to document from childhood onwards and particularly in MI/DCD population groups. In a study by Wind et al. (2010), 384 healthy Dutch children, adolescents and young adults between 8-20 years old performed isometric muscle strength measures of the following four muscle groups using a handheld dynamometer: shoulder abductors, grip strength, hip flexors and ankle dorsiflexors. The authors established that grip strength strongly correlated with total muscle strength and demonstrated correlation coefficients between d=0.736 and d=0.890 ($p <0.01$). Thus, the hand-grip or handheld dynamometer is another suitable technique for strength testing during short assessments in all population groups (Cohen et al., 2010; Kolber & Cleland, 2005). However, it is important to consider that optimal grip strength is influenced by hand size (aka grip span) and should be carefully explained and demonstrated during familiarisation prior to testing in children.

In Chapter 6, an analogue handgrip dynamometer (Takei 5001) was used as a strength measure during the screening sessions. Participants were asked to place their fingers over the handle and thumb supporting the device and trained testers adjusted the dynamometer to fit accordingly. The dynamometer was adjusted to start at 0 kg and the participant was instructed to hold the device with their dominant hand straight up above their head. Then they were asked to squeeze as hard as they could, swinging the dynamometer down to their side. The score was read in (kg) and the best of two attempts was recorded (Chapter 6.4.2.3).

3.9.3.2 Surface electromyography (sEMG) signal processing

As touched upon briefly in Section 3.9.2, the use of sEMG is widely applicable to medical research, rehabilitation, sports science and ergonomics for the assessment of muscle fibre recruitment and muscle activation. Electromyography (EMG) is an experimental technique involving the development, recording and analysis of myoelectric signals, which are formed by physiological variations in the state of muscle fibre membranes (Basmajian & De Luca, 1985). Among studies investigating the muscle characteristics, muscular activation and coordination of children with CP (Patikas et al., 2006), sEMG is gaining popularity as a non-invasive technique for gait analysis (De Stefano et al., 2004) and muscle force/biomechanical characteristics (Disselhorst-Klug et al., 2009; Lam et al., 2005). Thus, incorporating use of sEMG has many benefits including a direct "look" into the muscle and allowing for measurement of muscular performance, which has an important impact on health and quality of life in MI (Konrad, 2005).

Numerous factors (i.e., intrinsic and extrinsic sub-factors) can influence the amplitude and frequency characteristics of the raw electromyogram signal (De Luca, 1997). These factors are summarised and outlined below in Table 3.3 and can vary within and between individuals as well as within and across test days. Therefore, normalisation, or conversion of a raw EMG signal to a scale relative to a known and repeatable value, is often performed when interpreting and making comparisons. However, signals can be affected by electrode placement, subcutaneous fat and muscle properties and even position and length and must be taken into account (see Table 3.3).

Table 3.3 Intrinsic and extrinsic factors that influence the EMG signal adapted from (Halaki & Ginn, 2012).

Intrinsic Factors:	**Extrinsic Factors**:
▪ Physiological ▪ Anatomical ▪ Biochemical characteristics of the muscle ↓ ▪ Number of active motor units ▪ Fibre type composition ▪ Muscle fibre diameter ▪ Blood flow ▪ Tissue (i.e. Lean vs. Fat) between surface of muscle and electrode	▪ Electrode configuration (distance and shape) ▪ Electrode placement ▪ Skin preparation and impedance ▪ Perspiration ▪ Temperature

3.9.3.3 EMG median frequency

By examining the root mean square (RMS) and median frequency (MF) of the spectral parameters from EMG, one may quantitatively evaluate the function of motor units and muscle fatigue (Larsson et al., 1999; Leunkeu et al., 2010). More recently, sEMG has enabled researchers to identify early abnormalities in the quadriceps muscles electrical excitability and activation during voluntary contraction (Policy et al., 2001) and involuntary coactivation (Rose & McGill, 2005) in children with CP (McPherson et al., 2014). A study by Leunkeu et al. (2010) saw a significant difference in RMS values between control and affected legs in children with CP and found that they were unable to recruit higher threshold motor units or drive lower threshold motor units to higher firing rates. This could possibly be explained by examining the activation patterns in the quadriceps agonist muscle with sEMG, providing insight into the pathology of co-contraction, spasticity and weakness within CP and individuals with lower leg strength. Not to mention, the RMS profiles of the vastus lateralis (VL) muscle were significantly higher in control participants compared to CP, possibly indicating the recruitment of type II fibres during isometric contraction (Leunkeu et al., 2010).

It has been well established that long duration (continuous) exercise reduces the maximal voluntary force-generating capacity and moreover, appears to induce greater neuromuscular fatigue following highly variable (intermittent) cycling in healthy adults (Theurel & Lepers, 2008). Similarly, when compared to TD participants, previous studies have reported that children with CP have higher (mean) EMG frequencies (Lauer et al., 2008; Wakeling et al., 2007) and lower amplitudes (Lauer et al., 2008) in the lower limb muscles during walking or cycling (Van Gestel et al., 2012). As a result, for assessing muscle fatigue or "local muscle fatigue" (Chaffin, 1973) and analysing motor unit (MU) recruitment (Oskoei & Hu, 2008), the EMG signal is usually transformed in the time-domain to the frequency-domain or spectral-domain (Phinyomark et al., 2012). Essentially, a Fourier Transform of the autocorrelation function of the EMG signal is employed to produce the power spectrum (PS) or the power spectral density (PSD) by taking the square of the absolute value of the Fourier Transform of the EMG signal divided by the signal length. Both the mean frequency (MNF) and median frequency (MF) or median power frequency (MPF) (Figure 3.5) behave similarly, however, the performance and application of the two can be different (Phinyomark et al., 2012). For example, MNF is always slightly higher than MPF because of the skewed shape of the EMG power spectrum (Knaflitz et al., 1990), whereas the variance of MNF is typically lower than that of MPF. In contrast, the estimation of MPF is less affected by random noise, notably in the case of noise located in the high frequency band of the EMG power spectrum, and is more sensitive to muscle fatigue (Stulen & De Luca, 1981). Furthermore, due to the limited research studies utilising EMG measures in children, MPF will be the method of choice as featured in the electromyographic analysis of quadriceps muscle fatigue in children with CP (Leunkeu et al., 2010) and is described in greater detail in Chapter 4.3.5.

Figure 3.5 A visual diagram depicting the spectral modification, which occurs in the EMG signal during sustained contractions and a muscle fatigue index corresponding to the MPF of the spectrum. [omitted due to failure to obtain the right holders' permission De Luca (1997)].

3.10 Conclusion

This chapter aimed to review and provide an overview of the different methods and techniques used to measure components of fitness in children and adolescents. Throughout this thesis, the term fitness will encompass health-related and skill-related aspects. The different types of physiological measures utilised in this thesis include: categorisation of motor skill level by the BOT-2 SF, maximal and submaximal assessment of aerobic capacity (Chapter 4 and 5), power and agility (Chapter 6) and measures of muscle strength via MVICs, sEMG and handgrip dynamometer (Chapter 4 and 6). With regard to perceptual responses, RPE will be assessed using the CALER scale during and following exercise throughout the studies. Importantly, workload and HR will be used to monitor exercise responses and to quantify exercise intensity in the following chapters. Although many methods and techniques exist in the literature to assess and capture components of fitness in youth, thoughtful consideration was taken to select the specific measures used in the studies comprised in this thesis. Specifically, this chapter sought to provide a rationale for the techniques and methodologies suitable for use in testing a wide range of motor skills/abilities with emphasis for children and adolescents presenting with MI. These factors must be taken into account to ensure fitness assessments are accurately measured and depicted among individuals with MI who represent a heterogeneous group.

4

The physiological and perceptual responses to high and low-intensity exercise in children and adolescents with movement impairment

4.1 Abstract

Introduction: Children and adolescents with movement impairments (MI) exhibit a reduced exercise capacity; failing to exercise hard enough to maximally tax the cardiovascular system. Correspondingly, there is limited knowledge regarding how these youth respond to various exercise intensities in relationship to MI. **Purpose:** To determine the extent of physiological and perceptual responses in adolescents with MI compared with those without (NMI) during and following an acute bout of exercise at different intensities and the relationship of MI to aerobic capacity, muscle strength, fatigue and psychological factors. **Methods:** At baseline, 17 MI (14±2 yrs) and 21 NMI (15±2 yrs) participants were categorised by the Bruininks Oseretsky Test of Motor Proficiency 2 Short Form (BOT-2 SF) for assessment of MI (<17th percentile MI cutoff) and completed an incremental cycle ergometer test to exhaustion for a measure of peak oxygen uptake ($\dot{V}O_{2peak}$) and peak power output (PPO). Participants were assigned to perform both a low-intensity (LI) and high-intensity (HI) cycling protocol at visits 2 and 3 in a randomised order. The LI protocol involved continuous 30 min exercise at 50% peak power

($PP_{50\%}$), with the HI protocol consisting of 30 s cycling at $PP_{100\%}$, interspersed with 30 s rest, for 30 min. Therefore, both sessions were matched for total work. At all visits, heart rate (HR), rating of perceived exertion (RPE) for legs and breathing and maximal voluntary isometric contraction (MVIC) of the legs with surface electromyography (sEMG) was measured before, during and at 1, 3 and 7 min post-exercise (P1, P3, P7). **Results:** There was a significant relationship observed between BOT-2 SF score and $\dot{V}O_{2peak}$ ($r=0.62$, $p<.05$) and a significant difference in $\dot{V}O_{2peak}$ between groups (MI: 31.5±9.2 vs. NMI: 40.0±9.5 ml·kg·min1). PPO was significantly lower in the MI group (MI: 157±61 vs. NMI: 216±57 Watts, $p<0.05$) and for LI workload (MI: 85±38 and NMI: 121±29 watts, $p<0.05$). HR_{max} was similar between groups (MI: 170±25 and NMI: 180±17 bpm, $p>0.05$). HR_{avg} during HI cycling was lower in MI compared to NMI (140±18 and 157±14 bpm, $p<0.05$), but not for LI (133±18 and 143±17 bpm, $p>0.05$). Both groups experienced similar RPE for breathing and overall (MI: 7.0±3.0 vs. NMI: 6.0±2.0, $p>0.05$) at both intensities, but reported higher RPE in the legs towards the end of the 30 min bout (MI: 8.0±2.0; NMI: 7.0±2.0 HI and MI: 7.0±3.0; NMI: 6.0±2.0 LI, $p<0.01$). Additionally, significant differences were found in HR recovery at P1 following HI (MI: 128±25.9 vs. NMI: 154±20.2, $p<0.05$) but not for legs RPE at either intensity (MI: 8±2 vs. NMI: 7±2, $p>0.05$) and overall (MI: 7±3 vs. NMI: 6±2, $p>0.05$). During the HI session, both groups saw a decrease in percentage change (%△) from baseline torque values (MI: -3.8±4.1% P1; -7.5±4.3% P5, $p<0.05$) and (NMI:-11.6±3.2% P1; -8.2±3.9% P5, $p<0.05$). A greater drop was observed in the NMI group with a 12% difference between the LI and HI bout as expressed from 100% baseline for median power frequency (MPF/MF) calculations. However, the MI group did not appear to exhibit muscle fatigue following HI cycling and displayed a similar drop in MF as NMI post-LI. **Conclusion:** Adolescents with MI had reduced exercise capacity observed and considering the lower physiological responses, potentially due to central factors such as motivation and perceived adequacy as suggested by the RPE responses. Results from each acute session and the sEMG data alongside RPE indicate the MI group were less efficient movers and experienced perceived fatigue to be higher at the end of both exercise intensities. These findings contribute to future interventions and exercise prescriptions targeting aerobic and anaerobic fitness and muscle strength and power. Similar to endurance training, the

MI group tolerated the short duration, high-intensity exercise and therefore may be a feasible modality for improving aerobic fitness, however, its implications for improving health and well-being in the long-term still remains to be explored.

4.2 Introduction

Despite the well-established benefits of regular physical activity (PA) on health and well-being, current levels among children and adolescents are widely regarded as insufficient, with less than two-thirds of all young people meeting recommendations (Ekelund et al., 2011; World Health Organization, 2004). According to the World Health Organization (WHO), children and youth aged 5-17 years old should accumulate at least 60 minutes of moderate-to vigorous-intensity physical activity (MVPA) daily and incorporate vigorous-intensity PA three days per week (World Health Organization, 2015). In line with the PA guidelines, global recommendations also suggest that daily PA should be mostly aerobic, but also include exercises that strengthen muscle and bone (Townsend et al., 2015) to reap the health benefits associated with PA and play. Previous reports have concluded that the frequency, intensity and duration of PA contribute to overall health status (Cacola et al., 2016), advocating that a ‘threshold’ must be achieved and maintained in order to produce positive health effects (CDC, 1997, 1999; Dobbins et al., 2009; Tolfrey et al., 2000). However, understanding why youth fail to meet recommended PA levels is a complex phenomenon influenced by numerous factors that can be different for each individual (Buchan et al., 2013) and is even more multifaceted when it comes to children with MI and physical disabilities.

Poor physical fitness and low motor competence, commonly exhibited in individuals with motor impairment (MI) including developmental coordination disorder (DCD) and neurodevelopmental/neurological conditions (i.e., cerebral palsy), has been directly linked to insufficient participation levels and habitual PA (Balemans et al., 2013; Barnett et al., 2009; Cairney et al., 2005; Cantell et al., 2008; Majnemer et al., 2008), which has implications for many aspects of children’s development and health and well-being (Cantell et al., 2008; Haga, 2008). A study by Ullenhag et al.

(2014) further noted that children with disabilities who did participate in leisure activities, often did so at lower intensities, highlighting the need for more research to explore optimal levels of intensity. Major factors associated with lower levels of PA were reported to be linked to exercise-induced symptoms of muscle fatigue, poor physical tolerance and lower energy levels (Barnett et al., 2013). This is further evidenced in the literature indicating that children with motor coordination difficulties and MI commonly exhibit lower fitness (aerobic power, muscle strength, endurance, anaerobic power and PA levels) (Cermak & Larkin, 2002; Hands, 2008; Jane & Staples, 2016; Kolehmainen et al., 2015). One explanation may be that children with MI experience earlier fatigue than well-coordinated individuals due to inefficient and/or wasteful movements (Cantell et al., 2008), which ultimately contribute to a vicious cycle of reduced enjoyment, tolerance and participation compared to their motorically proficient peers (Capio et al., 2015; Morris et al., 2013). In addition, the impact of low-volume high-intensity interval training on fitness and health markers in healthy children and adults are well documented in the literature (Barker et al., 2014; Buchan et al., 2013). However, aspects pertaining to how youth with MI respond and recover to various exercise intensities may better inform exercise prescription and remains to be explored in this population group.

Notably, there is a complete lack of knowledge concerning the level of intensity in PA and leisure activities that are considered optimal for children with movement difficulties (Ullenhag et al., 2014) (Chapter 2). Numerous submaximal and maximal exercise studies have been employed to investigate the physiological limitations to acute bouts of exercise; examining aerobic power and the oxygen cost of children with and without MI (Faught et al., 2013; Morris et al., 2013; O'Beirne et al., 1994). However, these studies have mainly focused on assessing components of aerobic fitness within standardised exercise testing without extending their findings to actual activities that could potentially be implemented within school interventions. In the study by Morris et al. (2013), the level of movement impairment in relationship to fitness was further explored and highlighted the need for exercise interventions to target the development of muscular function. As observed, children with movement difficulties and poor coordination experienced earlier fatigue than well-coordinated individuals when engaging in PA; coinciding with poor muscle strength, low muscle tone, muscle co-contraction and spasticity as commonly presented in individuals with MI (Eken et al., 2013; Leunkeu et al., 2010; Raynor, 2001). Subsequently, the decreased muscular strength and/or the inability to exert maximal force and power (e.g. rate of performing work) often confounded by their limited movement experiences and difficulties (Faught et al., 2013; Missiuna et al., 2003; Morris et al., 2013; Raynor, 1998, 2001), may contribute to the lower fitness performance observed in children with MI (Cermak et al., 2015; Farhat et al., 2014; Knuttgen & Komi, 1992; Raynor, 2001).

The origins of fatigue have not been fully elucidated due to the complexity of investigating fatigue, manifested by the lack of agreement on defining the concept and what it represents, alongside the various measurement protocols to study it (Ratel et al., 2006). As touched upon briefly in Chapter 3.9.2.1, the potential factors involved in fatigue development can be classified into central factors involving the central nervous system (CNS) and peripheral factors occurring within the muscle itself (Fitts, 1994; Ratel et al., 2006; Westerblad et al., 1991). Whether it be physical and/or cognitive in nature, how an individual perceives fatigue is subjective and is often symptom-based (i.e., pain, tiredness and weakness) (Chaudhuri & Behan, 2004). As such, children with MI and their parents, including DCD, have previously reported fatigue as an internal factor impacting their participation in play and PA (Barnett et al., 2013). Children with MI may withdraw from activities that require continued use of muscle groups due to poor endurance and earlier fatigue; ultimately affecting the development of muscle strength and aerobic fitness (Rivilis et al., 2011) . However, the extent to which fatigue reflects the child's perceptions or real physiological mechanisms related to performing exercise and PA remains unclear. The limiting factors surrounding exercise capacity in children with MI have been suggested to be peripherally derived (e.g., local muscle fatigue) (Morris et al., 2013) and/or due to inefficiencies in the oxygen transport system (e.g., inadequate cardiac output). Moreover, centrally driven factors including motivation, perceived adequacy and attention may contribute to the complexity of understanding these limitations.

In adults, pain and discomfort ratings increase disproportionately with ratings of perceived exertion (RPE) during both progressive and interval exercise (Cook et al., 1997) and there have been significant advances in the efficacy of RPE scales to predict $\dot{V}O_{2max}$, time to volitional exhaustion, and maximal strength in adults and children (Eston, 2009). To elaborate on the definition of perceived exertion in Chapter 3.5.6, RPE during exercise represents an integration of information concerning previous experience, whereby the self-reported changes in effort reflect the physiological and psychological processes that under certain conditions induce fatigue (Noble & Robertson, 1996; Ratel et al., 2006). Fatigue could be defined as an acute impairment of exercise performance that includes both an increase in perceived effort required to produce a power output and the eventual inability to maintain power output (Davis & Bailey, 1996). Therefore, for the purposes of this study, muscle fatigue will be defined as 'the failure to maintain a required or expected force," (Edwards, 1983; Raynor, 2001). A better understanding of reported fatigue and perceived exertion during and following exercise of different intensities will contribute to the development of exercise prescription in MI.

Correspondingly, there has been a paucity of research on identifying the underlying deficits of strength, power and muscular organisation in individuals with MI. Previous studies in children with CP (Leunkeu et al., 2010) and DCD (Raynor, 2001) have used surface electromyography (sEMG), a non-invasive way to assess muscle activation and the functioning of neuromuscular systems, alongside assessment of quadriceps muscle fatigue to identify information about muscular activation and coordination (Disselhorst-Klug et al., 2009; Leunkeu et al., 2010). Accordingly, during isometric exercise in healthy participants, muscle fatigue is associated with an increase in the sEMG signal amplitude (RMS) and with a shift of the sEMG spectrum (MF) toward lower frequencies. Furthermore, a decrease in the median power frequency serves as an index of fatigue (Knaflitz et al., 1990) whereby a spectral shift to the left (towards lower frequencies) occurs as fatigue progresses. In comparison to typically developing peers, children and adolescents with MI may exhibit differences in muscle-fibre type distribution (Rose et al., 1994) as suggested by the increased motor times observed in DCD (Raynor, 2001). Provided that torque output at higher velocities are hypothesised to be related to the individual's fibre type (Coyle et al., 1979; Thortensson et al., 1977), there may be a difference in muscle fibre type between MI and TD children, thus influencing the decreased strength and power observed in MI. Although mostly speculative from studies investigating EMG analysis of muscle fatigue in CP and DCD (Eken et al., 2013; Leunkeu et al., 2010; Raynor, 2001), children with MI are likely to have a greater proportion of type II fast-twitch motor units (125-250 Hz), but smaller in fibre size resulting in less force producing elements in the muscle and delayed motor times.

Children with higher levels of MI have previously demonstrated reduced strength of the major locomotor muscle groups and an inability to exercise hard enough to tax the cardiovascular system despite their willingness to push themselves maximally during exercise testing (Morris et al., 2013). In addition to proposing PAs targeting aerobic fitness levels in MI, the findings from Morris et al. (2013) further suggests that utilising short duration, high-intensity exercise focusing on the development of the exercising musculature, may also be a feasible method for improving fitness parameters in this population group. As such, this type of intensity has not been investigated in children with MI yet the premise of including higher-intensity exercise in both healthy and clinical populations relates to the idea that vigorous activity bouts may be an effective strategy to enhance measures of physical fitness within a time-efficient manner (Buchan et al., 2013). In effect, the short time length and ensuing recovery intervals allow even untrained individuals to work harder than would otherwise be possible at a steady-state intensity (Kessler et al., 2012). Additionally, more aerobic, intermittent activity has shown to induce similar or even superior physiological effects on oxidative capacity and endurance performance compared to traditional continuous moderate exercise in both healthy individuals and patients with chronic disease (Kessler et al., 2012; Tschakert et al., 2015). Recent evidence established that high-intensity (HI) exercise was also associated with greater enjoyment compared with a similar duration of continuous exercise, despite higher ratings of perceived exertion in healthy children and adults (Bartlett et al., 2011; Buchan et al., 2013). Furthermore, the sporadic nature and short-bursts of PA and play interspersed with varying levels of intensity observed in youth during free-ranging natural conditions warrant the concept that high-intensity training (HIT) may mimic a more natural pattern of play in children (Buchan et al., 2013). Several studies have demonstrated positive results of HIT in acute (Barker et al., 2014; Crisp et al., 2012) and chronic longer-term (>7 weeks) (Buchan et al., 2013; Corte de Araujo et al., 2012) exercise interventions focused on improving measures of physical fitness (McManus et al., 1997) and cardiometabolic risk factors (Eiholzer et al., 2010; Kessler et al., 2012). Correspondingly, lighter intensity PA (Carson et al., 2013) and moderate-vigorous intensity active play (Baker et al., 2015; Westergren et al., 2016) approaches have equally demonstrated favourable health benefits in children. Provided that, both HI and LI activities have potential applications to inform exercise prescription and improve reduced exercise performance/capacity and PA patterns in children with MI. However, the impact of these different exercise intensities and how children and adolescents with MI tolerate and enjoy them remains unknown.

Aims and objectives

Therefore, the purpose of this study is to describe exercise responses to maximal exercise and then explore the extent of the physiological and perceptual responses to an acute cycling bout of high-intensity (HI) and lower-intensity (LI) exercise in children with movement impairment (MI) compared to no-movement impairment (NMI). We hypothesise that the MI group will respond differently to NMI and to the exercise intensities as a result of decreased strength and power, reduced aerobic capacity and heightened perceived fatigue.

4.3 Methods

This was a randomised crossover cross-sectional design study and was approved by the University Research Ethics Committee (UREC Registration No. 130773). Participants were recruited from local schools in Oxfordshire and the Clinical Exercise and Rehabilitation Unit (CLEAR) at Oxford Brookes University, where they attended gym sessions regularly. Families indicating that they were interested in taking part were sent separate child and parent information sheets and gave their written consent prior to the study. Participants attended the Movement Science Laboratory for testing on three separate occasions, with approximately seven days between each visit. Participants were asked to refrain from eating, performing exercise or drinking caffeine in the 2 h period before attending the sessions. All participants were fully familiarised with the testing protocol prior to data collection.

4.3.1 Participants

Children and adolescents ranging from 11-18 years old were recruited to participate in this study. For the inclusion criteria, participants were required to be able to walk with or without support for at least five metres and be able to safely take part and follow a two-step instruction during testing procedures. Participants with any known contraindications to exercise participation (i.e., muscular degenerative conditions, congenital heart disease, uncontrolled exercise-induced asthma, chronic obstructive pulmonary disorder, uncontrolled epilepsy/on medication for ≤ 12 weeks) were ineligible to take part.

Prior to the start, participants were required to complete a health screen questionnaire (PAR-Q) with their parents or guardians (Appendix D) and to provide written consent to participate (Appendix F). Participants and their parents/guardians were verbally informed and in writing that they were free to withdraw consent and terminate participation in the study at any time without reason.

4.3.1.1 Preliminary exercise measurements and primary outcome measures

During the first visit, preliminary anthropometric measurements and the BOT-2 SF were recorded. Participants were categorised as MI or NMI based on level of motor skill proficiency assessed by the Bruininks-Oseretsky Test of Motor Proficiency Short Form (BOT-2 SF) (Bruininks and Bruininks, 2005) (Chapter 3.4.1.3). This standardised test of motor proficiency was used to categorise level of movement impairment. Four motor area composites are included in the BOT-2 SF encompassing; fine motor control, manual coordination, body coordination and strength and agility. Thirteen items were individually administered as described in the test manual. Raw scores for each task were converted to a point score under each subtest and summed across to obtain a total standard score. The total standard scores were compared to normative scores and age equivalents to determine the individual's percentile rank and to describe overall motor skill proficiency level. Based on the BOT-2 SF manual, individuals scoring below the 17th percentile cut-off were considered to have lower motor skill proficiency (below average) (Bruininks and Bruininks, 2005). Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were recorded prior to the exercise test.

For the purposes of testing a wide range of movement abilities, measurement of $\dot{V}O_{2peak}$ was performed with an incremental step test on a cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) (Chapter 3.5.2.1). The protocol consisted of 1 min stages after an initial 2 min of unloaded cycling. Workload was progressed by 15-20 Watt (W) from unloaded cycling each minute based on the height of the participant (Godfrey et al., 1971). The test was terminated when the participant reached volitional exhaustion or was unable to maintain a cadence of 60 revolutions per minute (rpm) despite verbal encouragement. Oxygen uptake ($\dot{V}O_2$), carbon dioxide produced ($\dot{V}CO_2$) and volume of expired air per minute ($\dot{V}_E$) were measured breath-by-breath using an online gas analyser (Cortex Metalyser 3B, Cortex, Leipzig, Germany). Before each testing session, the gas analysers were calibrated according to manufacturer guidelines. The gas sample line was calibrated using gases of a known concentration and flow volume was calibrated using a 3 L syringe (Hans Rudolph). All participants wore a fitted face-mask covering the nose and mouth connected to a low resistance volume transducer (Triple V, Hoechberg, Germany). Additionally, heart rate (HR) was recorded continuously throughout the testing using short-range telemetry (Polar S810, Finland). Oxygen uptake was recorded as the highest 30 s average before the termination of the test. As outlined in Chapter 3.5.2.1, the criteria for obtaining a $\dot{V}O_{2peak}$was considered when two of the three following criteria was achieved: 1) HR >180 beats/min (Schulze-Neick et al., 1992), 2) RER > 1.06 (Armstrong et al., 2008; Winter et al., 2007), and/or 3) subjective signs of exhaustion (Verschuren et al., 2006). The PPO was determined as the highest workload in watts (W) attained at $\dot{V}O_{2peak.}$

The respiratory exchange ratio (RER) was calculated from the ratio of $\dot{V}O_2$ to $\dot{V}CO_2$ at each workload level throughout the exercise test as described in Chapter 3.5.2.2. For the measurement of muscular efficiency or the relationship between the amount of oxygen utilised for a given work rate, the linear slope of the relationship between $\dot{V}O_2$ and Watts ($\dot{V}O_2$/W) was derived. Oxygen pulse (O_2), a non-invasive indicator of cardiac function, was also calculated by dividing $\dot{V}O_{2peak}$ by HR_{peak} ($\dot{V}O_{2peak}/HR_{peak}$) and expressed as mL/beat (Chapter 3.5.4.1). Rating of perceived exertion (RPE) was measured at the end of each stage using the Cart and Load Scale (CALER), which has previously been used to assess children's perception of effort during exercise (Eston et al., 2000) (Chapter 3.5.6).

4.3.1.2 Secondary outcome measures

Maximal voluntary isometric contraction and muscle torque protocol

Prior to each exercise bout, participants performed a one-repetition max (1RM) leg extensor strength test on a specially designed isometric strength-testing chair (Chapter 3.9.3). The maximal isometric voluntary contraction (MVIC) was measured at 90˚of knee flexion and the rotation of axis of the strength chair was aligned with the knee axis. The upper body was secured using straps across both shoulders and waist to prevent any upper body movement to isolate the knee extensors. Participants were instructed to push their right leg as hard as possible and hold for three seconds, followed by a 30 s rest between each repetition. Each participant performed two submaximal familiarisation contractions before performing three individual repetitions (Theurel & Lepers, 2008) whereby 1RM was the maximum output reached. Real-time visual feedback of the torque trace was provided to the child via a computer display and verbal motivation was provided during all repetitions (Raynor, 2001). The repeatability of this apparatus for measurement of knee extensor contractile function in response to exercise of different intensities has been previously demonstrated in healthy adults (Morris et al., 2012; O'Leary et al., 2015). The electrical signals from the torque transducer were amplified (Digitimer Neurolog NL107 Recorder Amplifier) and digitised using an A/D converter at a sampling rate of 100 Hz (Micro 1401 mk-II, CED, UK) and saved for subsequent offline analysis.

Surface electromyography for measurement of median power frequency and cocontraction

Surface electromyography (sEMG) was measured using self-adhesive bipolar Ag-AgCl electrodes (10 mm diameter, 2 cm inter-electrode distance). According to sEMG for non-invasive assessment of muscle recommendations (SENIAM) (Hermens et al., 2000), the electrodes were placed on the belly of the right vastus lateralis (VL) muscle at approximately two-thirds of the line between the anterior superior iliac spine and the lateral border of the patella. For the biceps femoris (BF), the electrodes were placed at midpoint along the line connecting the anterior superior iliac to the superior aspect of the patella (Leunkeu et al., 2010). A reference electrode was also placed on the patella. Prior to placing the electrodes the area was shaved and cleaned using alcohol wipes. Then conducting gel was put on the electrodes and and placed on the marked sites while the participant was sitting in the position of performing a MVIC in the strength chair with the right knee at 90̊. During the within-day trial, the electrodes remained in place throughout the session, and during the between-day trial, the electrode position was photographed to allow for accurate placement in the following visits. The EMG recording of the VL and BF were amplified (x1000) (NL844, Neurolog Systems, Digitimer, UK), band-pass filtered with a 50 Hz notch (10-2000 Hz) (NL135, Neurolog, Digitimer, UK), and A/D converted at a sampling rate of 2000 Hz (Micro 1401 mk-II, CED, UK). Torque and EMG data were recorded on a PC for subsequent analysis (Spike 2 V5.2, CED, UK).

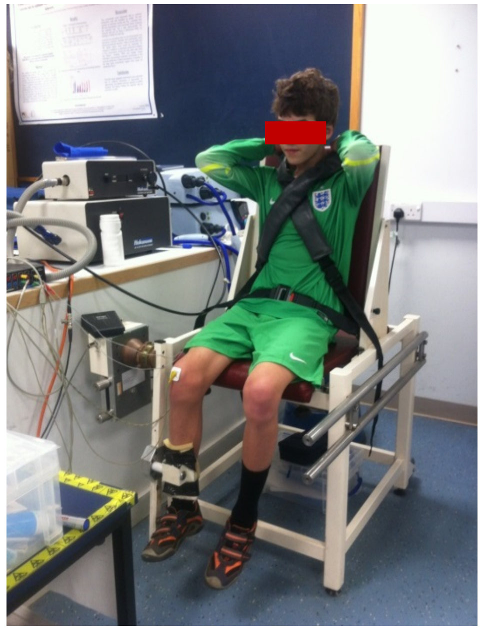


Figure 4.1 A typical set-up of the MVIC measurements performed on a specialised isometric strength testing chair described above in section 4.3.1.2.

4.3.2 Exercise interventions

Participants were asked to complete two experimental conditions in a randomised crossover design for the exercise intervention including: a high-intensity (HI) cycling bout and a lower-moderate intensity (LI) bout of cycling. The study design is presented schematically in Figure 4.2.

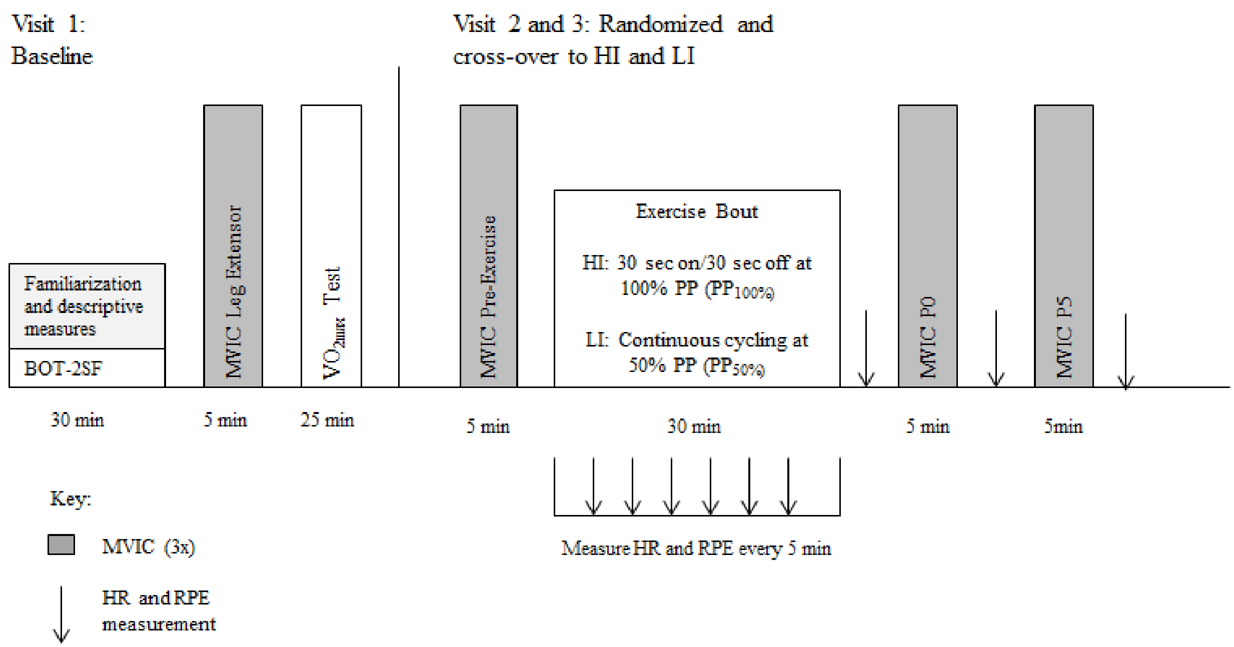


Figure 4.2 Diagram of the three-visit study protocol. BOT-2SF, Bruininks-Oseretsky Test of Motor Proficiency Short Form 2; HI, High-intensity; LI, Low-intensity; MVIC, maximal voluntary isometric contraction; PP, peak power; P0, immediately post-exercise; P5, post-5 min

The exercise was performed on a cycle ergometer (Lode Excalibur Sport, Groningen, The Netherlands) with the bike seat height adjusted to the participants' comfort and recorded for subsequent sessions. Participants performed the exercise at the same time of day for each session under standard temperature conditions in the laboratory (~20-22° C). For the HI session, participants were asked to perform a 30 min bout of cycling consisting of pedaling for 30 s-on, then no pedaling for 30 s-off at 100% PP ($PP_{100\%}$) as determined from PPO during the maximal incremental bike test. In contrast, for the LI session participants were asked to cycle continuously for 30 min at $PP_{50\%}$. Throughout the session, both HR (Polar S810, Finland) and RPE (CALER scale) was monitored and recorded at 5 min intervals. Participants was asked to rate their RPE for legs, breathing and overall using the CALER scale every 5 min. Additionally, all participants were asked to perform three MVICs prior to the exercise and immediately post-cycling (P0) and post-5 min (P5).

4.3.3 Outcomes

The primary outcome measures of the study were the physiological and perceptual responses during and following each exercise session. Preliminary exercise measurements at baseline provide information on anthropometric characteristics including height (m), weight (kg), BMI (kg/m^2) and level of sexual maturation (Tanner, 1962). Furthermore, the participants were categorised as MI or NMI group based on the BOT-2 SF assessment described earlier (Chapter 4.3.3.1). Level of aerobic fitness ($\dot{V}O_{2peak}$) was determined at baseline and the physiological measures (i.e., HR) and perceptual responses (i.e., RPE) were recorded before, during and after exercise (P1, P3, P7). The secondary outcomes of interest were leg muscle strength (torque) and surface electromyography (EMG) measures for the evaluation of median power frequency and cocontraction immediately (P0) and post-5 min (P5) (Chapter 4.3.1.2).

4.3.4 Sample size

Based on statistical power calculations using G*Power 3.1.9.2 (Heinrich-Heine-Universität, Düsseldorf, Germany), a sample size of 70-80 participants total (~35-40 in both MI and NMI) is required for a power of 0.95, an alpha (α) of 0.05 and an effect size (Cohen's d) of 0.80 to detect differences between the group means for HR based on previous HR change data.

4.3.5 Randomisation

Participants were randomised using an excel program which generated a random allocation to either the HI or LI-bout first. The researchers informed the participant which exercise intensity they would perform for the second session and then cross-over to the other intensity bout for the third and final session.

4.3.6 Data analysis

The strength variable that was analysed for the isometric action was the peak MVIC torque (Nm), which was represented as the highest instantaneous torque achieved during the three MVICs at each time point. EMG activity during each MVIC was quantified with the root mean square (RMS) value recorded over a 300 ms analysing window and determined over 1 s at peak torque. RMS values were expressed relative to the RMS of the maximum (peak) MVIC (RMS_M) established during the pre-exercise contractions within the session (RMS/RMS_M) (Gamet et al., 1996; Lepers et al., 2002; O'Leary et al., 2015). Power spectrum analysis, and more specifically median power frequency, was used to examine the indices of frequency shift (Soderberg & Knutson, 2000). The median frequency (MF) was defined as the frequency that divided the power spectrum density into two regions containing equal power and can be expressed as (1):

$$\sum_{j=1}^{\mathrm{MDF}} P_j = \sum_{j=\mathrm{MDF}}^{M} P_j = \frac{1}{2}\sum_{j=1}^{M} P_j \,, \qquad \text{(1) (Thongpanja et al., 2013)}$$

Digital filtering of the signal for each individual muscle channel was conducted using a high pass filter of 250 Hz with a transition gap of 8.5 Hz. Transformation from the time domain to the frequency domain for spectral analysis was performed using a Fast Fourier Transformation (FFT) size 512 and Hanning Window for a 1 s epoch of time in which peak torque ($MVIC_M$) occurred. For both groups, the RMS and MF values were averaged for each muscle and normalised as a percentage of initial values within that particular session.

The ability to effectively activate the agonist and antagonist muscle groups was analysed by measuring the level of coactivation between the VL and BF muscles, with the individual level of muscle activity quantified using the RMS value (Basmajian & De Luca, 1985). The coactivation ratio was calculated by dividing the RMS of the agonist muscle by the RMS of the antagonist muscle for a common 1 s period of time, with a lower ratio indicative of a greater level of coactivation (Raynor, 2001).

4.3.7 Statistical analysis for exercise parameters and muscle strength

All data are presented as mean ± SD. Statistical analyses were performed in SPSS for Windows v21 (SPSS Inc., Chicago, IL, USA). Normality of the data was checked by Shapiro Wilk tests. Homogeneity of variances was confirmed by Mauchley's test of sphericity and a Greenhouse-Geisser correction was applied to the degrees of freedom if the sphericity assumption was violated. Baseline exercise measurements ($\dot{V}O_{2peak}$, HR_{max}, RER, RPE, PPO) were analysed using student's t-test. A Pearson correlation coefficient (r) was used to examine the linear relationship between BOT-2 SF scores and baseline $\dot{V}O_{2peak}$. Within-session exercise measurements (HR, RPE, MVIC torque) were analysed using a linear mixed model (LMM) (Cnaan et al., 1997; Fisher, 1925; Jensen, 2006) for repeated measures over time by group to analyse the impact of the different exercise intensities (HI vs. LI) on outcome measures at baseline, during and post-exercise with fixed effects of group (MI vs. NMI), time (HI and LI session) and the interactions between group and time. This method prevented listwise deletion due to missing data (Weinger et al., 2011).

The LMM was represented in the following form with p fixed variables and q random variables: $Y_i = X_iB + Z_ib_i + e_i$, where Y_i represents a vector of values of the dependent measure of interest (i.e., HR and RPE) for the i^{th} participant, X_i represents a matrix of p predictors (independent variables including group and intensity) for the i^{th} participant, B represents a vector of p fixed effect beta weight estimates for each predictor in X_i, Z_i represents a matrix of q random effect predictors, b_i represents a vector of q random effect estimates, and e_i represents a vector of the model fit error, representing the discrepancy between the model prediction for each observation from the i^{th} participant and the actual value of that observation (Denny & Ochsner, 2014). The mixture of fixed and random effects is what makes the mixed model a mixed model. Furthermore, the assumptions of a LMM include linearity, multicollinearity and homoscedasticity of the data. Therefore, a scatter plot of the predicted values on the x-axis and the residuals on the y-axis were plotted to visually check for linearity whereby no obvious pattern should be displayed and outliers were identified. Thereafter, a Shapiro-Wilk test was performed to determine normality of residuals. Since only two repeats were assessed, an unstructured covariance structure was utilised.

4.4 Results

A total of 43 children and adolescents volunteered to participate in this study (Figure 4.3), out of the 52 originally recruited with results presented for 38 (11-18 years) as five of the participants were drop-outs or unable to complete all visits required for the study.

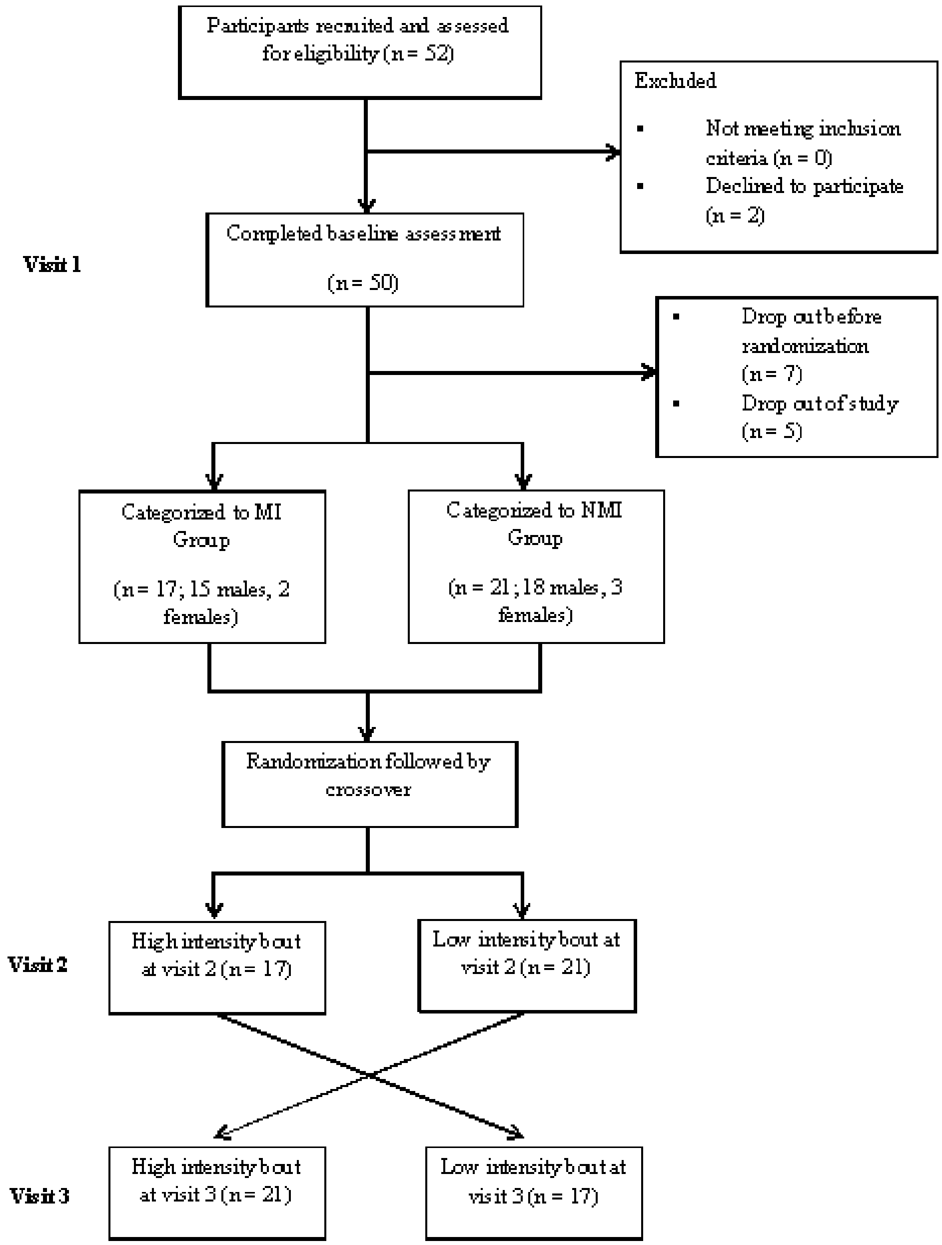


Figure 4.3 Flow diagram of participant recruitment and adherence throughout study. MI, movement impairment; NMI, no-movement impairment.

The participants were classified into two levels of motor impairment according to the BOT-2 SF: those with movement impairment (MI) (n = 17; 15 males, 2 females) and those who were normally coordinated, with no movement impairment (NMI) (n = 21; 18 males, 3 females). Baseline characteristics of participants are presented in Table 4.1.

Table 4.1 Baseline characteristics and outcome measures (mean ± SD)

N = 38	MI (n=17)	NMI (n=21)
Age (years)	14.5 ± 2.0	15.5 ± 2.0
Height (m)	1.70 ± 8.6	1.74 ± 10.6
Weight (kg)	63.3 ± 15.6	66.4 ± 16.3
BMI (kg/m^2)	22.0 ± 0.0	22.0 ± 0.0
Tanner	5.0 ± 0.0	5.0 ± 0.0
BOT-2SF Raw Score	61.0 ± 6.0*	71.0 ± 18.0
BOT-2SF Standard Score	36.0 ± 2.0*	44.0 ± 12.0

All data mean ± SD
*p ≤ 0.05 vs. NMI at baseline
BMI, body mass index; BOT-2 SF, Bruininks-Oseretsky Test of Motor Proficiency Short-Form 2; kg, kilogram; m, metre; Tanner, Tanner scale of sexual maturity.

4.4.1 Baseline measures

Seventeen of the participants considered to be MI scored below the BOT-2 SF 17th percentile (below average) and 21 were classified as having NMI (BOT-2 SF >17th percentile). Table 4.1 illustrates the participant characteristics from the motor proficiency assessment. There was a significant difference in the BOT-2 SF standard score between MI (36.0±2.0) and NMI (44.0±12.0) [95% CI: -14.18, -1.61; p<0.001] (Shvartz & Reibold, 1990).

Moreover, there was a significant relationship between BOT-2 SF score and $\dot{V}O_{2peak}$ (r=0.62, p<0.05) in both groups and a significant difference in $\dot{V}O_{2peak}$ between groups (MI: 31.5±9.2 vs. NMI: 40.0±9.5 ml·kg·min-^{1}) [t(36)=-2.28, p<0.01, 95% CI: -1.08, -0.29]. The PPO was significantly lower in the MI group (MI: 157.0±61.0 vs. NMI: 216.0±57.0 Watts) [t(33)=-3.05, p<0.01, 95% CI: -101.1, -20.12] and for the LI workload (MI: 85.0±38.0 and NMI: 121.0±29.0 Watts) [t(31)=-2.38, p<0.05, 95% CI: -51.4, -3.99]. With regard to assessment of movement economy, the MI group experienced greater inefficiencies during the maximal exercise test ($\dot{V}O_2$/workload) (MI: 13.0±3.0; NMI: 11.2±2.0 mL/Watts) [t(21)=2.12,

$p<0.05$, 95% CI: -2.85, 2.18]. However, HR_{max} was similar between groups (MI: 170.0±25.0 and NMI: 180.0±17.0 bpm) [$t(35)=-1.31$, $p>0.05$, 95% CI: -24.7, 5.48] and there were no significant differences in O_2 pulse (MI: 19.0±0.03; NMI: 20.0±0.05 mL/beat) [$t(36)=-0.34$, $p>0.05$, 95% CI: -1.79, 1.30]. Correspondingly, there was no difference in the perception of effort throughout the exercise test and at exercise termination, with all participants reporting an RPE rating of 9 or 10 at the end of the test despite the MI group demonstrating significantly lower PPO at the end of the incremental bike test as displayed in Table 4.2. Furthermore, all participants demonstrated a RER_{max} greater than 1.06 at the end of the test, however, there was a significant difference between the groups for the RER_{max} value (MI: 1.20±0.20 and NMI: 1.34±0.10) [$t(21)=-2.61$, $p=0.008$, 95% CI: -2.06, 0.88].

Table 4.2

Baseline characteristics and exercise intensity descriptors (mean ± SD)

N = 38	MI (n=17)	NMI (n=21)
$\dot{V}O_{2peak}$ (L/min)	1.90 ± 0.49*	2.39 ± 0.78
$\dot{V}O_{2peak}$ (mL/kg·min)	31.54 ± 9.2*	36.0 ± 11.0
HR_{max} (bpm)	170.0 ± 25.0	180.0 ± 17.0
PPO (Watts)	157.0 ± 60.5*	216.0 ± 57.0
$\dot{V}O_2$/workload (mL/Watts)	13.3 ± 4.0*	11.2 ± 2.0
O_2 pulse (mL/beat)	19.0 ± 0.03	20.0 ± 0.05
RPE	9.00 ± 1.0	8.00 ± 1.00
RER	1.20 ± 0.20*	1.34 ± 0.10
HI workload/PO (Watts)	145.0 ± 65.0*	216.0 ± 69.0
HI HR_{avg} (bpm)	139.0 ± 18.0*	156.0 ± 13.0
%△ $HI_{baseline}$	82.0 ± 18.0	87.0 ± 14.0
LI workload/PO (Watts)	80.0 ± 30.0*	108.0 ± 36.0
LI HR_{avg} (bpm)	134.0 ± 18.0	143.0 ± 16.0
%△ $LI_{baseline}$	78.0 ± 18.0	79.0± 16.0

Data are mean ± SD
*p≤0.05 vs. NMI at same time point
Avg, average; bpm, beats per minute; HR_{max}, heart rate maximum; HI, high intensity; LI, low intensity; L, Litre; mL, milliltre; movement impairment; NMI, no-movement impairment; O_2 pulse, Oxygen pulse; PPO, peak power output; RER, respiratory exchange ration; RPE, rating of perceived exertion; VO_{2peak}, peak oxygen uptake; $\dot{V}O_2$/workload, muscular efficiency; W, Watts; W_{peak} watt max; %△ $HI_{baseline}$, percentage change from baseline at HI (100%); %△ $LI_{baseline}$, percentage change from baseline LI (100%).

4.4.2 Cardiorespiratory and perceptual responses (LMM)

Mean workload during the LI cycling bout was 85.0±38.0 Watts in the MI group and 121.0±29.0 Watts in the NMI group ($p<0.05$). There was a significant difference between groups [$F(1,36.1)=7.1$, $p=0.012$] and an effect of intensity for HR_{avg} as demonstrated by the LMM [$F(1,33.3)=37.0$, $p<0.001$]. Overall, HR_{avg} during HI cycling, which took into account an average of each cycle (i.e., 30 s-on and 30 s-off) throughout the 30 min duration, was lower in MI compared to NMI (140.0±18.0 and 157.0±14.0 bpm, $p<0.05$) [$t(34)=-3.28$, $p=0.002$], but not during LI cycling (133.0±18.0 and 143.0±17.0 bpm, $p>0.05$) [$t(33)=-1.64$, $p>0.05$]. This denotes that there is a significant difference with regard to how the level of intensity affects the two groups with the MI group experiencing less HR_{avg} variability irrespective of intensity. When considering relative HR represented as percentage change (%△) from HR_{max} (i.e. %Pre HR_{max}), significant differences were only demonstrated during an average of the 30 min cycling bout for HI (MI: 82.0±9.5 vs. NMI: 87.0±7.1%) [$t(36)=-3.21$, $p=0.003$] (Figure 4.4 (a) and (b)). In contrast, the MI group did not demonstrate a great deal of change from HI during the LI bout (MI: 78.0±19.3 vs. NMI: 79.0±23.4%) [$t(36)=-0.27$, $p>0.05$]. To further validate the findings, a paired samples t-test showed no significant difference in HR_{avg}, however, relative change was significantly different in NMI [$t(20)=2.73$, $p=0.013$].

In the recovery phase, HR at post-1 min (P1) was significantly different for group following HI (MI: 128.0±24.2 vs. NMI: 145.0±22.3 bpm) and LI (MI: 121.0±23.0 vs. NMI: 131.0±23.4 bpm) [$F(1,35.2)=4.91$, $p<0.05$]. Significant differences for intensity were exhibited at P7 following HI (MI: 102.0±17.2 vs. NMI: 106.0±15.4 bpm) and LI (MI: 96.0±15.2 vs. 97.0±16.2 bpm) [$F(1,26.4)=9.80$, $p=0.004$] were also observed as illustrated in Figure 4.4 (c) (HI bout) and (d) (LI bout).

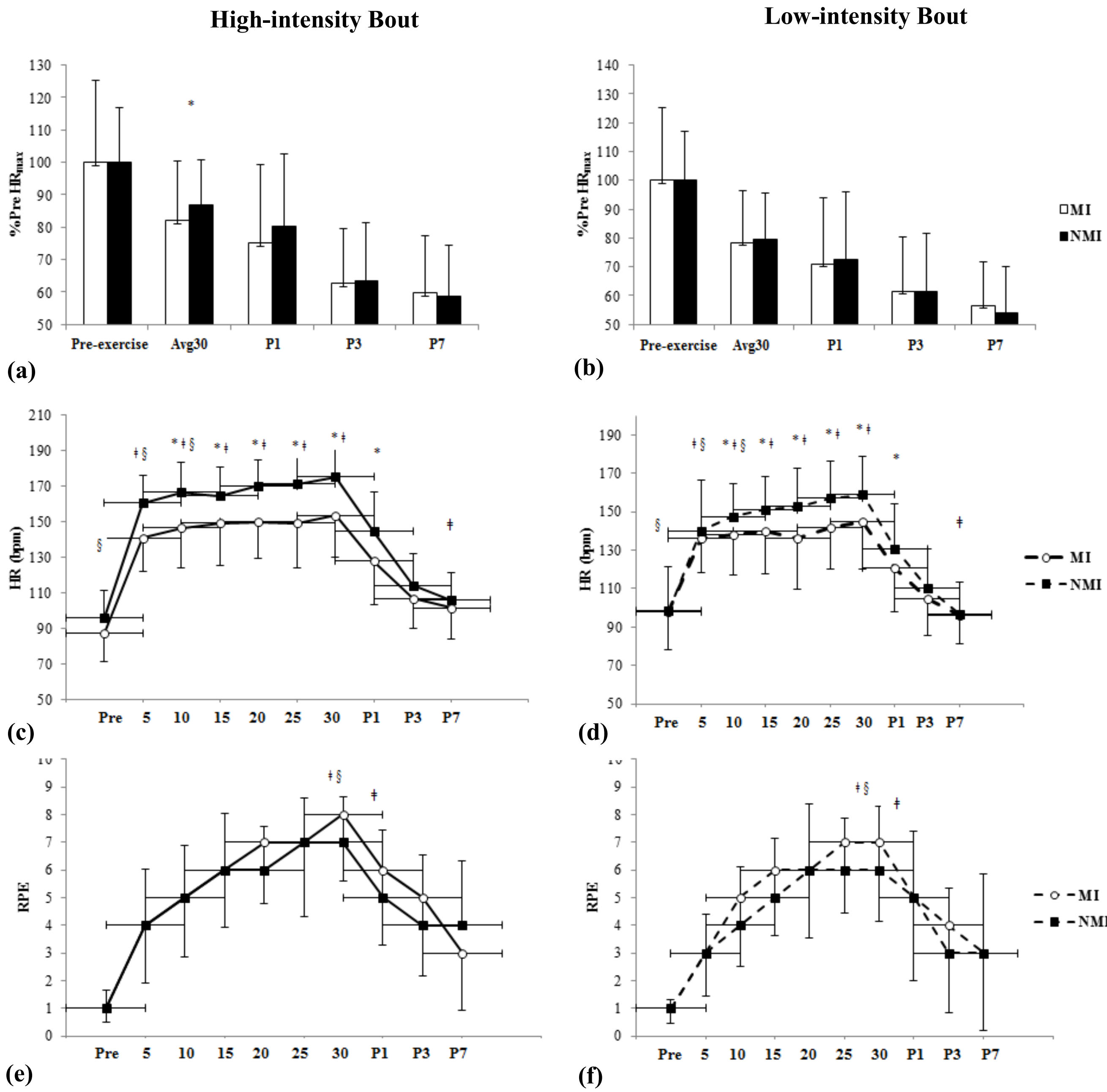


Figure 4.4 Percent change from baseline heart rate maximum (HR_{max}) during cycling bout and post-1, 3 and 7 min (P1, P3, P7) presented for high-intensity visit (HI) (a) and low-intensity visit (LI) (b). MI group (Hollow bars) and NMI group (filled bars). Figures (c) and (e) illustrate the change in HR and ratings of perceived exertion (RPE) pre, during and post-HI-cycling (solid line). Measures were recorded every 5 min throughout the cycling and following in recovery at P1, P3and P7. Figures (d) and (f) represent HR and RPE during the LI-cycling bout (dotted line). *p≤0.05 vs. NMI (group); ǂp≤0.05 for Intensity; §p ≤0.05 vs. NMI at same time point (Group x Intensity)

Both groups experienced similar RPE for breathing and overall (MI: 7.0±3.0 vs. NMI: 6.0±2.0, $p>0.05$) throughout the exercise at both intensities (Figure 4.4 (e) and (f)). However, significant differences were observed in RPE for legs during cycling at both intensities towards the end of the 30 min bout (MI: 8.0±2.0; NMI: 7.0±2.0 HI and MI: 7.0±3.0; NMI: 6.0±2.0 LI) [$F(1,33.0)=9.2$, $p<0.01$] and for group x intensity [$F(1,33.0)=4.8$, $p<0.05$]. Moreover, there was a notable difference for RPE in the legs [$F(1,28.5)=7.6$, $p=0.01$], breathing [$F(1,28.9)=9.2$, $p<0.01$] and overall [$F(1,28.7)=11.8$, $p<0.01$] at P1 HI (MI: 6.0±3.0 legs, 5.0±3.0 breathing, 6.0±3.0 overall vs. NMI: 5.0±2.0 legs, 5.0±2.0 breathing, 5.0±2.0 overall) and demonstrated at P1 for LI (MI: 5.0±3.0 legs, 4.0±3.0 breathing, 4.0±3.0 overall vs. NMI: 4.0±2.0 legs, 5.0±2.0 breathing, 4.0±3.0 overall) (see Figure 4.4 (e) and (d)). Interestingly, the MI group appeared to experience a similar level of RPE for both intensities despite achieving lower workloads (W) to complete the exercise in comparison to the NMI group.

4.4.3 MVIC and surface electromyographic data

The normalised torque frequencies demonstrated good reliability between tests (across sessions) as demonstrated with an ICC of 0.93 [95% CI: 0.946, 0.986]. Electromyographical and strength measures during the MVICs are presented in Table 4.3. For the MVIC strength measures, peak torque was significantly different for group (MI: 159±85.1 vs. NMI: 225.0±84.4 N·m), [$F(1,37.98)=4.65$, $p=0.038$] and peak torque post-5 min after the HI (MI: 156±63.0 vs. NMI: 207.0±104.3 N·m) and LI cycling bout (MI:152.0±84.0 vs. NMI:218.0±92.1) [$F(1,37.23)=4.23$, $p<0.05$]. As illustrated in Table 4.3 the MI group demonstrated a -5.6±2.3% drop from baseline post-LI and an increase +3.3±6.2% P5 following LI. Alternatively, the NMI group experienced a smaller decrease in peak torque -1.5±2.1% post-LI. However, a similar improvement of +3.9±2.2% to MI at P5 following LI cycling was also shown (Figure 4.5). During the HI session, both groups saw a decrease in %△ from baseline torque values (MI: -3.8±4.1% P1; -7.5±4.3% P5) and (NMI:-11.6±3.2% P1; -8.2±3.9% P5).

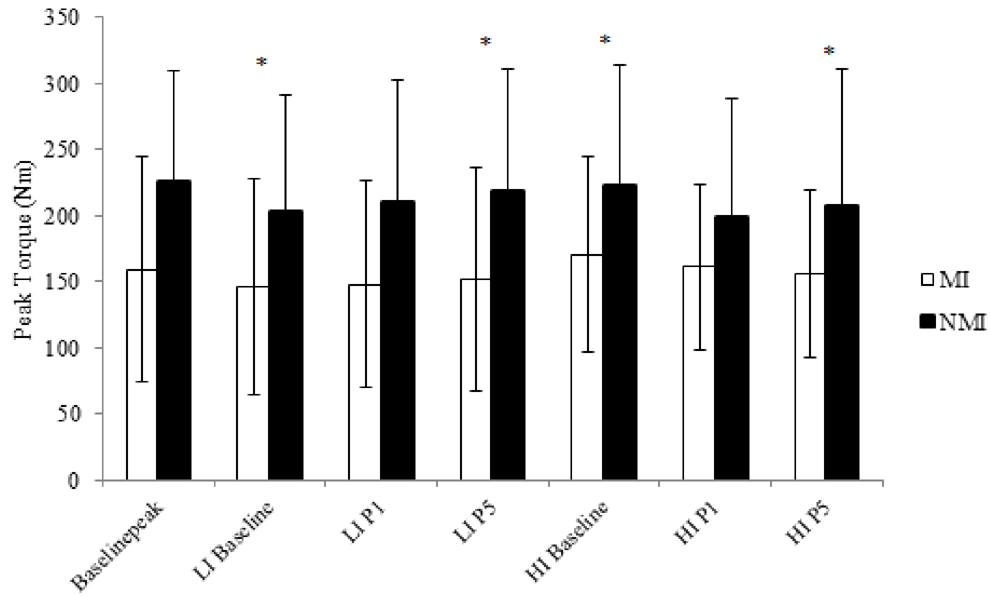


Figure 4.5 Peak torque (N·m) measured at each time point from the baseline session to the low-intensity (LI) and high intensity (HI) visit. Recovery period is represented as post-1 min (P1) and post-5 min (P5). Data represented as mean ± SE. *p≤0.05 vs. NMI

Significant differences were also observed for group when peak torque was normalised to body weight (kg) at baseline (MI: 1.30±0.35 vs. NMI: 2.54±0.35 N·m/kg), [$F(1,38.00)=7.23$, $p<0.01$] and at P5 [$F(1,37.25)=5.03$, $p<0.05$] but not for intensity (Table 4.3).

Table 4.3

Electromyographical and muscle strength characteristics during HI and LI (mean ±SD)

MVIC		Baseline	High-Intensity			Low-Intensity		
			Pre	P0	P5	Pre	P0	P5
N·m	(MI)	159.0 ± 85.1	171.0 ± 73.0*	162.0 ± 63.0	156.0± 63.0*	140.0 ± 64.1*	132.0 ± 62.8	152.0 ± 84.0*
	(NMI)	225.0 ± 84.4	223.0 ± 90.5	198.0 ± 90.0	207.0 ± 104.3	211.0 ± 88.5	209.0 ± 92.7	218.0 ± 92.1
N·m/kg	(MI)	1.30 ± 0.35*	2.55 ± 1.17	2.43 ± 1.12	2.19 ± 1.20*	2.37 ± 1.03	2.08± 1.14	2.32 ± 1.21*
	(NMI)	2.54 ± 0.35	3.13 ± 54	2.75 ± 1.36	3.00 ± 1.46	3.21 ± 1.10	3.16 ± 1.16	3.32 ± 1.12
RMS_{MVL}: RMS_{MBF}	(MI)	1.93 ± 0.57*ǂ	1.83 ± 0.52	2.99 ± 1.28*ǂ §	2.93 ± 1.43§	1.93 ± 0.57	0.87 ± 0.62*ǂ §	1.93 ± 0.57§
	(NMI)	3.48 ± 0.59	4.47 ± 1.20	10.5 ± 2.25	1.32 ± 0.30	3.48 ± 0.59	0.97 ± 0.13	0.29 ± 0.04
MF (Hz)	(MI)	70.8 ± 18.2	72.0 ± 13.8	68.0 ± 13.2§	--	71.7 ± 13.4	67.0 ± 14.1§	--
	(NMI)	71.0 ± 15.7	70.4 ± 11.8	69.5 ± 9.1	--	70.3 ± 10.9	64.0 ± 11.7	--

Data mean ± SD
*p≤0.05 vs. NMI (Group effect)
ǂp≤0.05 vs. NMI (Intensity effect)§ p≤0.05 vs. NMI (Group x Intensity effect)
Hz, hertz; HI, high-Intensity; LI, low-Intensity; MF, median frequency; MI, movement-impairment; MVIC, maximal voluntary isometric contraction; NMI, no-movement impairment; N·m, newton-metre; P0, immediately post-exercise; P5, 5 min post-exercise; RMS_{MBF}, max square for biceps femoris; RMS_{MVL}, max root mean square for vastus lateralis

A significant effect was demonstrated for intensity [$F(1,42.00)=12.81$, $p<0.001$] on level of co-contraction for the normalised RMS EMG_{VL} to RMS EMG_{BF} ratio (RMS_{MVL} agonist: RMS_{MBF} antagonist) at HI baseline (MI: 1.83±0.52; NMI: 4.47±1.20) compared to LI baseline (MI: 1.93±0.57; NMI: 3.48±1.59). Immediately post-exercise (P0) there was a significant difference between groups [$F(1,32.00)=5.34$, $p=0.027$], intensity [$F(1,32.4)=14.60$, $p<0.001$] and group x intensity [$F(1,32.43)=5.15$, $p<0.05$], notably indicating a substantial difference between MI and NMI and their interaction with the different intensity levels (see Table 4.3). A significant group x intensity effect was also discerned at P5 [$F(1,36.5)=4.49$, $p<0.05$] illustrating a steeper decrease in co-contraction ratios for MI and NMI post-5 (P5) min into recovery (Figure 4.6).

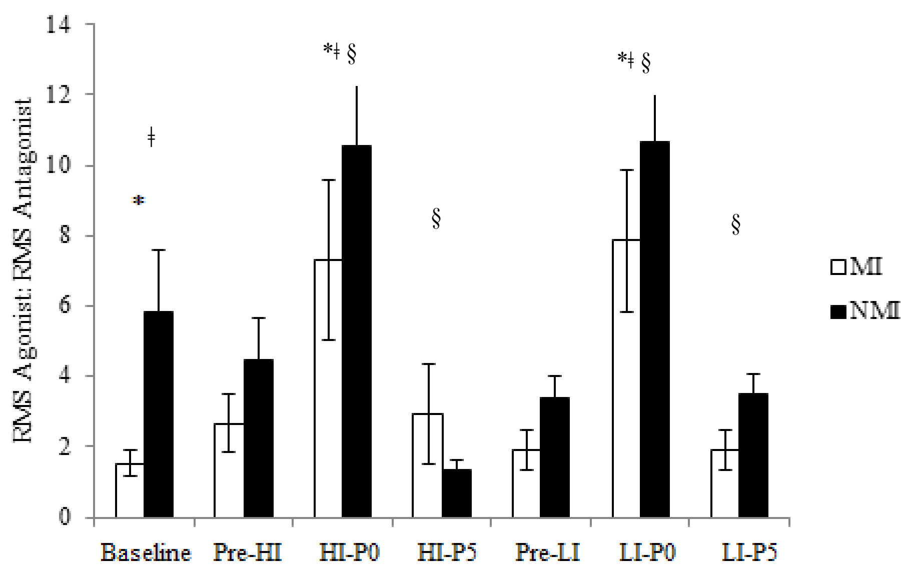


Figure 4.6 Cocontraction or coactivation ratio (RMS agonist: RMS antagonist) between MI and NMI during the isometric contractions at each visit (P0, immediately post-exercise; P5, 5 min post-exercise). Data represented as mean ± SE. *$p\leq0.05$ vs. NMI; ǂ$p\leq0.05$ for Intensity; §$p\leq0.05$ vs. NMI at same time point (Group x Intensity)

The median frequency (MF) or median power frequency (MPF) of the EMG_{VL} signals calculated from the power spectral density analysis was significantly different for group x intensity post-cycling exercise with a greater reduction %△ from pre-MF (represented as 100%) observed in NMI compared to MI following

LI (MI:89.9±40.8 vs. NMI:90.5±47.5%) and HI (MI:97.6±32.5 vs. NMI: 72.0±53.1%) [F(1, 30.7)=10.3, p=0.003]. Notably, a greater decrease was observed in the NMI group with a 12% difference between the LI and HI bout as expressed from 100% baseline. Interestingly, the MI group did not appear to exhibit muscle fatigue following HI cycling and displayed a similar drop in MF as NMI post-LI (Figure 4.7).

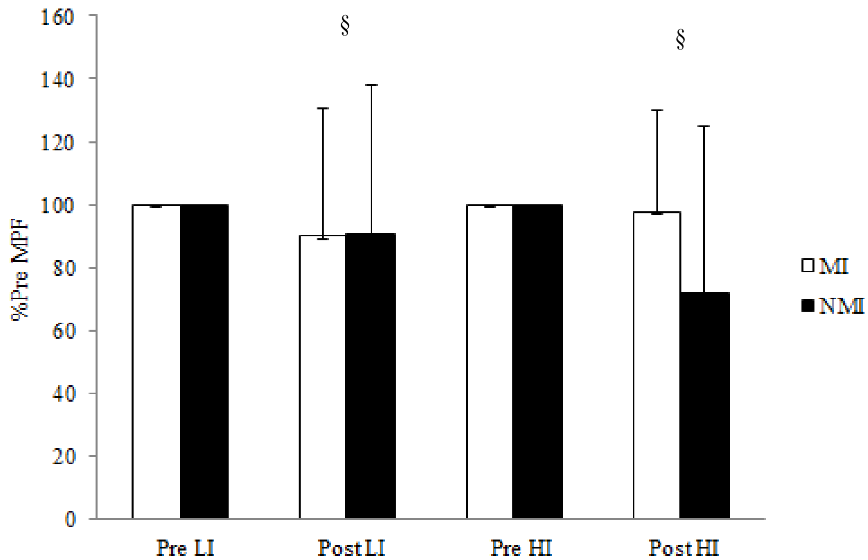


Figure 4.7 Percent change in median power frequency/median frequency (MPF/MF) taken from baseline EMG readings within each individual session (i.e., LI vs. HI) compared to post-exercise. The pre-exercise measurement was set as 100% and the post-exercise measures represent the change (%△) from there as a potential indicator of muscle fatigue. Data represented as mean ± SE. *p≤0.05 vs. NMI; +p≤0.05 for Intensity; §p≤0.05 vs. NMI at same time point (Group x Intensity)

4.5 Discussion

The main focus of this study was to establish and compare the effects of a single acute bout of HI and LI exercise on the physiological and perceptual measures and the recovery phase in children and adolescents with MI in order to inform better exercise prescription. Throughout the literature, it has been consistently shown that children with movement difficulties and/or impairment (i.e., pDCD and DCD) are disadvantaged to various degrees on exercise capacity and muscle strength. Individuals with MI perform less well on fitness parameters (Cairney et al., 2007; Haga, 2007) of: aerobic power, muscle strength, endurance, anaerobic power and body composition (Cermak & Larkin, 2002; Eken et al., 2013; Faught et al., 2013; Hands, 2008; Morris et al., 2013). Similar to previous findings examining submaximal and maximal exercise test measures (Faught et al., 2013; Morris et al., 2013), it was observed that children and adolescents with MI exhibited a lower $\dot{V}O_{2peak}$ and peak workload (PPO) compared to their typically developing (NMI) peers (MI: 157.0±61.0 vs. NMI: 216.0±57.0 Watts). Participants with MI had a reduced exercise capacity as demonstrated by a mean $\dot{V}O_{2peak}$ of 31.5 mL/kg·min. Furthermore, the $\dot{V}O_{2peak}$ for the MI group was below the cardiovascular fitness threshold (Ruiz et al., 2007) and, as such, associated with an increased risk of obesity, type II diabetes and cardiovascular and metabolic conditions in adulthood (Andersen et al., 2006; Anderssen et al., 2007).

Parallel to values reported by Faught et al. (2013), the HR_{max} was analogous between groups (MI: 170.0±25.0 and NMI: 180.0±17.0 bpm, $p>0.05$). However our findings deviated from the results in Morris et al. (2013), who saw a significant mean HR difference of 12 bpm in children with higher MI (176 bpm) versus NMI (188 bpm), which may be due to the small sample size in the current study not meeting the power calculations to detect mean differences (Chapter 4.3.4). In addition, perceived competence to complete the task could also limit the results of the $\dot{V}O_{2max}$ test in children with MI. It is important to note that the MI group demonstrated a similar RPE to NMI despite significant differences in $\dot{V}O_{2peak}$ performance and differences in exercise capacity between children with and without MI are unlikely to be the result of poor perception of effort and motivation with this protocol (Cairney et al., 2010). Nonetheless, the limiting factors to exercise may be more perceptually related and central in origin. Future research should assess the factors that influence aerobic fitness and how patterns of PA and physical fitness are created in children with poor motor competence to provide more information critical for the design of effective interventions (Farhat et al., 2014).

Interestingly, despite the reduced baseline aerobic fitness exhibited by the MI group, there was no difference in maximal RER or RPE between the two groups during the maximal exercise test. Both groups exceeded an average RER of 1.06 at the end of the exercise test; however, RER was notably higher in NMI (1.34 in NMI vs. 1.20 in MI), which was different to the findings in Morris et al. (2013). Substrate utilisation and fat oxidation levels during the maximal exercise test were within the range previously reported in healthy children and adolescents (Riddell et al., 2008). Moreover, although the MI group experienced a significantly lower PPO there was no difference in the perception of effort (RPE) reported throughout and at test termination similar to Morris et al., (2013). All participants reported a RPE rating of 9 or 10 at the end of the exercise test. Our findings further emphasise a lower level of aerobic muscle performance as a factor limiting exercise performance in children with MI as demonstrated by their greater muscular inefficiency ($\dot{V}O_2$/workload) rate in comparison to NMI (MI: 13.3±4.0; NMI: 11.2±2.0 mL W). According to Wasserman et al. (2011), $\dot{V}O_2$ kinetics normally rise at a rate of approximately 8.5-11 mL/min·W and are independent of sex, age, body mass or height in youth. Therefore, participants with MI in this study illustrated a reduced movement economy similar to that observed in children with pDCD during submaximal exercise intensities (Faught et al., 2013). In particular, Faught et al. (2013) noted that children with pDCD were disadvantaged from the beginning of the incremental exercise protocol at low workloads (i.e., <40 W) and worked at a greater percentage of their $\dot{V}O_2$ compared to healthy controls throughout the test. It is possible that even at very low exercise intensities, children with poor motor proficiency/coordination may need to utilise more energy to carry out basic movements associated with maintaining proper posture and posture on the cycle ergometer (Faught et al., 2013). This further suggests that children with MI may exercise at a higher metabolic rate to sustain the same the same level of workload relative to children without.

To our knowledge, this is the first study to investigate the impact of varying exercise intensities and the responses during the recovery phase, particularly following HI exercise, in youth with MI. As previously alluded in Morris et al. (2013), the evidence of children with MI to push themselves maximally warrants the potential applications of performing HI exercise on improving measures of health, muscle function and movement coordination. The results in this study revealed that the NMI group was able to tax the cardiovascular system sufficiently during the HI session as indicated by the 12% difference for HR_{avg} between the HI (157.0±14.0 bpm) and LI (143.0±17.0 bpm) cycling bouts. Conversely, the MI group did not appear to demonstrate considerable difference in HR measures between HI (140.0±18.0 bpm) and LI (133.0±18.0 bpm) cycling with only a 4% difference in percentage change from HR_{max} between intensities. These findings potentially suggest a smaller ventilatory threshold (VT), or point during exercise at which ventilation starts to increase at a faster rate than $\dot{V}O_2$, in children with MI compared to NMI. For most individuals, this threshold lies at exercise intensities between 50% and 75% of $\dot{V}O_{2max}$ and is dependent on the person's level of fitness (Hebestreit et al., 2000; Reybrouck et al., 1985). Exercise intensity for both HI and LI workload was set relatively to each child and therefore, considering the high peak RER observed in the MI group and lower actual intensity workload performed, it is likely that children with MI are exercising at a lower intensity relative to their VT. A limitation of this study was that the exercise intensities for the HI and LI cycling bouts were not determined from the VT and instead, calculated as a percentage of PPO ($PP_{50\%}$ and $PP_{100\%}$). Although difficult to interpret in a minority of children, the VT is a useful method to determine aerobic fitness in children (Hebestreit et al., 2000) and future studies should examine VT and $\dot{V}O_{2max}$ changes following different types of training (Buchan et al., 2013; Mahon & Vaccaro, 1989).

As previously mentioned, lower muscular strength and power may contribute to the decreased fitness levels and participation in physical activities among children and adolescents with MI. In children with DCD, the influence of muscular strength and power on everyday activities including weight-bearing propulsive activities such as jumping and hopping is evident (Raynor, 2001). Comparatively, reduced muscle capacity and strength of the major locomotor muscles was also observed in individuals with higher MI, suggesting that limitations to exercise in this group of children result from strong physiological underpinnings (Morris et al., 2013). In this study, strength measurements of the VL and BF muscles were assessed at baseline and pre- and post-cycling across sessions. The MI group had a significantly lower MVIC (expressed as peak torque) compared to NMI when assessed prior to the cycling bouts and following into recovery at P5, confirming the findings from other studies on DCD (Raynor, 2001) and children with higher levels of MI (Morris et al., 2013). For both exercise intensities, the MI group experienced a smaller decrease in peak torque compared to NMI. The reliability of the MVICs suggest that they were fully exerting their leg muscles but were potentially unable to fully recruit the muscle fibres (Raynor, 2001). In addition to weaker muscles, it is speculated that the MI group may not have physically worked as hard as their TD peers even though they felt they were during the exercise as confirmed by the lower workloads achieved.

The decreased muscular strength and power of children with DCD is considered to be partially attributable to difficulties with planning, inefficient muscular activation and increased levels of cocontraction (O'Beirne et al., 1994; Raynor, 2001). Few studies have focused on the neuromuscular aspects contributing to the decreased muscle strength levels observed in children with movement difficulties and MI. Therefore, another aim of this study was to determine if children with and without MI produced different levels of maximum force following varying cycling intensities (HI and moderate-LI) and if so, whether any strength deficits could be attributed to impaired neuromuscular performance (i.e., cocontraction/coactivation). Corresponding to the results of Raynor (2001), the MI group displayed increased levels of coactivation during the MVIC action following cycling compared to NMI (Figure 4.6). Increased levels of coactivation are often observed during the early stages of childhood and have been associated with unskilled movements and programming problems in DCD (Raynor, 2001). A study by Frost et al. (1997), quantified the amount of cocontraction present in thigh and leg muscles in three groups of healthy children (aged 7-16 years) during treadmill walking and running. The findings showed that the youngest group displayed higher cocontraction levels in relation to their $\dot{V}O_{2max}$ (Frost et al., 1997), which may further explain the higher metabolic cost in younger children in comparison to adolescents and adults. Given the importance of age and maturation when interpreting results, the MI and

NMI group in this study were similar thus, enabling the results to be comparable. Interestingly, despite significant differences for intensity in both groups, cocontraction ratios appeared to return to baseline levels similarly for HI and LI at P5, indicating more support for explosive and intermittent-type exercise. Other possible causes of decreased strength in MI include differences in muscle-fibre distribution. As a consequence of their limited movement experiences, children with DCD are suspected to have a smaller proportion of fast-twitch motor units (type-II muscle fibres) and thereby, less force-producing elements in the muscle (Raynor, 2001). While children generally refine their muscular activation patterns through various movement experiences and interactions with the environment (Basmajian & De Luca, 1985), the inefficient muscular activation patterns of children with MI may be a consequence of their limited movement experiences (Raynor, 2001). Thus, incorporating high intensity exercise and resistance strength training interventions not only has implications for improving aerobic fitness, but also improving overall movement and muscle function.

In the last decade, findings have suggested that children with lower motor competence exhibit significantly poorer performance on important components of physical fitness (i.e., aerobic, anaerobic endurance and muscular strength) (Farhat et al., 2014) and lower exercise tolerance. The ability of children to better maintain performance and resist muscle fatigue during repeated bouts of HI exercise may be related to lower fatigue levels during exercise or faster recovery following (Ratel et al., 2006). From a clinical perspective, muscle fatigue profiles are different between healthy TD children and individuals with neuromuscular and neuro-developmental conditions. For example, children with CP demonstrate a greater predominance of type I muscle fibres (slow-twitch) alongside more atrophy of type II fibres based on muscle biopsies (Rose et al., 1994). Consequently, the muscle profiles of CP is thought to be due to selective recruitment of lower frequency motor units, which innervate type I fibres while the type II fibres responding to higher frequencies are inhibited (Edstrom, 1968; Edstrom & Nystrom, 1969; Rose et al., 1994). The median frequency (MF), established from the power spectral density analysis, illustrated a greater percentage drop (~12%) from pre-MF in NMI compared to MI following both cycling intensities. Previous EMG data collected in CP suggest that muscle fatigue occurred sooner in children with CP relative to age-matched controls (Leunkeu et al., 2010). In the literature, children with DCD are likely to experience earlier fatigue due to reduced motor unit recruitment and muscle activities of agonists and antagonists (Farhat et al., 2014; Raynor, 1998). However, contrary to former studies, the MI group did not demonstrate muscle fatigue following HI cycling, which may be an artifact of the exercise dose (Figure 4.7). Considering that the MI group exercised at a lower workload for all sessions compared to NMI, the intensity level assigned may not have been difficult enough to elicit muscle fatigue despite expressing perceived fatigue. All participants were asked to perform each MVIC maximally with verbal encouragement and visual feedback to reach or surpass their peak MVIC. However observationally, some participants kept their eyes shut during the task, which could potentially influence their overall performance.

Nonetheless, the MI group did not experience any differences in perceived fatigue and muscle fatigue compared to NMI peers following either the HI or LI exercise. These observations are similar to studies reporting that children experience less fatigue during short-burst activities and often request to repeat high-intensity exercises after their completion determined to improve their previous performance (Bar-Or & Rowland, 2004; Ratel et al., 2006). However, during higher intensity exercise, the MI group reported higher levels of perceived fatigue in legs and breathing even though they performed at a lower overall exercise intensity (but still the same relatively) and achieved high RER values at $\dot{V}O_{2peak.}$ To further, the mechanistic data showed that children with MI did not display elevated muscle fatigue or a drop off in MPF following either exercise intensity. Therefore, as opposed to the findings observed in Morris et al. (2013), the factors limiting exercise performance and perceived fatigue in MI may be more central in origin rather than metabolic or peripheral. This suggests that the lower-intensity aerobic exercise will be better tolerated in the MI group in comparison to HI. Nevertheless, all participants completed each session without any adverse events and interestingly, both the MI and NMI group anecdotally preferred the HI cycling bout to the LI bout. With this in mind, children with MI and movement difficulties who experience different levels of exercise intensity may build up more confidence and self-efficacy to participate in more PA (Cairney et al., 2005; Silman et al., 2011). Thus, more research investigating the implementation of HI and LI exercise during longer-term interventions is required to further elucidate the sustainability of this type of activity and the potential benefits associated with it in children and adolescents with MI.

4.6 Conclusion

The findings from this study highlight the physiological, perceptual and recovery responses to different exercise intensities in children and adolescents with and without MI, which has not been explored in this population group to date. The reduced exercise capacity and muscular performance in children with MI substantiate results in the literature surrounding youth with movement difficulties. The exposure to both a HI, intermittent bout and a continuous LI cycling bout demonstrated a lower exercise capacity in children with MI and a higher perception of physiological symptoms while performing at a lower intensity generally. Furthermore, the results from the incremental exercise test alongside measures of muscle strength and fatigue before and after exercise suggest that central factors such as motivation and perceived adequacy are likely to be the limiting factor to exercise tolerance in MI. Interestingly, differences for group and intensity were observed in the recovery period, yet the pattern of recovery was similar between MI and NMI, which may be crucial for devising suitable exercises and activity intensities. Although the number of participants in this sample was relatively small, the novel results from each acute session contribute to future interventions and exercise prescriptions targeting aerobic and anaerobic fitness, strength and power and general participation in physical activities. Overall, all participants managed to complete the high and moderately-LI cycling bouts. However, whether short durations of HI intermittent exercise can feasibly improve health and fitness levels and longer-term engagement in physical activity in youth with movement impairment still remains to be explored.

5

Validation of submaximal testing to assess aerobic capacity

5.1 Abstract

Introduction: Children and adolescents with motor coordination problems and movement impairment (MI) often demonstrate lower cardiorespiratory fitness and aerobic capacity compared to typically developing (TD) peers. Although maximal exercise testing ($\dot{V}O_{2max}$) is considered the gold standard for measuring aerobic fitness, submaximal exercise tests may provide a feasible method to assess and monitor fitness in young individuals with and without movement difficulties. **Purpose:** This chapter focused on the criterion validation of two submaximal aerobic fitness tests used throughout the studies comprised in this thesis. The first part looked at the criterion validation and reliability of the Åstrand-Rhyming (A-R) cycle test to measure and estimate aerobic capacity in a group of children and adolescents with varying degrees of movement/motor skill proficiency. The second part consisted of validation of the Chester Step Test (CST) against direct measurement of $\dot{V}O_{2max}$ in a separate sample of participants during a mass testing session. **Methods:** Sixteen children and adolescents between the ages of 11-18 years participated in phase 1 with eight participants completing two separate A-R tests within a week of each session to determine reliability. All participants completed the Bruininks-Oseretsky Test of Motor Proficiency 2, Short Form (BOT-2 SF) to categorise motor skill level. The A-R test was performed on a bicycle ergometer with a two min warm-up followed by pedaling at 60-70 revolutions per min (rpm) at an initial workload of 60 Watt and 30 Watt (W) increments until a target heart rate (HR) (120-160 bpm) was reached. HR and rating of perceived exertion (RPE) was measured each min during the six min testing period. Maximal oxygen consumption was estimated by calculating the exercise heart rate (HR) and maximal oxygen consumption ($\dot{V}O_{2max}$) using the A-R nomogram technique. Direct measurement of $\dot{V}O_{2max}$ was performed via an incremental bike test (Godfrey protocol) until volitional exhaustion. In Phase 2, a separate group of 20 participants were recruited to perform the CST in a mass testing setting. The CST was performed on fitness stepper blocks (0.30 m height) and consisted of five stages with different step frequencies set by a metronome disc, which increased the stepping rate every two minutes ranging from ~15 to 35 cycles per minute. RPE and HR measurements were taken at the end of each stage to estimate $\dot{V}O_{2max}$. **Results:** In Phase 1, all participants (n = 18) completed the Åstrand cycle test and measured $\dot{V}O_{2max}$ test. Six participants scored below the 17th percentile cut-off on the BOT-2 SF and were categorised as having lower motor skill proficiency. Pearson's correlation coefficients (r) showed a positive, moderate relationship between estimated and measured $\dot{V}O_{2max}$ (r=0.58; p=0.01). When normalised for weight (ml/kg·min) and corrected for age, a medium strength of association was shown (r=0.49; p<0.05 and r=0.44; p=0.05). The paired t-test revealed a significant difference between the tests (p< 0.05) with the A-R test overestimating true $\dot{V}O_{2max}$ by approximately 10-30%. Pearson's correlation coefficient was statistically significant (p<0.01) and showed a strong, positive relationship between trial 1 and trial 2 of the estimated $\dot{V}O_{2max}$ (r=0.84). Computation of an ICC to assess inter-rater reliability indicated a reasonable consistency of ICC (3, 1) = 0.81, p=0.02, with a 95% CI [0.06, 0.96] and a moderate agreement between the two predicted A-R tests. In Phase 2, the mean measured $\dot{V}O_{2max}$ was 45.4±9.1 ml/kg·min compared to 50.4±11.5 ml/kg·min from the estimated CST in six participants. A moderate correlation was observed (r=0.34) and no significant differences were seen between measured and CST-predicted $\dot{V}O_{2max}$ [t(5)=-0.92, p>0.05, 95% CI: -11.94, 5.65]. Furthermore, the level of agreement (LoA) between the two methods was assessed using the 95% LoA: [-19.57, 13.28] showing no degree of proportional bias as represented by the Bland-Altman plot. **Conclusion:** A limitation of the A-R

method was that predicted $\dot{V}O_{2max}$ was over-estimated consistently and may need a correction factor for better accuracy. However, the A-R method can be used reliably and straightforwardly to monitor aerobic fitness in a range of movement skills. Moreover, the CST may be a feasible option to measure aerobic fitness in young adolescents within a group setting when the first stage of the test is excluded.

5.2 Introduction

Aerobic capacity or cardiorespiratory fitness (CRF) in children and adolescents has been reported to be an important marker of health, with higher aerobic capacity associated with lower total adiposity (Lee & Arslanian, 2007) and inversely associated with prevalence of cardio-metabolic risk factors (Ekblom, 2014; Hurtig-Wennlof et al., 2007). Poor aerobic fitness can limit a young individual's ability to engage in physical activity (PA) and to perform daily activities (Ekblom, 2014). Previous studies examining the relationship between motor skill problems and children with lower CRF have suggested that children with motor coordination problems are less aerobically fit than typically developing (TD) children (Hands & Larkin, 2006; Hay et al., 2003). Furthermore, a systematic review of the literature reported that children with developmental coordination difficulties (DCD) had on average 11-22% lower peak aerobic power ($\dot{V}O_{2peak}$) using lab based assessments and 17-28% lower aerobic power in field based tests (Rivilis et al., 2011). Therefore, utilising valid and reliable methods to systematically monitor aerobic capacity in children and adolescents of varying levels of motor skill proficiency may benefit proper evaluation and implementation of PA interventions. A review of the different methods to monitor and assess fitness components in Chapter 3 provided a justification for suitable tests to utilise in paediatric populations presenting with MI.

The measurement of maximal oxygen uptake ($\dot{V}O_{2max}$) or peak oxygen uptake ($\dot{V}O_{2peak}$) as elucidated in Chapter 3, is defined as the highest rate that the body can take up and use oxygen during maximal exercise (Krahenbuhl et al., 1985). Although the criterion measurement of $\dot{V}O_{2max}$ via direct gas exchange during maximal exercise to volitional exhaustion is regarded as the gold standard for assessing aerobic capacity (Chia et al., 2010) as utilised in Chapter 4, advanced equipment/facilities and well-trained individuals are required to administer the test. In addition, maximal exercise testing can be unpleasant and burdensome for individuals with physical limitations such as pain, fatigue, abnormal gait or impaired balance that are often observed in special population groups (Chia et al., 2013). Furthermore, direct measurement of $\dot{V}O_{2max}$ is generally not applicable for most public school settings, health promotion programs, or epidemiological field studies within paediatric research (Buono et al., 1991). Another consideration for using submaximal exercise tests to assess aerobic fitness is due to the fact that children and young individuals often do not demonstrate a plateau in $\dot{V}O_2$ as exhibited in the criteria of obtaining a true $\dot{V}O_{2max}$. Thus, the point of highest $\dot{V}O_2$ attained during a graded maximal exercise test to volitional exhaustion ($\dot{V}O_{2peak}$) is often used to represent aerobic fitness among youth (Shepard, 1968). Consequently, indirect methods (e.g., predictive submaximal exercise tests, shuttle run, step tests and walk tests) may be a more feasible method to assess aerobic fitness levels in non-laboratory settings and among clinical populations.

5.2.1 The Åstrand-Rhyming cycle test

The Åstrand-Rhyming (A-R) method is perhaps the most commonly used submaximal test in adults and adolescents aged 15 years and older (Ekblom, 2014). It is based on the relationship between steady-state heart rate (HR) during submaximal workloads and uses the nomogram technique (Åstrand and Rhyming, 1954) to predict $\dot{V}O_{2max}$. The accuracy of the A-R method to predict $\dot{V}O_{2max}$ was first studied in adults (Davies, 1968; Von Dobeln et al., 1967) with no age-correcting factors available at the time for individuals under 15 years of age (Ekblom, 2014). Studies conducted since then, have primarily observed children aged 11-12 years, noting the important training age in which most sports disciplines begin, thus leading to several regression models and age-correction factors (Ekblom, 2014; Olgun Binyildiz, 1980; Woynarowska, 1980). More recently, a study by Buono (1991) evaluated the A-R method with a correction factor in children 10-16 years old, which demonstrated moderate reliability (r=0.77) compared to a $\dot{V}O_{2max}$ treadmill test. However, the validity and reliability was only examined in TD individuals and may not necessarily be comparable due to the nature of the two tests (i.e. cycling vs. running). Furthermore, few studies have failed to take into account the wide range of motor skill abilities and/or levels and the heterogeneity of movement difficulties among youth with MI when validating such methods.

5.2.2 The Chester Step Test

As briefly mentioned in Chapter 3.6.3, the Chester Step Test (CST) is another popular submaximal test originally developed to assess aerobic fitness in fire brigades in Britain, Europe, USA and Asia and more recently for work with health institutions, ambulance services and corporate institutions (Sykes & Roberts, 2004). The CST has many advantages including a simple and safe protocol along with limited and portable equipment required (heart rate monitor, compact disk player, fitness step and perceived exertion scale). Prediction of $\dot{V}O_{2max}$ using the CST is based on the extrapolation of a "line of best fit", which passes through the submaximal HR responses for each stepping stage, up to a level which equals the participants' age-estimated HR_{max}. This is based on the assumption that a linear relation exists between each step stage of the CST with HR and $\dot{V}O_2$; meaning HR_{max} and $\dot{V}O_{2max}$ are coinciding events and that HR_{max} is equal to 220 minus the participant's age (Buckley, 2004). However, the reliability and validity of the CST has only been previously examined in adults (Buckley, 2004) and may therefore be untenable for children and adolescents.

5.2.3 Aims and objectives

The aims and objectives of this study was twofold: (i) to consider the criterion related validity of the Åstrand cycle test method and the CST in two separate groups of children and adolescents with varying degrees of motor skill proficiency to predict $\dot{V}O_{2max}$ compared to $\dot{V}O_{2max}$ measured directly in a laboratory and (ii) to examine the repeatability of the A-R to predict $\dot{V}O_{2max}$ in a sub-sample of children and adolescents to confirm reliability and suitability for use in MI.

The study is split into two parts:

- Phase 1: Criterion validity and reliability of A-R method and $\dot{V}O_{2max}$
- Phase 2: Criterion validity of CST to $\dot{V}O_{2max}$

5.3 Phase 1- Criterion validity and reliability of the Åstrand-Rhyming cycle test

5.3.1 Methods

The study was approved by the University Research Ethics Committee. Participants were recruited from local schools in Oxfordshire and the Clinical Exercise and Rehabilitation Unit (CLEAR) at Oxford Brookes University, where they attended exercise sessions regularly. Families indicating that they were interested in taking part were sent separate child and parent information sheets and gave their written consent prior to the study. Participants attended the Movement Science Laboratory for testing on three separate occasions and were either randomised to perform the submaximal test before or after the maximal exercise test. Participants were required to be able to walk with or without support for at least five meters and be able to safely take part and follow a two-step instruction during testing procedures. Prior to exercise testing, level of motor skill proficiency was assessed using the Bruininks-Oseretsky Test of Motor Proficiency Short Form (BOT-2 SF) (Bruininks and Bruininks, 2005).

Participants were asked to refrain from eating, performing exercise or drinking caffeine in the 2 h period before attending the sessions. All participants were fully familiarised with the testing protocol prior to data collection.

5.3.2 Participants and Protocol

Sixteen children and adolescents between the ages of 11-18 years were recruited for this study. A separate group of 20 participants were recruited to undergo the CST in a mass testing setting (Phase 2; section 5.8.1). Individuals were classified on the level of motor skill proficiency using the BOT-2 SF assessment.

5.3.3 BOT-2 SF

This standardised test of motor proficiency was used to categorise level of motor skill competence as described in Chapter 3.4.1.3. Four motor area composites are included in the BOT-2 SF encompassing fine motor control, manual coordination, body coordination and strength and agility. Thirteen items were individually administered as described in the test manual. Raw scores (max 88) for each task were converted to a point score under each subtest and summed across to obtain a total standard score. The total standard scores were compared to normative scores and age equivalents to determine the individual's percentile rank and to describe overall motor skill proficiency level. Based on the BOT-2 SF manual, individuals scoring below the 17^{th} percentile cut-off were considered to have lower motor skill proficiency (Bruininks and Bruininks, 2005).

5.3.4 Exercise Testing

Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were recorded prior to the exercise test. For the purposes of testing a wide range of motor abilities, participants performed an incremental step test on a cycle ergometer (Lode Excalibur Sport, Gronigen, the Netherlands) consisting of 1 min stages after an initial 2 min of unloaded cycling. Workload was progressed by 15-20 W from unloaded cycling each minute based on the height of the participant (Godfrey et al., 1971). The test was terminated when the participant reached volitional exhaustion or was unable to maintain a cadence of 60 revolutions per minute (rpm) despite verbal encouragement.

Pulmonary gas exchange (see Chapter 4.3.1.1) including, oxygen uptake ($\dot{V}O_2$), carbon dioxide produced ($\dot{V}CO_2$) and volume of expired air per minute ($\dot{V}_E$) were measured breath by breath using an online gas analyser (Cortex Metalyser 3B, Cortex, Leipzig, Germany). Before each testing session, the gas analyser was calibrated according to manufacturer guidelines. The gas sample line was calibrated using gases of a known concentration and flow volume was calibrated using a 3 L syringe (Hans Rudolph). All participants wore a fitted facemask covering the nose and mouth connected to a low resistance volume transducer (Triple V, Hoechberg, Germany). HR was recorded continuously throughout the testing using short-range telemetry (Polar S810, Finland). Oxygen uptake ($\dot{V}O_2$) was recorded as the highest 30 s of each stage, whereas $\dot{V}O_2$ was recorded as the highest 60 s average before the termination of the test (Morris et al., 2013). Although participants may not have demonstrated a plateau during maximal exercise, the criteria for obtaining a true maximal effort was still utilised and included a plateau in $\dot{V}O_{2max}$, a maximal HR >95% of age predicted maximum and/or an RER >1.06 (Winter, 2007). Additionally, ratings of perceived exertion (RPE) using the Cart and Load Effort Rating (CALER) scale (Barkley & Roemmich, 2008) was documented during each stage for legs, breathing and overall feeling.

5.3.5 Åstrand -Rhyming Test

The A-R test was performed on a bicycle ergometer (Monark 818E, The Netherlands). To ensure safety at the start of the test, blood pressure (BP) and HR was measured. The CALER scale was introduced to the participants, and reported prior to the test to monitor perceived exertion. The participant's bike seat was adjusted to a comfortable position and recorded for subsequent tests, and a two-minute warm-up phase was given prior to beginning the test with a pedal frequency of 60-70 rpm. The submaximal cycling workload was set at 60 W and increased by 30 W until target HR (i.e., 120-160 bpm) was reached and maintained (120-160 bpm). Heart rate and RPE was measured each minute during the six-minute testing period. If the HR for the 5^{th} and 6^{th} min did not differ by more than five bpm and the participant's mean HR was between 130 and 160 bpm, the workload was maintained until the end of the test. If HR differed by more than five bpm, the test was continued until this criteria was met (Astrand, 1952). At the completion of the test, participants completed a 2-3 min cool down (Andersson, 2004).

Eight participants completed two separate A-R tests within a week of each session to identify reliability of the submaximal test. Maximal oxygen consumption was determined by calculating the exercise heart rate and maximal oxygen consumption using the A-R nomogram technique (Astrand & Rhyming, 1954) (Figure 5.1).

5.3.5.1 Nomogram technique

Using the A-R nomogram and an age-correction factor, $\dot{V}O_{2max}$ was determined based on the participant's exercise HR, age, sex, and power output. To determine maximal consumption, the point representing average HR of the 5th and 6th min of the test based on the sex of the participant is connected to the point that represents the power output calculated. The total oxygen uptake score (in Liters) is at the point where the line crosses the maximal oxygen consumption line (Figure 5.1). Furthermore, estimated $\dot{V}O_{2max}$ established from the A-R nomogram was corrected for age using the Buono (1991) equation (Eq. 1), which is applicable for ages 11-18 years of age.

(Eq. 1) $\dot{V}O_{2\text{age-correction factor}}$ = [$\dot{V}O_{2\text{astrand}}$]*[0.66-0.028]*[age+0.026]*[weight+0.166] (Buono et al., 1991)

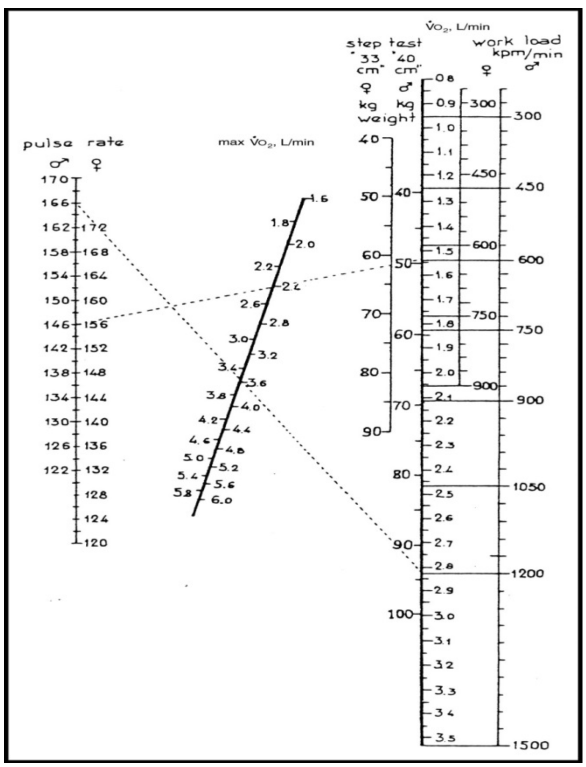


Figure 5.1 Åstrand-Rhyming test (1954) with its accompanying nomogram technique for calculation of aerobic capacity submaximally is based on the relationship between pulse rate during work and actual oxygen intake as a percentage of an individual's maximal aerobic capacity whereby a certain amount of oxygen is required for each workload [Printed with permission by author (Andersson, 2004)].

5.3.6 Statistical analyses

The mean difference between measures, the standard deviation ($SD_{difference}$) and the 95% limits of agreement (LoA): mean ± 1.96 · $SD_{difference}$ were calculated. All exercise testing measure distributions were examined for normality. Analyses were performed using SPSS 21 for Windows (SPSS Inc, Chicago, IL, USA). Statistical significance for all tests was set at $p<0.05$.

Validity

The criterion related validity of the A-R was examined by quantifying the agreement between the predicted $\dot{V}O_{2max}$ from the submaximal A-R cycle test including the nomogram technique compared to laboratory determined or measured $\dot{V}O_{2max.}$ Correlations were determined using Pearson′s correlation coefficient (r) comparing measured $\dot{V}O_{2max}$ and the predicted $\dot{V}O_{2max}$ from the A-R method. The correlation coefficient was interpreted according to Cohen (d) (1988), whereby 0.10-0.29 was considered small, 0.30-0.49 was considered moderate and 0.50-1.0 was considered a strong association (Cohen, 1988). Paired t-tests were used to test for potential differences between these measures. Additionally, the systematic agreement between the measured and estimated $\dot{V}O_{2max}$ was quantified using the 95% LoA method originally described by Bland and Altman (Bland & Altman, 1986). This was performed by computing a one-sample t-test to determine the mean difference and $SD_{difference}$, followed by plotting a scatterplot graph (Bland-Altman plot) of the participants' mean test results [(measured $\dot{V}O_2$ + estimated $\dot{V}O_2$)/2] on the x axis in correspondence to the difference between each participants' measures (measured $\dot{V}O_2$ − estimated $\dot{V}O_2$) on the y axis.

Reliability

Eight participants performed a second A-R cycle test to establish reliability in this population. The sequence of the tests were randomly performed to either before or after the $\dot{V}O_{2max}$ test and separated by one week. Test-retest reliability was determined via intraclass correlation coefficients (ICC) procedures comparing trial 1 versus trial 2 for the A-R cycle test. The ICC, which measures the proportion of total variance due to differences between subjects was conducted using a two-way mixed effects model, single measures (3, 1), expressed with associated 95% confidence intervals (CI) and interpreted as >.75 excellent, .40-.75 fair-to-good, and <.40 poor in reliability (Shrout & Fleiss, 1979). A one-sample t-test was also performed to test the hypothesis of no difference between the sample mean for trial 1 versus the sample mean for the retest (trial 2) to investigate any systematic bias.

5.4 Results

All participants (n = 18) completed the Åstrand cyle test and the measured $\dot{V}O_{2max}$ test. On the BOT-2 SF, six participants scored below the 17th percentile cut-off and were categorised as having lower motor skill proficiency and represented individuals presenting with MI.

Table 5.1.
Characteristics of participants (mean ± SD)

Characteristics	(N = 18)
Age (years)	14.5 ± 1.5
Weight (kg)	63.3 ± 4.7
Height (cm)	169.6 ± 10.4
BMI	22.1 ± 2.3
Tanner Scale	5.0 ± 0.0
BOT-2 SF (/88 max)	70/88 ± 7.0
VO_{2peak} (L/min)	2.41 ± 0.8
$VO_{2\ peak}$ (mL/kg·min)	37.6 ± 10.7
HR_{max} (bpm)	182.0 ± 14.0
RER maximum	1.28 ± 0.1
RPE maximum	8.0 ± 2.0

Abbreviations: BMI, body mass index; BOT-2 SF, Bruininks-Oseretsky Test of Motor Proficiency, Second Edition Short Form; BPM, beats per minute; HR_{max}, heart rate max; PPO, peak power output; RER, respiratory exchange ration; RPE, rating of perceived exertion (CALER).

Measured $\dot{V}O_{2max}$ test

The participants' characteristics for the $\dot{V}O_{2max}$ are presented in Table 5.1. All participants achieved a RER >1.06. All but two of the participants reached a HR_{max} within 10-15% of the age-predicted maximum HR using the Tanaka formula (208-0.7·age) (Tanaka et al., 2001).

Table 5.2.

Comparisons and correlations between the measured and estimate $\dot{V}O_{2max}$ values (mean ± SD)

Parameters	(mean ± SD)	p-value	r-value[1]	p-value (sig. 2-tailed)
N = 18 (Validity)				
Measured $\dot{V}O_{2max}$ (L/min)	2.4 ± 0.5	-	-	-
Measured$\dot{V}O_{2max}$ Normalised (ml/kg·min)	37.6 ± 10.7	-	-	-
A-R test trial 1 (L/min)	2.8 ± 0.5	0.010	0.59	**<0.002**
A-R test trial 1 corrected for age (L/min)	3.1 ± 0.7	0.056	0.46	**<0.026**
A-R test trial 1 Normalised (ml/kg·min)	45.1 ± 7.8	0.040	0.49	**<0.004**
n = 8 (Reliability)				
A-R test trial 2 (L/min)	3.1 ± 1.2	0.009	0.84	**<0.002**
A-R test trial 2 corrected for age (L/min)	3.2 ± 0.9	0.128	0.59	**<0.004**
A-R test trial 2 Normalised (ml/kg·min)	46.1 ± 6.5	0.055	0.69	**<0.002**

Paired t-test comparisons between the measured $\dot{V}O_{2max}$values and the estimated $\dot{V}O_{2max}$values using the Åstrand test (A-R) for trial 1 (N = 18) and test trial 2 (n = 8).

[1]Pearson's correlation coefficient (r), $\dot{V}O_{2max}$ = maximum oxygen uptake.

$p<0.05$ in bold

Åstrand vs. measured $\dot{V}O_{2max}$ test (Validity)

Pearson's correlation coefficients (r) showed a positive, strong relationship between the estimated and measured $\dot{V}O_{2max}$ ($r=0.58$; $p=0.01$). When normalised for weight (ml/kg·min) and corrected for age, a medium strength of association was shown ($r=0.49$; $p<0.05$ and $r=0.44$; $p=0.05$) (Table 5.2). The paired t-test revealed a significant difference between the tests ($p< 0.05$) indicating differences between the two methods with the A-R test overestimating the true $\dot{V}O_{2max}$ score by approximately 30% in 10 of the participants. However, for 12 out of the 18 participants, the estimated and measured $\dot{V}O_{2max}$ scores were within a 10-15% range. Based on a one-sample t-test, a significant difference was seen between A-R trial 1 and measured $\dot{V}O_{2max}$ [$t(17)=-2.44$, $p=0.03$; 95% CI:-0.68, -0.50] and therefore did not show a useful level of agreement. A significant difference was also seen with both the normalised predicted and measured $\dot{V}O_{2max}$ values [$t(17)=-3.31$, $p<0.01$; 95% CI:-12.34, -2.72].

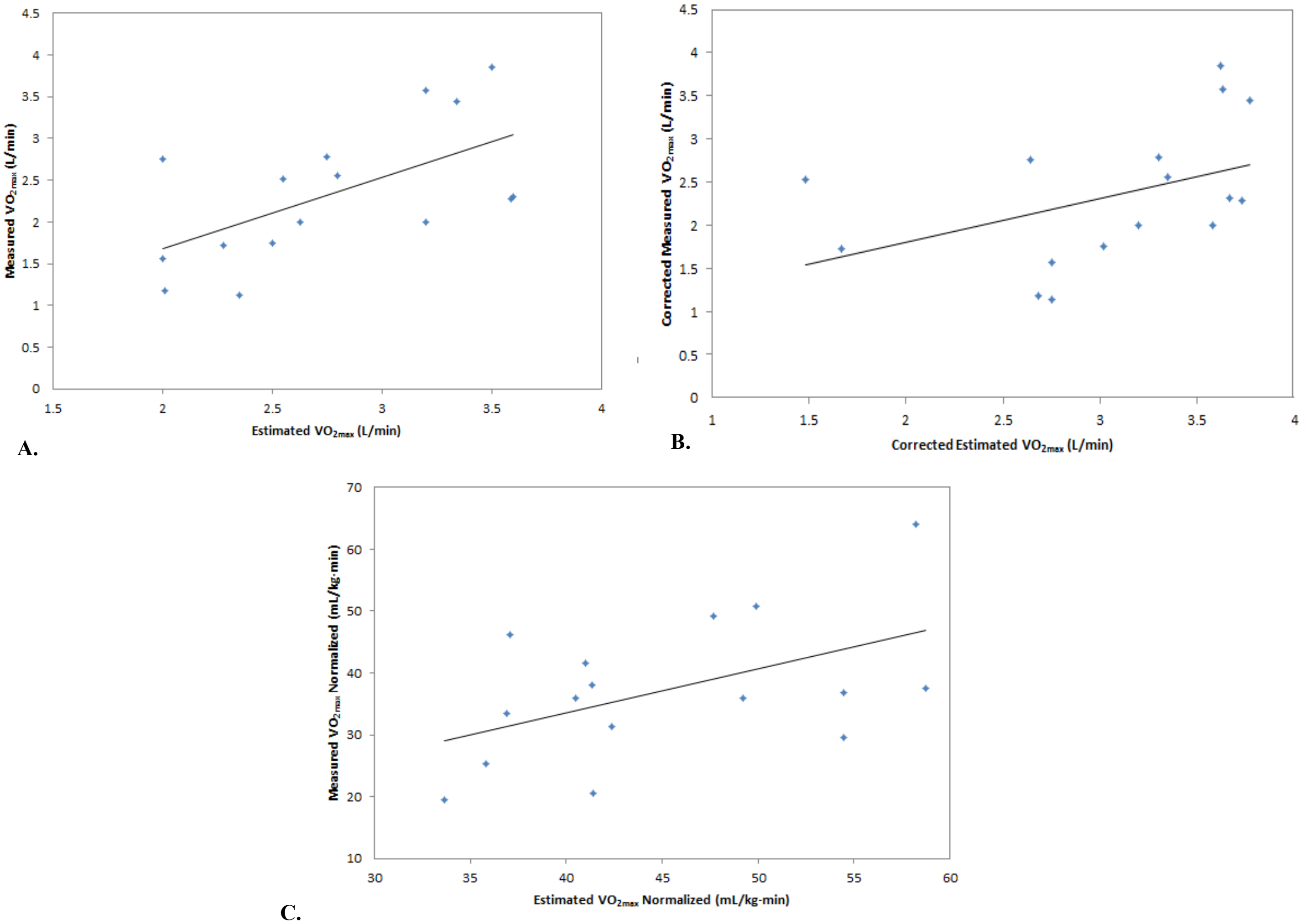
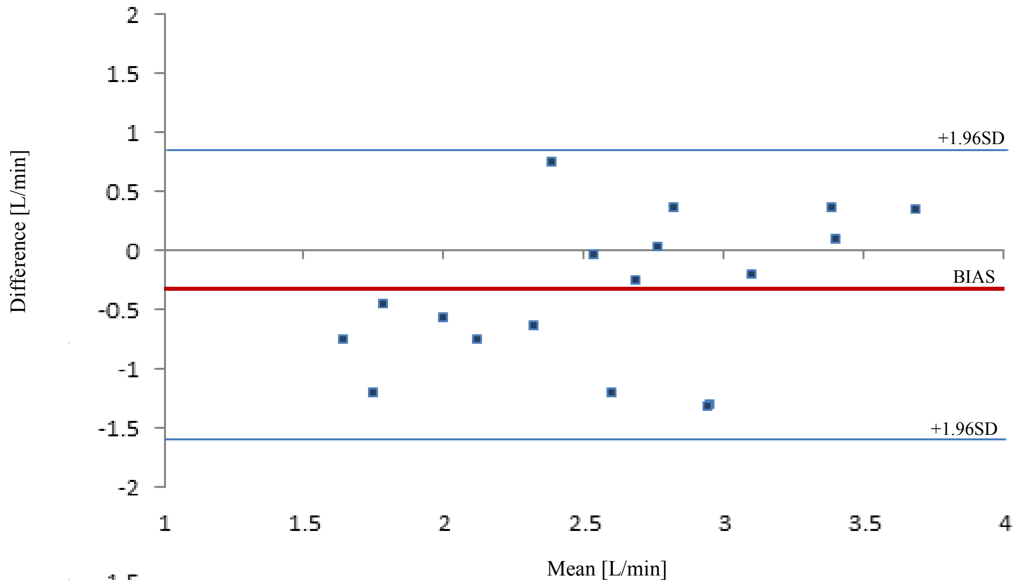


Figure 5.2 Measured vs. estimated maximal oxygen uptake ($\dot{V}O_{2max}$). Correlations between measured $\dot{V}O_{2max}$ and $\dot{V}O_{2max}$ estimated with the submaximal Åstrand-Rhyming (A-R) cycle test (A-B), expressed in L/min (A and B) and in ml/kg·min (C). Corrected estimated $\dot{V}O_{2max}$ for age (B) and normalised for weight (kg) in (C).

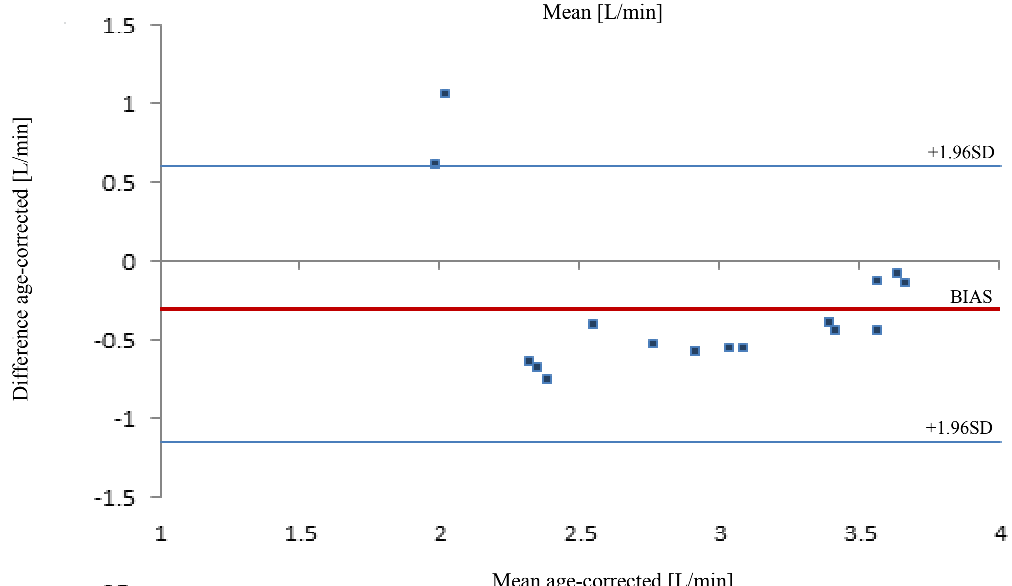
Although a Bland-Altman plot was not required due to the significant difference between predicted A-R and measured $\dot{V}O_{2max}$, a plot was still created to illustrate any variance and the degree of agreement (Figure 5.3). The 95% limits of agreement (LoA) for the estimated $\dot{V}O_{2max}$ were wide, ranging from -1.61 to 0.88 L/min and -26.48 to 11.42 ml/kg·min normalised and demonstrated equal variance around the mean differences and no degree of proportional bias.

Åstrand test vs. measured $\dot{V}O_{2max}$ test corrected for age

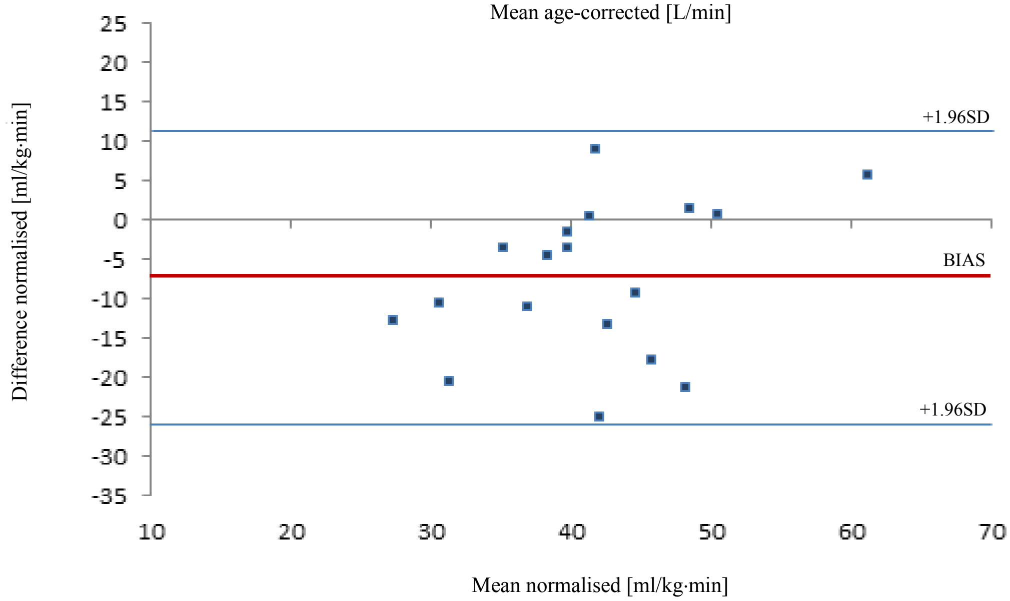
When using the Buono correction factor (Eq.1) (Buono et al., 1991) to adjust for age, the Pearson's correlation coefficient (r) demonstrated a moderate relationship between the estimated and measured $\dot{V}O_{2max}$ (r=0.48). A paired t-test did not show a significant difference between the two tests. However, a one sample t-test showed that the difference between these two measures were significantly different and thus, did not indicate a useful level of agreement between the two methods [t(17)=-2.80, p=0.01; 95% CI: -0.54, -0.08] as confirmed with Bland-Altman analysis plot (Figure 5.3(B)). No obvious relationship between the difference and the mean difference of the data points were observed, suggesting no proportional bias. Furthermore, the 95% LoA ranged from -1.21 L/min to 0.60 L/min with the age-correction factor and were small enough to denote confidence in using the age-corrected predicted method. However, more of the data points were clustered below the mean difference line with two points driving the bias, which results in over-predicting estimated.


Difference [L/min]
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
+1.96SD
BIAS
+1.96SD
1
1.5
2
2.5
3
3.5
4
Mean [L/min]

A.


Difference age-corrected [L/min]
1.5
1
0.5
0
-0.5
-1
-1.5
+1.96SD
BIAS
+1.96SD
1
1.5
2
2.5
3
3.5
4
Mean age-corrected [L/min]

B.


Difference normalised [ml/kg·min]
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
+1.96SD
BIAS
+1.96SD
10
20
30
40
50
60
70
Mean normalised [ml/kg·min]

C.

Figure 5.3. Bland-Altman plots of measured and estimated maximal oxygen uptake $\dot{V}O_{2max}$. Differences of $\dot{V}O_{2max}$ in L/min (A), corrected for age in L/min using Buono's (1991) age-correction factor (B) and normalised in ml/kg·min (C) between the Åstrand submaximal test (A-R) and the measured $\dot{V}O_{2max}$ test, plotted against the mean $\dot{V}O_{2max}$ of these two tests.

Åstrand test trial 1 vs. trial 2 (reliability)

Eight of the 18 participants performed two A-R cycle tests on separate occasions to assess test-retest reliability of the submaximal test (Table 5.3). Pearson's correlation coefficient was statistically significant ($p<0.01$) and showed a strong, positive relationship between trial 1 and trial 2 of the estimated $\dot{V}O_{2max}$ ($r=0.84$). Computation of an ICC to assess inter-rater reliability indicated a reasonable consistency of ICC (3, 1) = 0.81, p=0.02, with a 95% CI [0.06, 0.96] and a moderate agreement between the two predicted A-R tests. The 95% CI had a lower bound value of .06 and an upper bound value of 0.77, indicating good reliability. When normalised for weight (kg), the estimated $\dot{V}O_{2max}$ had a good reliability (R=0.86), and an ICC of 0.91, p=0.03 and a 95% CI [0.55, 0.98]. Furthermore, a one-sample t-test demonstrated a non-significant difference between trial 1 and trial 2 [t(7)=-1.59, p=0.16; 95% CI: -5.98, 1.18].

Table 5.3.
Characteristics of participants performing test-retest A-R (mean ± SD)

(N = 8)	
Age (years)	15.0 ± 2.0
Weight (kg)	60.5 ± 4.8
Height (cm)	164.0 ± 13.0
BMI	22.7 ± 3.3
Tanner Scale	4.0 ± 0.0
BOT-2 SF (/88 max)	70/88 ± 7.0
A-R Trial 1	2.8 ± 1.0
A-R Trial 2	3.1 ± 1.2
$\dot{V}O_{2peak}$ (L/min)	2.00 ± 0.8
$\dot{V}O_{peak}$ (mL/kg·min)	32.6 ± 10.4
HR_{max} (bpm)	179.0 ± 10.0
RER maximum	1.32 ± 0.1
RPE maximum	8.0 ± 2.0

Abbreviations: A-R, Astrand-Rhyming Test; BMI, body mass index; BOT-2 SF, Bruininks-Oseretsky Test of Motor Proficiency, Second Edition Short Form; BPM, beats per minute; HR_{max}, heart rate max; PPO, peak power output; RER, respiratory exchange ration; RPE, rating of perceived exertion (CALER); $\dot{V}O_{2peak}$, peak oxygen uptake.

5.5 Discussion

This study aimed to examine the criterion validity of the submaximal Åstrand cycle test to estimate and predict $\dot{V}O_{2max}$ in conjunction with the A-R nomogram technique. A secondary aim was to assess the reliability of the Åstrand method over separate days. In general, submaximal data from ergometer-based tests can be used to estimate maximal aerobic capacity in children across a range of motor skill abilities. The results in this study showed that the test overestimated $\dot{V}O_{2max}$ substantially by 10-12% and as high as 30%, which should be taken into consideration when interpreting the results. However, despite this limitation, the test along with the A-R nomogram technique may be a useful method for measuring aerobic fitness and a feasible option depending on the population group. The justification for submaximal testing is warranted due to poorer exercise intolerance, decreased motivation and or increased fatigue often symptomatic in children and adolescents presenting with MI and/or other movement difficulties including DCD and CP (Cantell et al., 2008).

In the present study, the cycle ergometer was the only mode of exercise performed for both the submaximal and maximal tests to eliminate any error that may be introduced with regard to motivation of the individual near-maximal efforts (Buono et al., 1991). When performing a cycle test for the first time, anxiety and inexperience with the test situation and environment may have an impact on the test outcome, however, all participants had a warm-up and familiarisation period before each session to reduce any performance anxiety. Furthermore, although the timed distance run has shown to be superior in reliability (r=0.95) and validity in predicting treadmill-based $\dot{V}O_{2max}$ compared to both the cycle and step test in 10-18 years old (Buono et al., 1991), such a field test requires greater coordination and may therefore be less practical for children and adolescents of varying motor skill proficiency. Six of the participants in this study scored below average on the BOT-2 SF assessment and were considered as having poor motor skill levels or MI, but were nevertheless, fully capable in completing all testing. Despite lower maximum HRs in the participants with lower motor skill proficiency (mean = 176) compared to their TD peers (mean = 196), our results are consistent with the findings by Morris et al. (2013), who found that the low level of aerobic muscle performance was limiting the ability of children with higher motor impairments to push themselves hard enough to maximally tax their cardiovascular system.

Based on the data from this study, the A-R method tended to overestimate true $\dot{V}O_{2max}$ by 10-15%, which is in agreement with previous studies in healthy individuals (Jessup et al., 1977; Jette, 1979) and in children aged 11-12 years old (Ekblom, 2014). A study by Woynarowska (1980) saw average differences between indirect and direct measure of $\dot{V}O_{2max}$ by approximately 26% in boys and 23% in girls, with better accuracy increased by using proposed regression equations (Olgun Binyildiz, 1980). In the present study, the A-R estimated and measured $\dot{V}O_{2max}$ scores were within a 10-15% range of each other, however, a larger overestimation of 30% was demonstrated in 10 out of the 18 participants, similar to the results in previous studies (Ekblom, 2014; Halicka-Ambroziak et al., 1975; Hartung et al., 1995; Noonan

& Dean, 2000), possibly due to the lower aerobic capacity in several of the participants. Additionally, the lack of suitable heart and work rate combinations with the A-R method may result in lost, unusable data due to work rates being too low and not featured on the nomogram (Ekblom, 2014). For instance, HRs above 170 bpm at work rates of 50 W or 100 W are fairly common in younger subjects below the age of 12-13 years. However, this work and HR combination is absent in the A-R nomogram, which may lead to frequently missed values or inaccurate predictions. Subsequently, the Woynarowska regression (1980) was proposed to correct the values obtained using the A-R method for better precision and less underestimation.

Correspondingly, age-adjusted methods underestimated capacity in well-trained children according to Ekblom (2014), which was consistent with the few participants who reached a maximal HR during the $\dot{V}O_{2max}$ test. One possible explanation for the variability discerned include only 40% of the participants reaching a HR_{max} close to their age-predicted maximum estimated by the Tanaka equation (Tanaka et al., 2001), indicating the inaccuracy of the age-predicted maximal HR relationship. However, all participants attained an RER >1.06, meeting at least one of the criteria for maximal effort. According to Buono et al. (1991), predicting $\dot{V}O_{2max}$ from submaximal HR is often limited by one or more of the following assumptions including: linearity of the HR/O_2 uptake relationship; accuracy of the age-predicted HR_{max}; constant oxygen cost of external work; and the day-to-day variation in heart rate (McArdle et al., 1986).

The test-retest of the cycle test using the A-R nomogram demonstrated a moderate reliability (r=0.84) in this study, which is in agreement with the results of Buono et al., (1991), who measured this in a large sample of children (N = 90) in 5th, 8th and 11th graders (r=0.77). The weaker correlation when normalised for weight was attributed as a mathematical consequence of the weight index giving a lower range in relation to the mean and thus, leading to less optimal prerequisites for obtaining high r-values (Nordgren et al., 2015). Although the A-R estimates were not treated using multiple correction factors, the multiple regression by Buono et al. (1991) was utilised as it encompassed a wide age range. This equation had a multiple r=0.84 and a standard error of estimate of 4.3 ml/kg·min, or 9.0%, similar to Massicotte et al.

(1985). Conversely, using this correction factor led to a lower correlation between predicted and measured $\dot{V}O_{2max}$ (r=0.48), potentially impacted by the limited small sample size. Statistically, the A-R method did not demonstrate a useful level of agreement with the direct measurement of $\dot{V}O_{2max}$, however the measures were not clinically important (i.e. focused on treatment effect) (Peterson, 2008) and may still be used interchangeably in the context of practical and feasibility of utility. Furthermore, the mean differences were within the 95% LoA and showed no proportional bias, suggesting some limitations associated with this study need to be further considered. For example, the population in the present study consisted of a range of children and adolescents 11-18 years and also included a wide range of fitness levels. Assessing young individuals with varying levels of motor skill proficiency may influence the motivation and effort to perform the tests, however, the participants in this study willingly volunteered to undergo the testing and many have been familiarised with the procedures previously. Furthermore, for a few participants who had lower motor skill levels, mechanical efficiency could be lower (Morris et al., 2013), leading to a higher HR and workload ratio and consequently underestimation of $\dot{V}O_{2max}$ (Nordgren et al., 2015) as demonstrated by our findings. Despite the limitations in this study, provided that the Åstrand test is standardised and conducted according to the test protocol, the A-R method may be a feasible approach to prospective monitoring of aerobic fitness in MI and TD youth.

5.6 Phase 2- Validation of the Chester Step Test

In this part of the chapter, the aim was to establish the criterion-validity of the CST against direct measurement of $\dot{V}O_{2max}$ for the purpose of assessing aerobic capacity in group settings (Chapter 6).

5.6.1 Background

As previously mentioned, Sykes and Roberts (1996) reported acceptable validity (r=0.92) in adults for the CST with an error of 5-15%. In contrast, a study by Buckley et al. (2004), set out to assess the reliability and validity of both the CST's prediction of $\dot{V}O_{2max}$ and its three main measurement components (RPE, heart rate and estimated $\dot{V}O_2$) at each test stage in healthy young adults (22.4±4.6 years) and found the predicted $\dot{V}O_{2max}$ from the CST underestimated actual $\dot{V}O_{2max}$ on multiple trials by 11-19% respectively, questioning the accuracy of the CST to predict maximal aerobic power. However, the reliability results demonstrated little inter-trial bias (-0.8 ml/kgmin) and an acceptable 95% LoA (±3.7 ml/kg·min). The findings highlighted the importance of selecting an appropriate step height and utilising Stage I as a familiarisation and warm-up stage to ensure linearity between work-rate increments and HR and $\dot{V}O_{2max}$ (Buckley, 2004). Furthermore, the step height, which can range from 0.15 to 0.30 m and determines the stepping intensity along with the step rate to provide an estimate of the oxygen cost ($\dot{V}O_2$) for each of the five stages (Table 5.4) must be taken into account among young population groups. Correspondingly, previous studies have not looked at the criterion validation of the CST in younger populations as a method to assess and monitor aerobic fitness. Thus, this part of the study aimed to validate the CST for mass screening purposes within school-settings.

Stage	**I**	**II**	**III**	**IV**	**V**
Stepping rate	15	20	25	30	35
$\dot{V}O_2$ (ml/kg/min)					
0.15 m step	11	14	18	21	25
0.20 m step	12	17	21	26	29
0.25 m step	14	19	24	28	33

Table 5.4 The five stages of the Chester Step Test and the oxygen cost estimates ($\dot{V}O_2$) for varying step heights (m) and stepping rates (steps/min). Adapted from Buckley et al., (2004).

5.7 Methods

This study was approved by the University Research Ethics Committee. Participants were recruited from local schools participating in an Open Day run by the Movement Science Group at Oxford Brookes University with local schools whereby participants were invited by their school to take part in the session and were given opt-in consent prior to partaking in testing. Participants attended the Movement Science Laboratory for testing in the morning.

5.7.1 Participants

Twenty young participants between the ages of 14-19 years were recruited separately and organised to perform the CST within a group setting. Individuals were classified on the level of motor skill proficiency using the BOT-2 SF assessment and preliminary anthropometric measurements were recorded as described in the previous section (5.2.1.2). Six out of the 20 participants performed a maximal cycle test in addition to the CST as detailed in Chapter (5.2.1.3).

5.7.2 Protocol

On the day of the G&T testing, the participants were split into groups of six and rotated through the different test sessions consisting of the BOT-2 SF, the CST and a submaximal and maximal bike test. The CST was performed on fitness stepper blocks (The Step, USA) set at a 0.30 m height. Instructions were provided and each participant was asked to wear a Polar HR chest monitor (Polar S810, Finland) during the test. The CST lasted 10 min and consisted of five stages with different step frequencies set by a metronome disc, which increases the stepping rate every two minutes ranging from ~15 to 35 cycles per minute. One cycle represents stepping on and off a designated step with both feet (Sykes, 1998). Prior to the start, the participant's HR_{max} and 80% of HR_{max} were calculated. The test always began with a brief introduction, followed by a demonstration of the initial stepping rate (~15 steps/min), a 12 s warm-up and then a stepping stage lasting 100 s each. Once the CST commenced, the participants were encouraged to step at the appropriate stepping rate and to maintain so throughout the stage duration. Furthermore, RPE using the 10-point Cart and Load Effort Rating (CALER) scale (Eston et al.,2000) was checked at the end of each stage and was followed by a 23, 21, 20 and 22 s rest stage, respectively.

5.7.3 Data analysis

To estimate $\dot{V}O_{2max}$ utilising the HR recorded at the end of each stepping stage, a master sheet was created on Microsoft Excel (Windows 7; 2010) to automatically generate a linear line based on the HRs inputted and the given $\dot{V}O_2$ normalised corresponding for each stage (Sykes, 1998). The $\dot{V}O_2$ (ml/kg·min) were pre-determined on the data collection sheet as follows: Stage 1 = 16 ml/kg·min; Stage 2 = 21 ml/kg·min; Stage 3 = 27 ml/kg·min; Stage 4 = 32 ml/kg·min; and Stage 5 = 37 ml/kg·min. A graph was generated with $\dot{V}O_2$ on the y-axis and HR (bpm) on the x-axis. From there, a linear equation y=ax+b was determined and computation of estimated $\dot{V}O_{2max}$ was performed using the average of the HRs for all stages, maximal HR determined from the Tanaka equation (208-0.7·age) (Tanaka et al., 2001) and the values for "a" and "b" generated from the linear equation.

For the CST method, predicted $\dot{V}O_{2max}$ was determined from the maximum HR calculated from the Tanaka equation. Thereafter, calculation of the estimated $\dot{V}O_2$ (ml/kg·min) normalised was achieved using the CST manual (version 3) categorisations for each CST stage, whereby the estimations were 16, 21, 27, 32 and 37 ml/kg·min, for stages one to five at a step height of 0.30 m (Sykes, 1998). Once the average HR of the last 10 s of each step stage was plotted at each of the $\dot{V}O_2$ levels, the predicted $\dot{V}O_{2max}$ was then extrapolated. For the six participants who completed a $\dot{V}O_{2max}$ test, $\dot{V}O_2$ was recorded as the highest 30 s average of each stage.

5.7.4 Statistical analyses

Data were analysed using the statistical methods presented in Section (5.3.6). Descriptive statistics (mean ± SD, range) were calculated for all variables and examined for normality. All analyses were performed using SPSS 21 for Windows (SPSS Inc, Chicago, IL, USA). Statistical significance for all tests was set at $p < 0.05$.

5.8 Results

Twenty TD participants (15.2±0.3 yrs old) were recruited and performed the CST in combination with HR measurements (Table 5.5). All participants completed the BOT-2 SF and the descriptive score was categorized as average (n=18) (BOT-2 SF >17th percentile), above average (n=1) and well above average (n=1) (BOT-2 SF >95th percentile and >99th percentile). The six participants who also performed a maximal cycle test all met the criteria for reaching maximal effort during the exercise test (Table 5.5).

Table 5.5.
Baseline characteristics and outcome measures (mean ± SD)

N = 20	**Mean ± SD**	**Range**
Age (years)	15.2 ± 0.3	14.7 - 15.6
Height (m)	1.73 ± 0.1	1.63 - 1.86
Weight (kg)	60.7 ± 6.0	51.6 - 67.7
BOT-2 SF Standard Score	54.2 ± 8.1	41.0 – 74.0
Est. $\dot{V}O_{2max}$ (CST) (mL/kg·min)	53.6 ± 8.4	42.5 - 67.4
n = 6		
Age (years)	15.2 ± 1.7	14 - 15
Height	1.75 ± 6.1	1.70 - 1.81
Weight	66.4 ± 3.5	60.1 - 70.1
HR_{max}(bpm)	192.0 ± 9.3	194.0 - 198.0
RER	1.14 ± 0.1	1.1 – 1.2
$\dot{V}O_{2peak}$ (mL/kg·min)	45.4 ± 9.1	37.6 - 64.0
Est. $\dot{V}O_{2peak}$ (mL/kg·min)	50.4 ± 11.5	36.2 - 65.2

Abbreviations: BMI, body mass index; BPM, beats per minute; CST, Chester Step Test; Est. VO_{2max}, estimated maximal oxygen uptake; Est. VO_{2peak}, estimated peak oxygen uptake; HR_{max}, heart rate maximum; RER, respiratory exchange ratio.

A small negative correlation was demonstrated between the BOT-2 SF standard scores and the CST estimated $\dot{V}O_{2max}$ (r=-0.26). Conversely, the BOT-2 SF standard scores (mean 54.0±6.3) correlated well with measured $\dot{V}O_{2max}$ (r=0.63) (Figure 5.4). For the six participants who also performed a maximal cycle test, the mean measured $\dot{V}O_{2max}$ was 45.4±9.1 ml/kg·min compared to 50.4±11.5 ml/kg·min from the estimated CST. A moderate correlation was observed (r=0.34) and no significant differences were seen between measured and CST-predicted $\dot{V}O_{2max}$ [t(5)=-0.92, p>0.05, 95% CI: -11.94, 5.65].

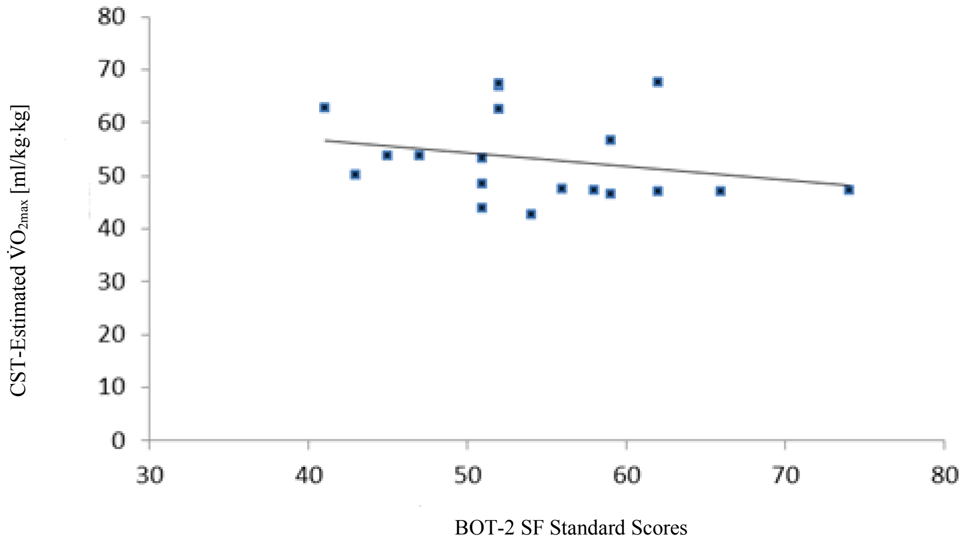


Figure 5.4 Relationship between the Bruininks-Oseretsky Test of Motor Proficiency Short Form (BOT-2 SF) standard scores and the CST estimated $\dot{V}O_{2max.}$

Furthermore, the level of agreement between the two methods was assessed using the 95% LoA: [-19.57, 13.28] showing no degree of proportional bias as visually represented by the Bland-Altman plot

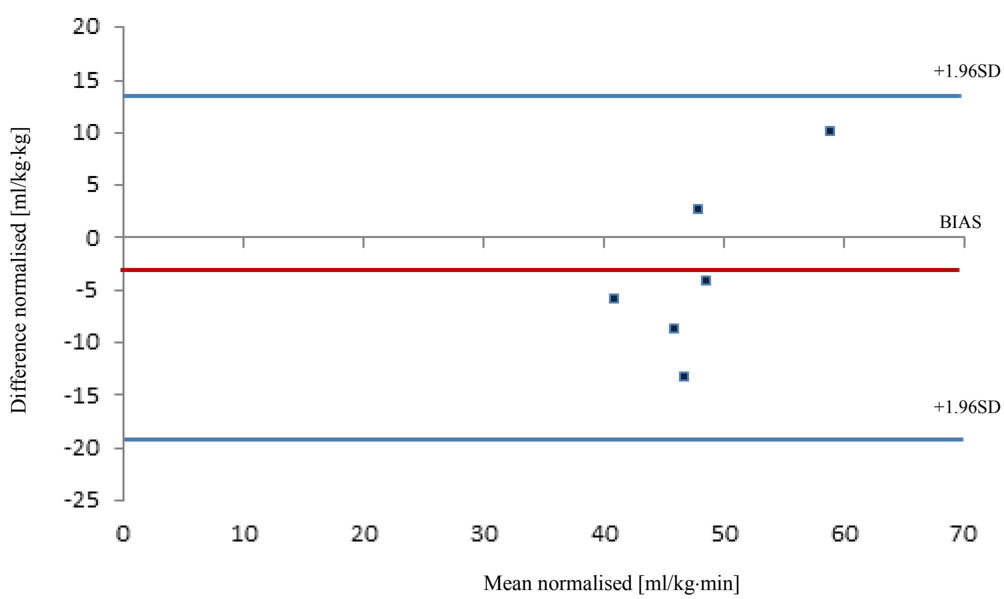


Figure 5.5 Bland-Altman scatter-plot of measured and CST-estimated maximal oxygen uptake $\dot{V}O_{2max}$. Difference of $\dot{V}O_{2max}$ from the two methods normalised (ml/kg·min) on the y-axis plotted against the mean $\dot{V}O_{2max}$ of these two tests on the x-axis.

(Figure 5.5). A higher correlation was observed between directly measured $\dot{V}O_{2max}$ and estimated CST $\dot{V}O_{2max}$ when using HR data for CST Stages II-V (r=0.798) versus CST Stages I-V (r=0.685). When including HR from stage I to estimate $\dot{V}O_{2max}$, the CST method over-predicted $\dot{V}O_{2max}$ by 2-3 times more. Moreover, a paired samples t-test showed a statistically significant difference ($p<0.001$) between the mean estimated $\dot{V}O_{2max}$ data for stages I-V (56.6±9.5 ml/kg·min) of the CST compared to only stages II-V (53.3±8.4 ml/kg·min) [t(19)=3.74, 95% CI [1.55, 5.47].

5.9 Discussion

This study aimed to examine the validity of the CST method to estimate and predict $\dot{V}O_{2max}$ in young individuals for mass screening purposes. Overall, the estimated $\dot{V}O_{2max}$ exemplified a moderate correlation (r=0.34) with direct measurement of $\dot{V}O_{2max}$ and may be a suitable submaximal test to evaluate aerobic fitness in adolescents.

The CST was selected in this study to be used for group testing due to the feasibility of the test and ease of administration. The findings demonstrated a moderate correlation between CST-estimated $\dot{V}O_{2max}$ and direct measurement with a reasonable level of agreement between the two methods. For individuals with higher levels of fitness and/or familiarised with the CST protocol, workload may appear to be consistent for all stages despite HR increasing during each of the five stages. Based on the results, it is recommended to exclude the first stage of the CST, as it is primarily a warm-up stage and participants can get a higher HR in this stage compared to the second stage when they have become familiar with the test, which may anomalise the prediction of aerobic capacity. This was in agreement with a study by Buckley (2004), who showed a significantly greater actual $\dot{V}O_2$ compared with CST estimated $\dot{V}O_2$ at stage I leading to a curvilinear relationship. As a result, a possible correction to attain linearity between work rate increments, HR and $\dot{V}O_2$, could be to exclude HR data from stage I when drawing the line of best fit used to determine HR_{max} and to predict $\dot{V}O_{2max}$. Step height was not a concern in this study as a standard height of 0.30 m step was only used and all participants managed to complete all stages. However, it is important to note that choice of step height could be problematic in the completion of the CST and for accurate prediction of $\dot{V}O_{2max}$ (Buckley, 2004) and therefore, must be considered before choosing the appropriate bench or step height to use in mass testing environments, in particular with children.

The prediction of $\dot{V}O_{2max}$ from the CST significantly underestimated the actual $\dot{V}O_{2max}$ during test-retest trials by -2.7 ml/kg·min. The bias ±95% LoA for both trials showed that the CST could potentially underestimate $\dot{V}O_{2max}$ by approximately 9 ml/kg·min or overestimate $\dot{V}O_{2max}$ by as much as 5.5 ml/kg·min which could lead to false results for occupational assessment purposes (i.e. falsely failing or passing a firefighter). In this group of young participants, mean measured $\dot{V}O_{2max}$ was 45.4±9.1 ml/kg·min compared to 50.4±11.5 ml/kg·min via the CST method, thus resulting in an overestimation by 10% similarly reported by Stevens and Sykes (1996). This level of error may be acceptable for fitness assessment and health promotion purposes, but not necessarily suitable for accurately predicting $\dot{V}O_{2max}$ in occupational performance.

Furthermore, a negative correlation was observed between BOT-2 SF standard score and CST-predicted $\dot{V}O_{2max}$. However, there was no relationship between BOT-2 SF score and HR measurements, possibly due to all participants in this study scoring 'average' and 'above average' on the BOT-2 SF. Due to the homogeneity of the participants' fitness and motor skill levels in this study, the agreement between estimated and measured $\dot{V}O_{2max}$ may not be generalisable. Therefore, further studies should be conducted to validate the CST across age ranges and for varying levels of motor skill levels. Consequently, it may be relevant to explore overall workload measured with accelerometers and HR monitors to determine if there is any relationship between CST performance and motor skill proficiency in future studies. In addition, a main component of the CST relates to rhythm and stepping on the beat, which may be problematic for children and adolescents with lower motor skill proficiency. Further research should aim to quantify coordination and movement using accelerometers, inertial measurement unit sensors while performing a task with a metronome beat.

5.10 Conclusion

Key issues to bear in mind when deciding on a suitable submaximal method include purpose of data being collected, the sample size/target population and how the results will be used. In this study, a limitation of using the A-R method in this particular age group was that predicted $\dot{V}O_{2max}$ was over-estimated and thus cannot be taken as face value. However, the A-R method can be used reliably and straightforwardly to monitor aerobic fitness in both laboratory and field-based settings (i.e., gyms). Furthermore, the groups did not look different from each other as based on the observational analysis of the varying levels of motor skill in the study group. Nonetheless, it should be noted that individuals who failed to meet the criteria for reaching a true maximal effort were excluded and it may be that for some individuals with lower motor skills and movement difficulties, the estimated $\dot{V}O_{2max}$ will be less accurate in them. Therefore, we strongly encourage conducting the repeatability of the A-R test in a larger sample of children and adolescents across a range of motor skills in order to ascertain the suitability of the test for wider use within research and clinical purposes.

As presented in Phase 2 of this study, the CST may be a feasible option to measure aerobic fitness in young adolescents within group and mass screening settings (Chapter 6). However, it is recommended to exclude the first stage of the CST and consider it a warm-up stage as the comparisons between utilising CST stages I-V versus stages II-V led to a less accurate extrapolation of $\dot{V}O_{2max}$. Future studies should aim to validate the CST across different age groups and among a range of motor skill levels for more use in school settings.

6

Study 3: Exploring the impact and feasibility of a pathway to sport and longer-term participation in adolescents with movement impairment: the EPIC study

6.1 Abstract

Background: Increased physical activity (PA) may be beneficial for adolescents presenting with movement impairment (MI) and movement difficulties who do not regularly participate in play and sports. In Chapter 4, the results showed the potential health and fitness applications for both high- and low-intensity exercise in MI, but exploring the feasibility and impact of a long-term mixed training design is warranted. Knowledge about how to identify and encourage youth presenting with MI, poorer movement skills and reduced fitness to be physically active is required. *Objective*: In the present study, we aimed evaluate the feasibility of a screening pathway within Year 9 (13-14 years old) students to identify and recruit adolescents with MI and lower gross fitness coordinating levels (LFC). Following targeted recruitment, we aimed to pilot a 6-week exercise intervention designed to improve fitness levels and examine attendance rate, exercise intensity and youth's perceptions of participating. **Methods**: 522 adolescents across three year 9 classes (Schools A, B and C) completed the screening sessions and 155 individuals were recruited to take part in the EPIC study intervention. 31 participants joined in the 45-60 min exercise gym sessions 1-2 times weekly for 6-weeks. The data analysed included determination of rate of recruitment and extent of intervention delivery. Evaluation of attendance, quantitative fitness outcomes pre- and post-intervention and field observations of the sessions were conducted. **Results**: The average attendance rate during the EPIC Club intervention pilot was approximately 90%. Pre-intervention assessments were conducted in 15 participants from School A and 8 from School B due to absences or later start. Post-intervention assessments were collected from 8 participants in School A and 7 from School B with no significant differences observed on fitness outcomes. Exercise intensity between 65-95% of maximal heart rate (HR_{max}) was recorded for two of the EPIC Club sessions. Participants continued (School A: n=6, School B: n=11) with EPIC up to 30 weeks. Field observations and reports from the adolescents highlight the novelty of the EPIC Club intervention incorporating exercises and circuit-style mixed training within gym settings. **Conclusions**: The screening process and target recruitment strategy was feasible for identifying adolescents in Year 9 scoring in the ≤25th percentile on fitness and movement skill measures (LFC). The EPIC intervention pilot focusing on mixed cardio and strength training exercises had a high attendance rate and reached desirable exercise intensities. A fully powered randomised controlled trial of the EPIC study including a control group and different exercise intensities should be conducted to evaluate effect on physical fitness, health and well-being measures, confidence and self-efficacy, PA level and longer-term participation in other activities and sports. **Trial registration**: The trial was registered with ClinicalTrials.gov (http://clinicaltrials.gov) on 08 June 2015 (Registration Number: NCT0517333). **Trial funding**: Sport England Community Sport Activation Fund (CSAF) (Ref: 2013018570)

6.2 Introduction

According to the World Health Organization (World Health Organization, 2010), physical inactivity is now recognised as the fourth leading risk factor for global mortality with strong evidence demonstrating physical inactivity increases the risk of numerous adverse health conditions (World Health Organization, 2010); notably major non-communicable diseases including coronary heart disease (Andersen et al., 2006;

Steinberger, 2003), type 2 diabetes (Gill & Cooper, 2008) and breast and colon cancers (Khaw et al., 2008; Lee et al., 2012). In the UK, a 2012 report by the Chief Medical Officer (Chief Medical Officer, 2011) highlighted the importance of physical activity (PA) among young people (Davies, 2012) and more recently, a published report from the All-Party Commission on Physical Activity addressed a provision for a more diverse and inclusive offer of PA within schools (All Party Commission on Physical Activity, 2014). To add, a recent meta-analysis examining the effectiveness of PA promotion interventions in young people (Metcalf et al., 2012) emphasised that only two out of the 30 included studies with objective outcomes focused on adolescents over the age of 13 years (Haerens et al., 2006; Jago et al., 2006). Since then, numerous studies have focused on developing exercise and lifestyle programmes to improve PA levels among adolescents (Changsavang et al., 2015; Corder et al., 2015). The importance and prioritisation of PA research warrant the need for more high quality research in the development and evaluation of potentially successful strategies to improve longer-term PA in youth (Corder et al., 2015; Sallis et al., 2000).

According to PA guidelines for children and young people (ages 5-18), the CMO recommends regular participation in moderate-to-vigorous physical activity (MVPA) for at least 60 min a day to reduce the risk of children developing cardiovascular conditions in adulthood (Chief Medical Officer, 2011; Lipnowski & LeBlanc, 2012). A review by Kriemler et al. (2011) found that 47-65% of school-related PA intervention studies demonstrated the public health relevance and potential of school-based PA interventions for increasing PA and fitness in healthy youth. This was in contrast to the dearth of studies focused on school-based PA programs promoting PA and fitness in children and adolescents which were ineffective in increasing PA rates among adolescents, or in reducing health and fitness markers (i.e., blood pressure, blood cholesterol, BMI and HR), potentially due to insufficient PA intensities attained (Dobbins et al., 2009). Notably, the ROOTS study (Collings et al., 2014) which explored PA volume and intensity levels in a sample of healthy UK adolescents, emphasised that most adolescents are insufficiently active and spend a substantial amount of time at sedentary levels (Corder et al., 2015).

Correspondingly, PA components varied by gender, temporal factors and body composition in UK adolescents with both genders predominantly engaged in light-intensity PA and males markedly more physically active than females at all intensities overall (Collings et al., 2014; Corder et al., 2015). A consistent decline in PA over the school age years is seen with males decreasing about 2.7% per year and females decreasing at a greater rate of about 7.4% per year (Sallis, 1993). Thus, in conjunction with research promoting vigorous-intensity PA and the unique health benefits it confers (Buchan et al., 2013; Janssen & Leblanc, 2010) the findings in Collings et al. (2014) suggests there is a need to promote more participation and evaluation of such programs within the vigorous-activity domain as investigated in Chapter 4. The findings in Chapters 2 and 4 further highlighted the association between motor coordination and reduced health related components of fitness in youth with movement difficulties. This was demonstrated by marked impairment in performing motor skills, coordination, endurance strength, power and overall lower gross fitness coordination (LFC). Notably, longitudinal studies have indicated that children and adolescents with movement impairment (MI) carry-over their movement deficits and physical inactivity into adulthood (Kirby et al., 2010), creating an alarming risk profile for development of cardiovascular and metabolic co-morbidities.

As such, strategies and interventions targeting adolescents presenting with MI and LFC remains a public health priority. Exercise programmes that include both resistance and high-intensity aerobic training was proposed as a suitable health impact modality for obese adolescents (Peña et al., 2006; Stoner et al., 2013) and specifically in 13 and 14 year olds (Corder et al., 2015). Moreover, previous work has shown that the condition of a child's muscle strength may be a major contributing factor to exercise participation and tolerance, particularly at an intensity level high enough to induce a training effect (Benson et al., 2008; Faigenbaum et al., 1999; Ratel et al., 2006). Strength is an essential component of motor skill performance (Katzmarzyk et al., 2012) and has become a crucial element incorporated in PA and training interventions in children (Wrotniak et al., 2006). Developing competence and confidence to perform resistance strength exercise during the growing years may have important long-term implications for health, fitness and sports performance (Hallal et al., 2006; Lloyd et al., 2013; Myer et al., 2015; Viner et al., 2012). This is even more apparent for children and adolescents without the tools, environment and opportunities to foster positive behaviour patterns. In accordance, measures of fitness appear to all be interconnected, with level of motor skill and impairment correlated to aerobic fitness (i.e., VO_{2peak} attained) (Ferguson et al., 2014; Rivilis et al., 2011; Schott et al., 2007) and muscular strength (Morris et al., 2013). Exploring the relationships between motor skill ability (Fong et al., 2011; Haga, 2009), VO_{2peak} (Silman et al., 2011) and aerobic endurance (Wu et al., 2010) performance in children may provide insights into the basic role of physical fitness in dictating exercise capacity and identify appropriate training regimens in youth (Rowland, 2013). A clearer understanding of the interplay between physiological, psychological and social constraints and barriers limiting long-term PA participation and exercise engagement in children with MI and LFC remains a priority. As such, implementing interventions that incorporate tasks to improve in conjunction with coordination, muscle function and performance are warranted (Verschuren et al., 2008).

Additional research exploring the development, execution, implementation and feasibility of interventions to increase outcome measures needs to be further addressed (Ekelund et al., 2011). Considering the need and potential for school-based approaches as outlined by the CMO (add CMO ref), we set out to evaluate a school pathway. In line with the theoretical underpinnings of the 'capability', 'opportunity', 'motivation' and 'behaviour' model (COM-B) (Michie et al., 2011), which recognises that behaviour is part of an interactive system of all these components, we proposed that interventions should address these components by providing opportunity in school with an exercise approach that our target group (LFC) were capable and motivated (Barnett et al., 2013) to performing. This was set out through developing each individual's physical capacity and ability to perform the exercise, while reinforcing confidence, self-efficacy and perceived adequacy (Cairney et al., 2005) by encouraging group dynamics. This study was a proof-of-principle pilot study aiming to provide a pathway for engagement, participation, inclusion and confidence (EPIC) in sport and PA in young people presenting with neurodevelopmental conditions, movement impairment (MI), and/or lower gross fitness coordination levels (LFC). In the present study, we aimed to evaluate the feasibility (i.e., recruitment ability and program adherence) of a screening process within school settings and the delivery of a 6-week exercise intervention. The secondary purpose was to determine the effect of mixed strength and aerobic training programme on fitness components in adolescents participating in the 6-week gym intervention.

Aims and objectives

i.) To evaluate the delivery of a pathway via the determination of recruitment (i.e., screening process and invitation to join an exercise intervention EPIC Club) for adolescents presenting with LFC

ii.) Evaluation and assessment of intervention delivery/feasibility (i.e., attendance and participation) and compliance with components of intervention

iii.) Completion of fitness and health outcome measures and determine the potential for change in selected outcomes

Table 6.1 Feasibility process and intervention components

Feasibility process	Assigned Intervention
1.) Screen within Year 9 Class 2.) Targeted recruitment for those scoring in bottom 25th percentile (LFC) 3.) Invite students to take part in 6-week exercise training intervention 4.) Enroll students participating 5.) Pre-intervention assessment 6.) Start 6-week EPIC Club gym intervention (1-2 times weekly for 46-60 min) consisting of 30 min cardiovascular exercise and 25-30 min strength/resistance and weight training 7.) Post-intervention assessment 8.) Exit to longer-term sport/PA	**EPIC Club** ▪ Weekly exercise gym sessions (1-2 times weekly) for 45-60 min each session. ▪ Participants will start with a warm-up consisting of 30 min cardiovascular training performing either cycling, treadmill running or cross-training. ▪ The remainder of the session consists of strength/resistance and weight training involving leg press, leg extensor, pull downs, kettle bells, dumbbells and other machines relevant within the individual gyms. ▪ The gym sessions aimed to incorporate bursts of high-intensity (HI) activity and monitoring of heart rate (HR) throughout (potentially with wrist activity monitors with HR measurement) to identify level of PA intensity. ▪ Participants will also have the opportunity to attend and engage in 'Have a go' sports days organized by the Oxfordshire Sports Partnership.

6.3 Methods and design

6.3.1 Trial design

The proposed trial is a single blind, multisite, exploratory feasibility study of a pathway to long-term physical activity utilising a screening process, targeted recruitment and group-based exercise intervention (EPIC Club). The trial schema is illustrated in Figure 6.1.

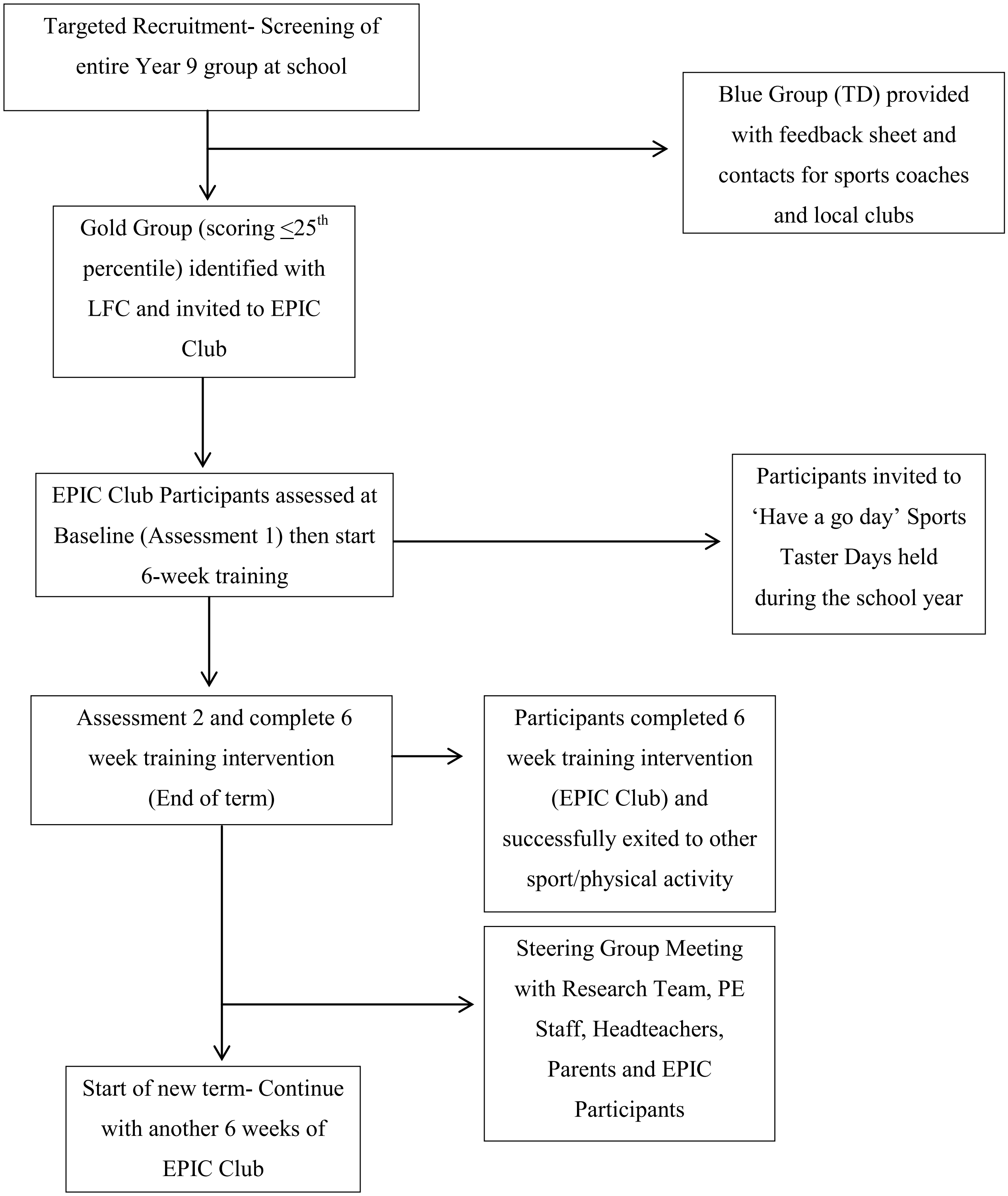


Figure 6.1 Study flow diagram illustrating screening and implementation of EPIC Club programme for Year 9 students. The Gold Group included individuals scoring ≤25th percentile during the screening sessions and identified with LFC and invited to EPIC Club. The Blue Group included individuals scoring >25th percentile during the screening and identified as TD. LFC, Lower Fitness and/or lowest sporting coordination skills; TD, Typically Developing

Based on the theoretical underpinnings of the COM-B model (Michie et al., 2011), a special screening process was adopted and implemented within school settings to identify adolescents with LFC and to deliver a 6-week exercise intervention (EPIC Club) to the selected participants. During the recruitment process, we aimed to provide an opportunity to motivate students during the screening phase and encourage individuals scoring in the $\leq 25^{th}$ percentile on fitness assessments (LFC group) to participate in EPIC Club. We focused on developing an individualised approach to increase PA, in which interpersonal interactions with the coach, peers and gym setting created a novel opportunity for engagement. Throughout the intervention, participants were encouraged to increase volume, repetition and intensity during the sessions. Incentives including EPIC Club t-shirts, vouchers and 'Bring-A-Friend' Days were offered to participants upon completion of the 6-weeks.

6.3.2 Participants

Three schools within Oxfordshire agreed to participate in the Community Sport Activation Fund (CSAF) initiative funded by Sport England (Ref: 2013018570) titled the EPIC Study (Engagement, Participation, Inclusion and Confidence in Sport). The trial was carried out in Year 9 Students (aged 13-14 years) within schools gym facilities and in one school, which had no facilities; the intervention was delivered at the Oxford Brookes University Clinical Exercise and Rehabilitation Unit (CLEAR) Unit.

6.3.3 Randomisation procedure

For practical reasons half of the schools participating were intended to be randomised into a delayed entry control group and enter the study the following term. However, given that this was the pilot stage of the study, no control group was required. As part of the feasibility, all participants enrolled in the study were allocated to the experimental arm (a group of participants that receives the intervention that is the focus of the study) with no control group or active comparator arm in this pilot phase of the study.

6.3.4 Recruitment

For this feasibility trial, we aimed to successfully identify individuals scoring in the bottom fourth of their Year 9 class on gross motor and fitness screening measures based on normative values established for UK adolescents and relative to overall class average scores (LFC Gold Group) (Figure 6.2). Following the screening sessions, all students were provided with a coded ID number and the data was analysed and input electronically via an encrypted database. Only the research team and head PE teachers had access to the data. Prior to distributing invitation letters for the selectively identified students to join the EPIC study intervention, a list of potential participants to recruit was discussed with the head PE teacher to ensure agreement/confirmation on screening test results and general PE performance at school. We went through the participant list and confirmed the next steps to provide feedback to the class and recruit the selected students. Once the final list was generated, an invitation letter and information sheet packet was distributed to the selected students and feedback using a spider-web format of individual performance on the fitness tests was provided to the entire Year group. The research team also organised an assembly to meet with the target group students to discuss details about the EPIC Study and to answer any questions or concerns. Furthermore, a parent information night was also planned to meet with parents/guardians interested for their child to participate. During the information meetings, the EPIC team discussed the goals and purpose of the study and emphasised the opportunity to develop new skills, try new exercises and build-up confidence within a group setting. Feedback regarding the best days/time slots to run the EPIC sessions was also discussed.

6.3.5 Inclusion and exclusion criteria

Participants were eligible to take part in the study if they met the following inclusion criteria: (1) individual must be able to walk with or without support for at least five metres and (2) be able to follow instructions safely. Furthermore, the participant should be able to mount a cycle ergometer with or without assistance. The exclusion criteria for this study included any behavioural issues that would prevent safe participation, put the participant, investigators and others at risk and/or any contraindications to perform maximal exercise. Adolescents diagnosed with a muscular degenerative condition were excluded from partaking in the study. Individuals with a diagnosis of asthma, diabetes and epilepsy were free to participate as long as their medication was stable (i.e., on medication for a period of at least 12 weeks). In addition, participants with asthma were asked to bring their inhaler to the screening PE sessions and EPIC Club sessions. Motor skill level was assessed during the screening day session and the head PE staff at each school was asked to distribute a General Health Screen questionnaire (PAR-Q) (Appendix D) to be completed by a parent/guardian prior to the start of the study.

6.3.6 Ethics statement and consent

The University Research Ethics Committee approved the study (UREC Registration No: 140844) and the trial registered under ClinicalTrials.gov on 08 June 2015 (NCT02517333). Permission for 'opt in' was granted by the schools' headteacher and written and parental 'opt out' consent was gained for all participants for screening (Appendix I). Information sheets were sent out to parents directly from the school and included the rationale for the screening days. Following the screening, a separate participant information sheet and informed consent form was distributed to parents/guardians of students invited to take part in the EPIC intervention (Appendix L and M). Informed opt-in consent (Appendix M) was further obtained from all participants' parents before the start of the intervention. Following the Helsinki Declaration (1964) recommendations for research on human participants adopted by the 18^{th} World Medical Association and later revisions (Association, 2014), parents and participants were informed that withdrawal from the study at any point would have no detrimental impact on their performance at school.

6.3.7 Screening sessions

Following distribution of the EPIC screening letter and opt-out consent forms to the Year 9 students and parents, the research team organised screening sessions held within PE lessons. The entire year group was measured. Depending on the size of the class, each screening session was designed to test a portion of the students with males and females split into two groups (approximately 35-40 students each). For instance, on the first screening session, all males were designated to perform the aerobic fitness test (i.e., Chester Step Test; Buckley, (2004)) (Chapter 5) and the females were divided into smaller groups of 5-8 and instructed to rotate around a five station circuit comprised of different motor skill tasks and fitness tests (Appendix J). The two sides would then crossover and perform the alternate assessment from the previous session to complete the full fitness screening. Although PE lessons were designated a one-hour time slot, the session was essentially reduced to 35 min when including time for the students to get dressed into their PE kit. A range of measures of fitness components carefully selected (Chapter 3) were assessed during the screening including: coordination, agility, power, muscle strength and aerobic fitness (Table 6.1). The specific tests to measure each of these components were selected based on its suitability for field-testing and the normative data available for the fitness measures. To assess movement skills, School A performed the entire Bruininks-Oseretsky Test of Motor Proficiency Short Form (BOT-2 SF, Bruininks and Bruininks, (2005)) however, the 14-items were reduced to dribbling, balance beam and penny transfer for School C based on calculations showing the subtests that correlated the most with their total score. Overall, the tests/measures selected had to be efficient but also meaningful for assessing fitness levels/motor skills of these students. Moreover, each test was previously piloted during Gifted and Talented Day (G&T) involving students aged 13-16 from participating schools in Oxfordshire.

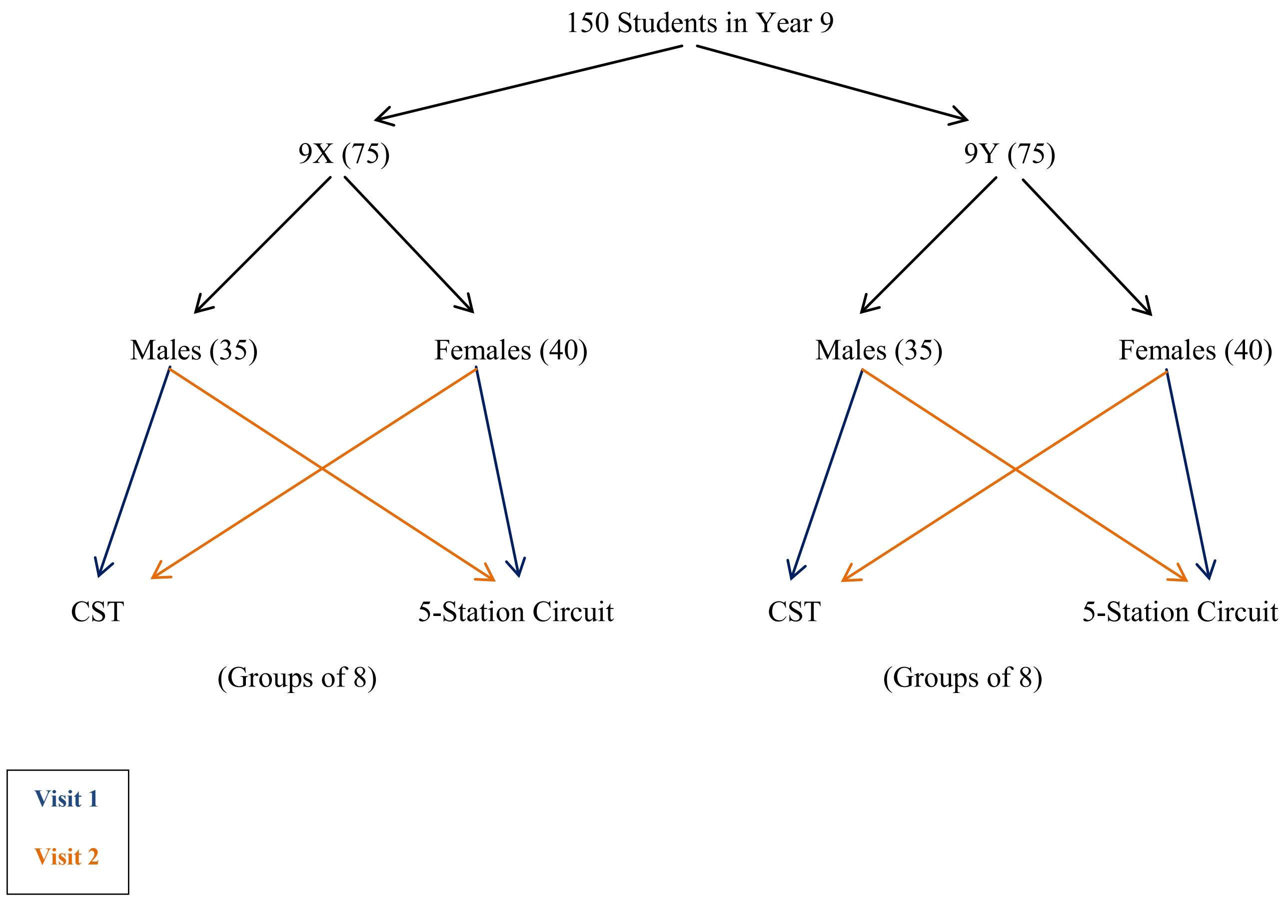


Figure 6.2 Illustration of Year 9 group split and cross-over design of testing over multiple PE lessons/screening sessions. CST, Chester Step Test (Buckley, 2004).

During the screening, each student was given an identification number and marked with it on their hand or a sticker at the beginning of the PE lesson. Once the students were given a number they were seated in the sports hall for a brief introduction to the research team and given an explanation of the purpose of the screening and what to expect. Next, the males were asked to perform the Chester Step Test (CST; (Buckley, 2004)) (protocol described in Chapter 5) at one end of the sports hall while the females were divided into smaller groups of 5-8 and rotated around a circuit consisting of eight stations on the opposite side of the sports hall (Table 6.2). Full details and instructions for each assessment are described in the EPIC screening guide (Appendix J). For the circuit, a trained tester supervised each station and recorded the scores for each student using the ID number provided at the beginning. A PE staff member was asked to fill out a registrar list with the students' full name matched to their number to ensure the data could be input and decoded later.

Table 6.2 Outline of stations for screening sessions

Screening session 1	**Screening session 2**
Station 1: 10-metre shuttle run (Bianco et al., 2015; Verschuren & Takken, 2010)	
Station 2: Grip strength, finger tap (Bohannon, 1986)	Chester step test (CST) (Buckley, 2004)
Station 3: Dribbling ball, catch-and-drop, jumping in sync (Bruininks & Bruininks, 2005)	
Station 4: Penny transfer (R.H. Bruininks & B.D Bruininks, 2005)	
Station 5: Balance beam, hopping, walk on straight line (R.H. Bruininks & B.D Bruininks, 2005)	
Station 6: Height/weight (De Migel-Etayo et al., 2014)	
Station 7: Vertical jump test/standing broad jump (Castro-Pinero et al., 2010)	
Station 8: Drawing (R.H. Bruininks & B.D Bruininks, 2005)	

6.3.7.1 Post-screening data analysis and feedback

Following completion of the screening, the data was de-identified and re-coded with their given ID numbers for entry into the database. A separate tab was used for each of the stations and then collated at the end. Once all the raw scores were inputted to a corresponding ID number, the percentiles for each score was calculated based on normative data values determined for each fitness measure. Subsequently, the raw score for each student was compared to normative scores and further allocated to a percentile category of 20th, 40th, 60th, and 80th and above percentile. As part of the EPIC aims, individuals scoring below the 25th percentile on at least 3/6 screening assessments were considered the eligible participants to recruit for the training intervention for the next phase of the study. In order to be able to compare the raw scores and adeptly discuss particular scores within the group, z-scores were generated in addition to the average (AVG) and standard deviation (STD). The z-scores indicate whether a particular score is equal to the mean or how far above or below (reference). Once z-scores were created for each column of data, it was sorted smallest to largest (value) for all measures except under agility, in which a lower score actually represented a faster time. After the z-scores were calculated, the first 1/4th (i.e., 30-40 IDs) of the list was highlighted. Because this was a feasibility study, percentages (i.e., bottom 25th to 30th percent of the class) were used Correspondingly, it was important to highlight the first 1/4th of scores because each time the next test measure data was sorted, all other data columns were sorted as well. Therefore, this process was performed for each test measure then collated side by side to assure that all columns could be compared and looked at (Appendix T).

After all data was inputted, feedback sheets (Appendix N) were generated for every student who took part in the screening. The feedback format was based on a 6-point spider-web shape, which was generated by allocating a number ranking for each fitness component to each level of the web (6=best, 1=worst). Therefore, regardless of how each individual performed on the fitness tests, the feedback was relative to the individual and provided students a picture of their strongest fitness components. Once the feedback sheets were completed, a short assembly was arranged with the Year 9 class and a research member explained the sheet and what the different fitness components were. Furthermore, after the researchers identified individuals scoring below average on 3/6 screening assessments, a list of names were compiled and sent to the head PE teacher for deliberation. The lead researcher then set up a meeting to discuss the screening results with the head PE teacher to confirm the list of students invited to join EPIC.

6.4 The EPIC intervention

'EPIC' consists of exercise training elements aimed to improve fitness and physical activity levels and enhance confidence within gym settings (Table 6.2). Effectively, the intervention was designed to enable participants to increase volume and intensity of exercise at a pace that they felt manageable and comfortable with performing over the 6 weeks. More specifically, the intervention followed the COM-B model (Michie et al., 2011) to create opportunities and motivation to participate in PA. We focused on developing an individualised approach to increase PA, in which interpersonal interactions with the coach, peers and gym setting created a novel opportunity for engagement.

6.4.1 Outcome measurements

The primary outcome measures focused on the screening process to identify and successfully recruit adolescents scoring in the bottom 25^{th} percentile of their class (LFC). Evaluation of recruitment and delivery of intervention was also assessed based on number of participants attending sessions and adherence rates. Lastly, a pilot of the delivery of EPIC Club gym intervention to improve fitness parameters was determined from post-exercise training results. These findings will also provide insight on the feasibility and efficacy of the intervention.

Secondary outcome measures were used to quantify PA levels and quality of life (QoL) and well-being using questionnaires at the start of the intervention. Furthermore, an economic evaluation of paediatric QoL and well-being used by the NHS to aid in decision making and cost utility analysis of interventions was explored using 'The Child Health Utility 9D' (CHU9D; University of Sheffield, UK) (Appendix Q). The CHU9D has been developed and validated exclusively with children age 7-17 years old and is intended for self-completion of nine questions asking children and adolescents to value a selection of health states from a recall period of today/last night. In addition, a PA audit questionnaire (PAQ-A) (Appendix R) comprised of 23 questions was incorporated to capture a general picture of the participant's level of PA over the past 7 days. This questionnaire has demonstrated a moderate convergent validity to overall PA measures in adolescent children (r=0.73) (Kowalski et al., 1997).

6.4.2 Pre- and post-intervention assessments

The assessments were administered at baseline (pre-) and post-intervention. At the start of EPIC Club, the participants were provided with details regarding the assessment procedures. Signed informed consent forms were collected and a participant Physical Activity Readiness Questionnaire (PAR-Q) was filled out with a researcher at the start of each assessment visit. Blood pressure was taken (Omron M3, Japan) at the start of the session to ensure the participant was within a normal range (120/80-140/90 mmHg systolic over diastolic blood pressure) and able to safely perform exercise.

6.4.2.1 Anthropometrics

Height (Holtain stadiometer), weight (Seca scales) and body mass index (BMI) were recorded prior to the fitness assessments. Level of maturation was assessed via the self-reported Tanner Scale (Tanner, 1962) (Appendix G) as described in Chapter 4.

6.4.2.2 Movement skill

Individuals were classified on the level of movement skill using the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2 SF) (Bruininks and Bruininks, 2005) previously mentioned in Chapter 3. The descriptive categories used for the interpretation of BOT-2 SF results include 98% or greater (70> standard score) is defined as well-above average, 84-97% (70-60 above average), 18-83% (41-59 average), 3-17% (31-40 below average) and 2% or less (30 or less well-below average) (Bruininks and Bruininks, 2005). Participants invited to join EPIC performed in the bottom 25^{th}-30^{th} quintile on the adapted subtests of the BOT-2 SF and/or on the other standardised fitness tests during the screening. However, a full assessment of movement skills on the BOT-2 SF provided the researchers with a better depiction of the participants' baseline characteristics.

6.4.2.3 Strength

As previously delineated in Chapter 3.9.3.1, an analogue handgrip dynamometer (Takei 5001, Takei Scientific Instruments Co., Ltd, Japan) was used to measure strength. Participants were asked to place their fingers over the handle and thumb supporting the device and trained testers adjusted the dynamometer to fit accordingly. The dynamometer was adjusted to start at 0 and the participant was instructed to hold the device with their dominant hand straight up above their head. Then, they were asked to squeeze as hard as they could, swinging the dynamometer down to their side. The score was read in (kgf) and the best of two attempts was recorded (Chapter 3.9.3.1). Furthermore, maximal voluntary isometric contraction (MVIC) and leg muscle torque was assessed on a special isometric strength-testing chair (Morris et al., 2012; O'Leary et al., 2015) portably with their right leg positioned in a 90˚ angle of knee flexion and the rotation of axis of the strength chair apparatus aligned with the knee axis. To prevent upper-body movement, participants were asked to cross their arms with the hands placed on the shoulders during the contractions. Once situated, each participant was instructed to perform a one rep-max (1 RM), pushing their right leg as hard as possible and holding that position for 3 s followed by a 30 s rest between each repetition. Verbal encouragement was provided throughout the test to attain maximum force and visual feedback of the torque output was provided during the tests.

6.4.2.4 Cardiorespiratory fitness

The Åstrand cycle test (A-R) (Astrand, 1952) is a submaximal method administered conjointly with the Åstrand-Rhyming Nomogram technique (Astrand & Rhyming, 1954) to assess cardiorespiratory fitness (CRF) and estimate peak oxygen uptake ($\dot{V}O_{2peak}$) at baseline and post-intervention (see Chapter 5). For School B, the A-R test was performed on a standard gym bicycle, which was calibrated and validated to the bicycle ergometer (Monark 818E, The Netherlands) used in the laboratory. The protocol is described in full detail in Chapter 5.3.5.

6.4.3 The EPIC Club intervention pilot

The EPIC Club gym intervention was offered 1-2 times weekly over the course of 6-weeks from November 2014 to July 2015 with staggered start times across the schools. The research team organised the 6-week intervention block out of a total of 8 weeks dates to start and end around half-term dates planned for each school. Once the session time slots were agreed on by the EPIC coach, staff members and PE teachers, e-mail reminders were sent out to the participants using their school e-mail addresses and text messages where possible. Furthermore, PE teachers were asked to remind the students about the EPIC sessions prior to the start. The exercises were designed and directed by experienced sports coaches/instructors from Oxford Brookes University. For School A, the training took place in the CLEAR Unit, which is an indoor gym located at the Oxford Brookes University Sports Centre. However, to accommodate ease of transportation for School B and C, the training was held on-site the school's gym facility. The equipment varied to some extent from each facility, however, the exercises planned for each intervention session was identical for each school. Each session started with a 20-25 min warm-up consisting of cardio/aerobic exercise including cycling, treadmill running and/or elliptical cross-training (see Table 6.3). Then, participants joined the main section of the session consisting of circuit style format whereby each person spent 2 min on each station guided by a trained instructor, then rotated to the next station lasting for 25-30 min total. Towards the end of the session, the participants gathered into a group circle and concluded with some cool-down stretches for 5-10 min as described in detail in Table 6.3.

Table 6.3 Description of elements in the EPIC Club gym intervention

	Exercise	Description
Warm-up (20-25 min)	Cycling	Pedaling 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
	Elliptical/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.
Main section (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 (HR_{max}).
	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 scaption 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 4 kg to 30kg 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 bending 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.

6.4.4 Fidelity and field observations

Implementation fidelity is critical to the successful translation of evidence-based interventions into practice (Breitenstein et al., 2010). To assess the intervention fidelity or extent to which the intervention is delivered as it was intended (Gearing et al., 2011), we aimed to record HR throughout the EPIC Club sessions and monitor the progression of sets/reps of each exercise using records and diaries.

Similar to the pilot study protocol conducted by Westergren et al. (2016), field observations in this study focused on fitness assessments pre- and post-intervention and the six EPIC Club exercise sessions observed during the intervention period. The lead investigator had previous experience working in clinical settings and volunteering as an exercise instructor in the CLEAR unit and gym programs within local schools conducted all test assessments and observations of the training sessions. The objective of the observations was to observe and examine the participants' interaction with their peers and instructors. The aspects of their interaction and opinions/discussions regarding how they found the training session and what they hope to achieve within the session was explored as an anecdotal measure of their progression throughout the study. Particular facets the researchers focused on include their level of participation during the different activities (i.e., level of intensity and HR), impressions about the different exercises and their peers attending the sessions and in particular their competency to perform the activities.

During the field observations, the researcher assumed an ‘observer-participant’ role (Hammersley & Atkinson, 2007) by participating in the activities to make the participants comfortable with her presence. Although the researcher did not interfere with the instructions, she assisted in running the sessions and participated in the warm-up endurance exercise, main circuit activities and the cool-down at the end. Immediately following each session, field notes including memos and analytical notes were written for documentation (Hammersley & Atkinson, 2007; Westergren et al., 2016). Any observed interactions and behaviours noted during the sessions were discussed during focus groups, steering group meetings and among the research team to improve and gain insight into the development of the study.

6.4.5 Sample size

This was a proof-of-principle pilot study in the feasibility and developmental phase of EPIC and therefore, a sample size and effect size was not pre-determined. Feasibility results cannot necessarily be generalised beyond the inclusion and exclusion criteria of the pilot design (Leon et al., 2011). Results from this initial phase can inform feasibility and identify modifications needed in the design of a larger, ensuing hypothesis-testing study. Sample sizes between 25-50 participants have been recommended to estimate standard deviations in outcome measures for use in future sample size calculation (Browne, 1995; Julious, 2005; Sim & Lewis, 2012). Loss to follow-up including dropouts and missing data will be discussed in the results (Chapter 6.5.4).

6.4.6 Data management

Each participant was provided with an ID number prior to data collection to ensure data protection. All assessment and intervention data was collected on data collection sheets and entered directly into a study-specific database by the research staff. The database was accessed via password-protected laptops. Paper versions of the screening and intervention assessments were kept in a secure room as a backup.

6.4.7 Analysis of data

Baseline characteristics were analysed using descriptive statistics and expressed as mean ± SD. Descriptive and frequency statistics were reported for recruitment and adherence data. Quantitative data for pre-and post-intervention assessments were performed via independent samples t-test in SPSS 22.0 (SPSS Inc, Chicago, IL, USA).

6.5 Results and Findings

The novelty of this study emanate from a pathway devised to identify the desired population group (LFC) through a unique screening process and targeted recruitment method. In addition to improving fitness parameters and building confidence within gym settings, the primary goal was to provide opportunities for the participant to try new sports and activities; providing the resources both internally and externally to enable longer-term participation in PA. For this thesis, the dissemination of results only included School A and School B due to the timing of data collection and the circumstances surrounding School C's end of term/exams dates, which affected their participation during this feasibility phase. A flow diagram describing the results and number of participants involved at each stage of the study is illustrated below in Figure 6.3.

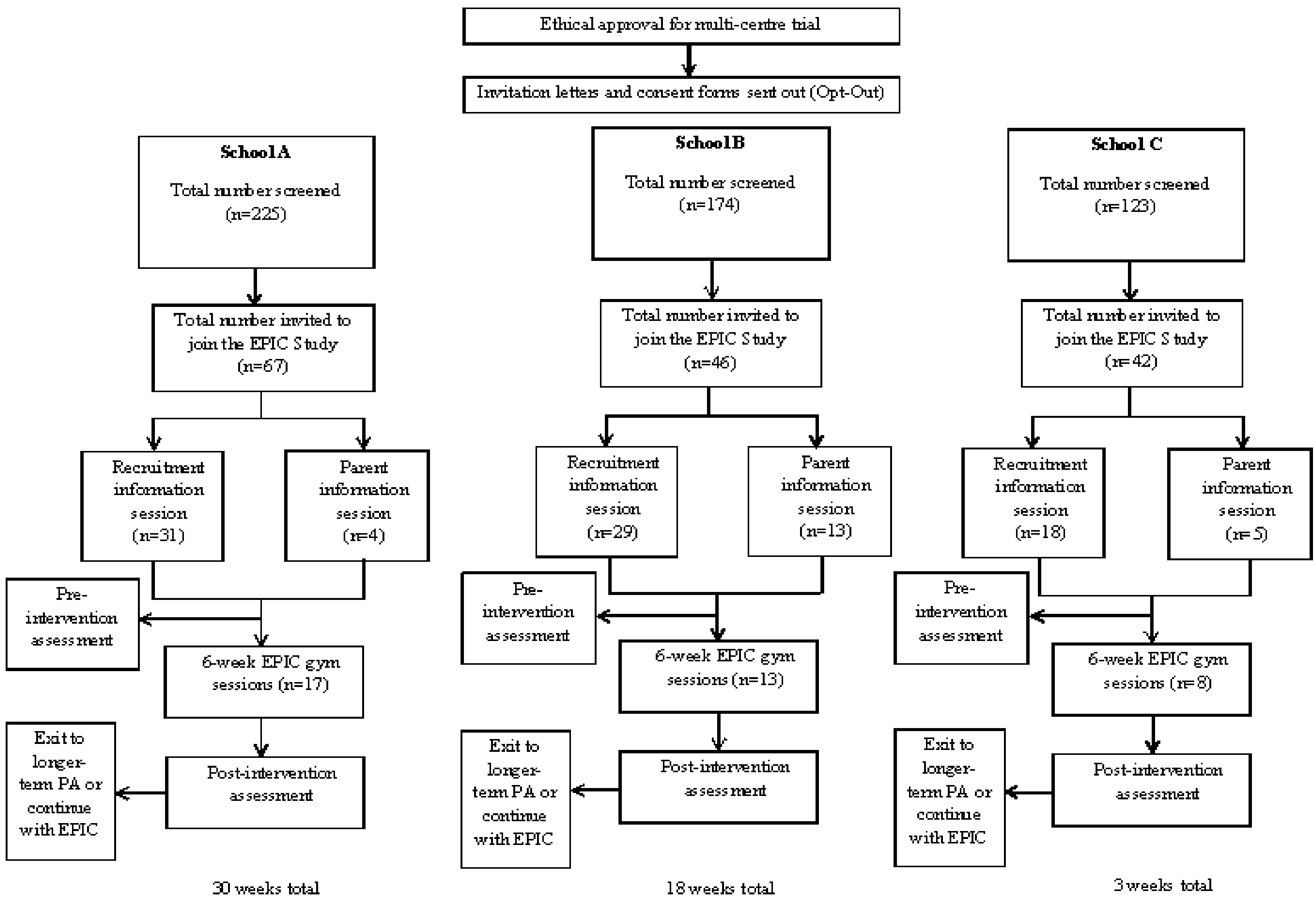


Figure 6.3 Flow diagram of the results for Schools A, B and C for each stage of the study from screening to recruitment and continuing to the EPIC intervention.

6.5.1 Screening and recruitment

A total of 552 Year 9 students participated in the screening. For Schools A (n=225), B (n=174) and C (n=123), two screening sessions were required to test the entire Year 9 class. Based on the results, the individuals scoring in the bottom 25th percentile of their class were identified as LFC and recruited to join the EPIC study (School A: n= 67; School B: n=46; School C: n=42). Invited students were asked to attend an informational meeting during lunchtime arranged by their head PE teacher to meet the research team and to learn more about the purpose of EPIC Club (School A: n=31; School B: 29; School C: 18). Additionally, at School B, 13 parents/guardians attended the information night however, a lower turnout was observed for School A (n=4) and C (n=5).

6.5.2 Baseline characteristics

A total of 38 participants signed-up for EPIC Club (School A: n=17; School B: n=13) but no results were included for School C (n=8) due to the intervention period terminating prior to the full 6-weeks. Baseline characteristics of participants from School A (males=2, females=15) and B (males=2, females=11) are illustrated in Table 6.4. Overall, mean age for both schools was 13 years old (A: 13.0 ± 0.50; B: 13.0 ± 0.40 years old). School B demonstrated a slightly higher average BOT-2 SF raw score (63 out of max score 88) and standard score (38.0 ± 5.0) compared to School A (raw score = 61/88, standard score = 36.0 ± 3.0) but were not significantly different.

Table 6.4
Baseline characteristics (mean ± SD)

N = 30	School A (n=17)	School B (n=13)
Age (years)	13.3 ± 0.46	13.2 ± 0.38
Height (m)	1.61 ± 7.7	1.64 ± 6.9
Weight (kg)	54.8 ± 7.9	60.3 ± 17.4
BMI (kg/m^2)	22.0 ± 0.0	23.0 ± 0.0
Tanner	5.0 ± 0.0	5.0 ± 0.0
BOT-2 SF Raw Score (/88max)	61/88	63/88
BOT-2 SF Standard Score	36.0 ± 3.0	38.0 ± 5.0

Abbreviations: BMI, body mass index; BOT-2 SF, Bruininks-Oseretsky Test of Motor Proficiency Short Form 2; Kg, kilogram; m, metre; Tanner, Tanner Maturation Scale

6.5.3 Pre-EPIC assessment

Prior to starting the 6-week intervention, participants performed pre-assessments to monitor progression throughout the sessions. Out of the total number of participants who joined EPIC Club, only 22 (School A: 15; School B: 10) took part in the pre-intervention assessment due to absence on the day of testing or participants starting later in the intervention. The tests were administered individually and conducted at the Oxford Brookes University Movement Science Lab for School A and in a quiet designated area of the sports centre facilities for School B. The pre-assessment results for the four fitness measures are illustrated below in Table 6.5. The pre-assessment results for the four fitness component are illustrated in Table 6.5. School A performed higher on leg (5%) and grip (37%) strength and balance beam (40%) compared to School B (Table 6.5). However, School B demonstrated a 19% higher $\dot{V}O_{2peak}$ (52.7 ± 11.1 mL/kg·min) in comparison to School A (42.7 ± 6.2 mL/kg·min).

6.5.4 Post-EPIC assessment

Following the sixth week of EPIC, the participants were asked to repeat the four fitness tests performed at the beginning for post-intervention assessments. Due to the timing of the assessments taking place towards the end of school term, only post-assessment data was collected for 8 participants from School A

(47% follow-up loss) and 7 participants from School B (53% follow-up loss). It is important to note that due to missing data from participants unable to attend the final assessment, the post-intervention results were limited and inconclusive. The efficacy of the exercise training on muscle strength, exercise capacity and coordination results are provided in Table 6.5. There were no significant differences found between pre- and post-training. There were no significant differences found between pre- and post-training. School A demonstrated an improved change (Δ) in leg strength (19%Δ) and grip (5%Δ) strength but no difference in balance beam performance. Interestingly, $\dot{V}O_{2peak}$ performance decreased by 2.2 mL/kg·min (5%) between pre- to post-assessment. Given the variability of the submaximal test, there is likely to have been any change here. For School B, there was a 20% improvement in leg strength and balance beam time (25%), but no difference in grip strength or normalised $\dot{V}O_{2peak}$ (Table 6.5).

Table 6.5
Pre-and post-EPIC intervention assessment characteristics (mean ± SD)

	Pre-assessment School A (n=15)	Post-assessment School A (n=8)	Pre-assessment School B (n=10)	Post-assessment School B (n=7)
MVIC peak torque (N·m)	78.3 ± 21.49	93.2 ± 24.8	74.3 ± 30.48	92.5 ± 15.4
Grip strength (kg)	27.5 ± 3.9	28.8 ± 4.0	20.1 ± 5.3	20.0 ± 5.8
Balance Beam (/30 s)	30/30	30/30	18/30	24/30
A-R ($\dot{V}O_{2peak}$) (L/min)	2.3 ± 0.2	2.22 ± 0.2	2.98 ± 0.3	3.17 ± 0.3
Normalised $\dot{V}O_{2peak}$ (mL/kg·min)	42.7 ± 6.2	40.5 ± 7.0	52.7 ± 11.1	52.5 ± 11.0

Abbreviations: A-R, Åstrand-Rhyming Cycle Test; MVIC, maximal isometric voluntary contraction; N·m, Newton-metre; $\dot{V}O_{2peak}$, peak oxygen uptake

6.5.5 Post-EPIC follow-up

The EPIC study gym intervention (EPIC Club) was designed to take place twice weekly for a total of 6-weeks. Once participants completed the intervention, those who desired to continue with the EPIC Club gym sessions were encouraged to participate until the end of the 30-week study period. From January to July 2015, six participants from School A continued attending EPIC sessions. Correspondingly, 11 out the 13 participants from School B extended their involvement with EPIC from April to July 2015. In total, EPIC sessions were offered for 30 weeks for School A while School B ran for 18 weeks. Three participants from School A reported that they started other after school sports activities including cricket, football and field hockey. For School B, one participant showed interest in playing rugby post-EPIC. Furthermore, during the intervention period, "Have a Go" Days and Sports Taster Days were organised by the Oxfordshire Sports Partnership (OSP) once or twice a term. These activity days were meant to provide EPIC-goers with an opportunity to try different sports and activities that they could pick up following the EPIC study period. One participant from School A attended the "Have a Go" Day and none from School B.

6.5.6 Evaluation of intervention delivery and attendance

The attendance rate during the EPIC Club intervention pilot was approximately 90%. For School A, one participant dropped-out after the first session due to health conditions. During weeks 2-4, two participants were absent from the gym session and in week 5 four participants were unable to attend due to other after-school commitments and/or illness. Following week 6, only eight participants attended the post-assessment testing. At School B, the EPIC sessions had a 60% attendance rate for weeks 4 and 5. For the post-assessment session in week 6, six participants were unable to attend the testing due to a school fieldtrip.

As part of the intervention feasibility and efficacy of the programme, we aimed to monitor the delivery of the EPIC Club sessions and record HR to capture the level of intensity participants achieved.

Consequently, the research team only managed to record HR for 2 out of the 6 sessions due to staffing shortages. For both schools, average HR (HR_{avg}) during the 20 min warm-up on the treadmill, bikes or ellipticals was 140 bpm for one session and 155 bpm (range 124-194 bpm; 65-95% HR_{max}) for the other. During the second half of the EPIC Club session, the HR_{avg} reached 177 bpm (86% HR_{max}) during the kettle bells station in one session and 179 bpm (87%HR_{max}) for the second (range 148-200 bpm). We intended to record and collect participant HR, number of sets/reps and rating of perceived exertion for each exercise throughout the intervention period. However, due to a shortage of team members/staff to assist the sessions and time constraints, this could not practically be performed.

6.5.7 Themes

A main theme describing the participants' experiences of everyday life and their participation in the EPIC Club intervention pilot was to gain insight and perspective towards barriers and constraints to engaging in sports and PA. Some of the responses provided anecdotally during the gym sessions were:

> *"I'm too tired. I have a lot of homework and don't have time to do sports when I need to revise." (Female, 14 years old from School A)*

> *"I've never tried running on a treadmill before. I really like it." (Male, 13 years old from School B)*

During within-session conversations with the participants, it was mentioned that they never utilised the gym kit nor performed the exercises introduced in EPIC because they were never allowed to use the gym. Several participants perceived attending the intervention sessions to be considered mature like adults and celebrities use the gym. Furthermore, the participants reported that it was not problematic to attend the EPIC Club sessions since they conveniently took place at the sports centre near their school.

6.6 Discussion

The objective of this study was to develop a 6-week community-based exercise training program (comprising mixed aerobic and strength exercises) for adolescents with MI and LFC recruited through a screening process, and to evaluate the feasibility and efficacy of this pathway. A main finding of this study was the successful recruitment strategy and engagement of the Year 9 students, which serves as a powerful pathway for adolescents within school settings. However, this was a short-term evaluation of the EPIC pathway and therefore little to no change was observed in fitness outcomes and the findings are still inconclusive.

To the authors' knowledge, this is the first feasibility pilot trial to assess the impact of a pathway to longer-term sport and PA in adolescents presenting with MI and LFC through a unique screening process and targeted recruitment conducted in secondary schools. The exercise pathway was safe and achieved exceptional screening, moderate recruitment of target group (20%), and high attendance rates (90%) during the intervention period with participants reaching desirable exercise intensities (ranging 87% target HR) in measured sessions. Completion of outcome measures in the school setting, particularly at the end of the intervention proved problematic and prospective research will require more resources and increased staffing are recommended for subsequent programmes to enable more monitoring and bespoke testing sessions. However our initial results are promising with potential benefit on a number of fitness components and a future trial implementing suggested amendments is warranted.

During the screening process, we incorporated components of the COM-B model (Michie et al., 2011) to pragmatically and strategically identify Year 9 students with MI and LFC, while motivating the entire class with the assessments and personalised feedback. In addition, it was important to involve the PE staff and parents with the recruitment process, which has been recommended by previous intervention studies (Dobbins et al., 2013; Sugden, 2007; Takken et al., 2009). In this feasibility study we successfully engaged 13-14 year old adolescents in PA, introducing a habit of regular exercise (minimum once a week, 45 minutes based on findings from the systematic review in Chapter 2). A main aim of the EPIC Club sessions were to introduce a larger number of young people in school to this pathway and build up lifetime patterns of PA and sport participation. According to the 2012 Health Survey England (2013), boys age 5-15 years were considered more physically active than girls, with 21% and 16% reaching the recommended PA levels respectively (WHO, 2012). With nearly less than 1/3rd of youth in the UK attaining sufficient levels of PA, this framework effectively screened and identified Year 9 students performing in the <25th percentile of their class (LFC). Based on the results of the fitness and movement skill tests specifically selected and adapted for screening within PE lessons, the assessments were suitable for identifying students performing in the bottom third of their class. The PE teachers played a crucial role in assisting the research team during the screening process and in arranging feedback assemblies and informational meetings. Similarly, it was important for the research team to discuss with the head PE teacher about whether the students who displayed LFC and reduced movement skills during screening were the appropriate individuals to invite to join EPIC. A number of additional recruitment mechanisms will be trialed and evaluated throughout this three-year study.

This pilot study identified 155/552 students screened (28%) performing in the bottom 25th percentile of their class on fitness and motor coordination components. Based on the screening results, 31 LFC adolescents were recruited to take part in the EPIC Club intervention, which accounted for 20% of the targeted recruitment. From there, 30 students took part in the pilot EPIC Club interventions therefore accounting for 25% of the target recruitment. Interestingly, participants taking part in the exercise intervention were predominately females, which is in agreement with the gender-based disparity in PA among youth observed in the literature (Hallal et al., 2012; Telford et al., 2016; Trost et al., 2002). Influences on PA at the school and family levels and extending through extracurricular sport participation are weaker in girls than boys (Telford et al., 2016).

Currently, it is unclear what school factors are most influential on PA despite one study in 92 British schools exploring different correlates of PA including school size, density location, availability and accessibility of sporting facilities (Telford et al., 2016; van Sluijs et al., 2011). Therefore, this study aimed to provide a feasible PA pathway to implement within schools to address the current challenges in MI and typically developing students. To further, girls were observed to have less favourable individual attributes associated with PA, including lower CRF and hand-eye coordination, higher body fat percentage and lower levels of perceived competence in PE (Telford et al., 2016; Whitehead & Biddle, 2008). These findings are in agreement with the screening data and recruitment numbers in this study illustrating a higher number of girls taking part. Correspondingly, recommendations to increase participation in adolescent girls include introducing peer mentoring schemes and providing activities that are informal and fun involving participation with friends (Whitehead & Biddle, 2008). In this trial, the researchers offered one session where participants were encouraged to bring a friend to EPIC Club however, future work should introduce this strategy more frequently and capture the social experiences between peer influences and group-based interactions.

Only brief accounts of what some of the participants reported as barriers and constraints to PA and sports were described in this study. Although the Coach and research team provided anecdotal observations of the sessions, written reports detailing the sessions and standardised recording of the frequency, intensity and duration of exercises should be documented for each session in the future. Staffing was a limitation to the delivery of the EPIC Club sessions and therefore remains a fundamental element to monitor for improving feasibility. As a consequence, HR monitoring was only featured for two sessions over the 6-week intervention period. Questionnaires including that PAQ-A and CHU9D were only completed and returned by three students. For future purposes, the questionnaires should be administered by a researcher and completed within the first gym session to capture self-reported PA levels and QoL/well-being measures. Moreover, individual interviews and focus groups with participants regarding the recruitment process and intervention programme may provide an open platform for ways to improve the pathway.

Input from EPIC participants may offer insight on fostering engagement in PA with the intervention, maintaining commitment and avoiding drop-out and developing and refining intervention design. Steering group meetings with students, PE teachers and parents should be conducted in the future to provide feedback and improvement strategies for implementation school-based research studies. In addition, the timing of the intervention period should be highlighted and taken into account for differences in attendance rates between schools. According to Collings et al. (2014), with regards to school term; light and moderate intensity physical activities were lower while sedentary time was higher by approximately 30 min/day in autumn and spring term compared to summer term. Although attendance rates remained relatively high (60-90%) throughout the 6-week pilot, extending the intervention period and monitoring the attendance and timing of the assessments may provide a better picture of the relationship between PA levels and school terms as evidenced in Chapter 2.

6.6.1 Future directions

Due to the feasibility phase of this study, the participants could not be randomised to a control group or active comparator arm as initially planned. However, based on the findings established in Chapter 4 and during this feasibility stage, the aim is to eventually incorporate a parallel design to the RCT whereby one group of participants (Group A) would receive the "high-intensity" training intervention and the other group of participants (Group B) could perform "lower-moderate intensity" continuous exercise simultaneously to identify any differences between the two training paradigms. According to the HRs measured in two of the sessions, the participants reached 65-95% maximal HR (HR_{max}) for their age. A study by Baquet et al. (2003), stated that exercise at the anaerobic threshold or at an intensity >80% of HR_{max} induces greater improvements in physical fitness compared with lower intensity exercise. Moreover, following an exercise intervention it has been suggested that level of intensity rather than mode of endurance-based activity is one of the most important factors for improving physical fitness (Ekelund et al., 2012; Wanrooji et al., 2014; Willis et al., 2015). Therefore, with proper technique training and exposure to a variety of mixed-training equipment and exercises, the EPIC Club intervention could be a viable option for improving PA levels during or after school and for limiting sedentary time behaviour (Foulkes et al., 2017). No significant differences were seen for the fitness outcomes assessed post-intervention, however, the researchers acknowledged that one session a week for 6 weeks is too short of a period to elicit any physiological changes. Numerous studies in the literature implemented physical exercise training programmes with a duration of at least 12 weeks and on average, 2-3 sessions per week for 45-60 min each to improve measures of fitness in children and young adults (Buchan et al., 2013; Dobbins et al., 2009; Duppen et al., 2013; Verschuren et al., 2008). Although 1-2 sessions were offered, the shortage of staff members made it challenging to run multiple sessions. Therefore, for this pilot phase, participants were only required to attend one session albeit evidence from the systematic review (Chapter 2) supporting a minimum of 2-3 sessions weekly for 10-12 weeks duration (Cacola et al., 2016).

The opportunity to try new activities and exercises was important in the design of EPIC for increasing PA among Year 9 students. For most participants, the circuit-style gym sessions were considered a novel activity they have never tried before or had the opportunity to. The research team wanted to incorporate a mixture of cardio and strength training exercises to improve performance, fitness and skill. It is acknowledged that muscular strength is important for effective movement skill performance and physical performance. Findings from a recent meta-analysis showed that progressive resistance training has been shown to be a safe and effective mode of exercise to improve muscle function, enhance movement skill performance (i.e., jumping, running and throwing tasks) and improve metabolic markers (Behringer et al., 2010). Further benefits include a sense of well-being, perceptions of changes to body image and functional competence (Goldfield et al., 2015). Despite a small increase in peak torque, no significant changes were observed in the fitness outcomes post-exercise training. We hypothesise that extending the intervention period to a minimum of 12 weeks or more may be required for any physiological changes to take place as supported by Cacola et al. (2016) and the systematic review conducted in Chapter 2. Participants were also encouraged to increase activity speed, volume, repetitions and duration of activities over the intervention period to continuously challenge them and generate improvements with their performance and technique weekly. Importantly, developing the confidence and competency to perform difference exercises may facilitate participation in sports and other leisure activities (Cairney et al., 2005).

6.6.2 Strengths and limitations

A strength of this study was the feasibility of the screening process to assess the entire Year 9 class within PE lessons and to identify adolescents with MI and LFC. The screening tests and recruitment strategy was a strong feature of this framework and future work utilising this pathway as part of a RCT (Foulkes et al., 2017) may allow researchers to better target populations most in need of PA promotion strategies. The pilot of the EPIC Club gym sessions in conjunction with 'Have a Go' Days and Sports Taster Days provided a novel approach for increasing PA and play and introducing our target group (LFC) to new exercises and training practices. However, prospective work should establish the benefits and potential negative effects of the EPIC intervention on measures of fitness, mood, self-efficacy and self-esteem to gain a comprehensive picture. Due to the short intervention period, no conclusive findings could be made regarding the effectiveness of the EPIC Club gym sessions. The next stage of the pilot should incorporate a control group and/or active comparator arm with proper randomisation procedures and matched for anthropometrics to determine the efficacy of EPIC Club. With regard to intervention fidelity, training diaries for participants and observational reports from the Coach and research staff will assist with quantifying and documenting training progression. On reflection, more qualitative work including small group interviews and focus groups with participants attending EPIC Club would further allow us to refine the programme before implementing the RCT.

6.7 Conclusion

In conclusion, we developed a pragmatic and novel approach to screen adolescent 13-14 year olds within school settings. The screening process was refined and evaluated during this phase on its suitability to identify and recruit individuals demonstrating MI/LFC into a 6-week gym-based intervention. Overall, the screening process was a robust strategy for engaging adolescents and motivating them with the battery of tests and feedback. Findings from this feasibility stage provided insight regarding adherence and participation throughout EPIC and post-intervention highlighting strong participation adherence and positive engagement between staff and peers. Further pilot research of the intervention should incorporate a control group and different exercise intensity groups for a longer training period and follow-up stage. Future work should further extend these findings and examine the effectiveness of the EPIC pathway on measures of fitness, well-being and applications for promoting longer-term PA.

7

General discussions and conclusions

7.1 Summary

The aim of this thesis was to explore the physiological and perceptual responses to acute and chronic longer-term exercise to better understand the multifaceted factors impacting exercise tolerance in children and adolescents with MI and to help inform the development of long-term exercise interventions in this group. A number of different approaches were undertaken, employing a range of acute and chronic exercise protocols and adapted testing from lab-based settings to field-based assessments. Firstly, a systematic review of the literature on interventions targeting physical activity (PA) and fitness in MI was performed to provide an update of the literature and an evaluation of intervention effectiveness. Chapter 4 examined the exercise capacity and neurophysiological mechanisms/responses during and following an acute session of high-intensity (HI) and low-intensity (LI) cycling in children with and without MI. In Chapter 5, the reliability and validity of submaximal tests to measure aerobic fitness in varying levels of MI for mass screening purposes was assessed. Chapter 6 extended the findings from the previous experimental studies and explored the feasibility of a pathway to longer-term PA and play in adolescents with MI and lower fitness coordination (LFC) using a targeted recruitment process and gym intervention focused on fitness components. This Chapter will provide an overview of the main findings of this thesis and the implications of these findings.

7.2 Main findings

The results of this thesis provide an important contribution to our understanding of the complexity of MI in children. In Chapter 2, several types of interventions to promote PA and exercise in MI were reviewed for methodological quality and treatment effectiveness on fitness outcomes. Motor skill proficiency/motor coordination and functional performance was most commonly assessed across the different interventions, highlighting the importance of incorporating PA and exercise strategies targeting development of motor skills and functional movement. Furthermore, only moderate evidence was found for sports training/therapy and skill development study designs for improving one or more fitness parameter. This was informative considering the consistent observations of poor aerobic fitness and muscle strength in children with MI (Faught et al., 2013; Morris et al., 2013; O'Beirne et al., 1994; Raynor, 2001; Rivilis et al., 2011). Consequently, reduced fitness levels early in life may impact PA patterns carried into adulthood and result in the development of cardiovascular diseases (Berenson, 2002; Twisk et al., 2002) and metabolic syndrome (Ekelund et al., 2007). Corroborating the findings of Ullenhag et al. (2014), youth with MI who do engage in PA and play often do so at lower intensities and fail to attain sufficient PA compared to typically developing (TD) peers. In fact, only three out of the 14 studies (Menz et al., 2013; Pesce et al., 2013; Tsai et al., 2012) captured intensity level with the consensus that interventions should monitor activity intensity to capture dose-response relationships of treatment or training and fitness improvements (Reilly et al., 2006). The current recommendations for achieving >60 min per day of moderate-to-vigorous physical activity (MVPA) (World Health Organization, 2010) may be an intimidating goal for children with MI (Janssen & Leblanc, 2010). Therefore, different strategies for accumulating sufficient PA, potentially including shorter bouts of higher intensity and sporadic type activity are warranted.

7.2.1 Exercise protocols and intensity level

Based on the evidence in Chapter 2, larger RCT studies with follow-up periods implemented in school-based and community settings may better elucidate the impact of interventions on fitness components in MI. Thus, Chapter 4 sought to highlight the findings of the systematic review and extend the results from a previous study by Morris et al. (2013) to address how children with and without MI respond and recover from different exercise intensities. One aim of the studies presented in this thesis was to investigate the efficacy of traditional endurance-based exercise and novel, high-intensity exercise in boys and girls presenting with MI and MD. There is accumulating evidence in the literature demonstrating the effectiveness of high-intensity interval activities including running, cycling and jump-roping to enhance measures of fitness in youth (Barker et al., 2014; Buchan et al., 2013; McNarry et al., 2015; Meßler et al., 2016). Although numerous studies have assessed maximal exercise performance and exercise capacity in MI (Farhat et al., 2014; Faught et al., 2013; Morris et al., 2013), to date, no study has explored the impact of short duration, high-intensity (HI) exercise bouts in this group. The evidence of their willingness to push themselves maximally in the study by Morris et al. (2013), warrants the potential application of such activity intensities to improve measures of cardiovascular health and movement. Moreover, as a consequence of the inefficient movement patterns and potential difficulties to performing running activities in children with MI, the use of cycle ergometry was considered to be a safe and feasible option for implementing HI exercise.

The exercise protocol in this study consisted of a maximal incremental bike test to determine peak oxygen uptake ($\dot{V}O_{2peak}$) followed by assignment of exercise intensity based on percentages of the participant's attained workload. Due to ethical constraints to incorporate blood and metabolic markers in children, the designation of exercise intensity was based on relative peak power (PP) whereby the HI cycling bout consisted of pedaling maximally for 30 s-on then no pedaling for 30 s-off at 100% PP ($PP_{100\%}$). In contrast, the low-intensity (LI) session was focused on endurance-based exercise in which participants were asked to cycle continuously for 30 min at $PP_{50\%}$. Furthermore, the randomised, crossover design ensured all participants had the opportunity to perform each intensity level while assessing heart rate and perceived exertion during and following into recovery. The post-exercise responses were important for establishing whether children with MI and without (NMI) experienced differences in recovery responses, which may affect the motivation or desire to perform the exercise. In fact, a crucial challenge for designing PA programmes and interventions in this group relates to compliance, willingness and enjoyment of the chosen activity for longer-term engagement. Additionally, constraints and barriers such as poor exercise tolerance, fatigue and perceived adequacy have been reported as limiting factors to participation in PA in MI (Barnett et al., 2013; CairneyHayFaughtWade et al., 2005). Therefore, in conjunction with electromyography (EMG) recordings, measurement of muscle strength using a reliable maximal voluntary isometric contraction (MVIC) protocol for children, provided insight regarding the impact of the exercise intensities on peripheral muscle fatigue and signs of cocontraction.

This study demonstrated that there was a significant relationship observed between level of MI categorised on the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2 SF) (Bruininks, 1978) and aerobic fitness ($\dot{V}O_{2peak}$). The use of physiological (i.e., heart rate, muscle strength, neuromuscular performance) and perceptual (i.e., rating of perceived exertion) measures during and following an acute bout of HI and LI-cycling provided insight on the underlying factors limiting exercise tolerance in MI. In general, children with MI exhibited a reduced exercise capacity due to weaker muscle strength/power, cocontraction (Raynor, 2001) and inefficient movement patterns (Faught et al., 2013). This was supported by the significantly lower MVICs compared to NMI pre-cycling and following into recovery at post-5 min (P5). The reliability of the MVICs suggest that the MI group were fully exerting their leg muscles but were potentially unable to fully recruit the muscle fibres (Raynor, 2001). Corresponding to the results of Raynor (2001), the MI group also displayed increased levels of cocontraction/coactivation (RMS agonist: RMS antagonist ratio; RMS_{MVL}/RMS_{MBF}) with a significant effect of intensity to HI baseline (MI: 1.83±0.52; NMI: 4.47±1.20 RMS_{MVL}/RMS_{MBF}) compared to LI baseline (MI: 1.93±0.57; NMI: 3.48±1.59 RMS_{MVL}/RMS_{MBF}). In the literature, children with DCD are likely to experience earlier fatigue due to reduced motor unit recruitment and muscle activities of agonists and antagonists (Farhat et al., 2014; Raynor, 1998). However, contrary to former studies, the MI group did not demonstrate muscle fatigue following HI cycling, which may have been an artifact of the exercise dose.

Notably, limitations to exercise performance in MI was further suggested to be attributed to more central factors such as motivation and perceived adequacy as illustrated by the lack of differences in perceived fatigue and muscle fatigue compared to TD controls following HI and LI exercise. In addition to strategies to improve fitness levels, self-efficacy and perceived adequacy to participate in PA and play remains an important area of focus in MI (Barnett et al., 2013; Cairney et al., 2005). Although there were only anecdotal reports of the participants enjoying the HI bout, all exercise sessions were well tolerated by both groups. In particular, the ability of the MI group to perform both intensities highlights the potential for both endurance training and intermittent HI exercise to feasibly improve fitness. As an alternative to moderate-intensity exercise, HI bouts may be better suited to the sporadic and intermittent nature of play in young people and represent an attractive strategy for increasing fitness (Buchan et al., 2013) and metabolic health benefits (Thackray et al., 2013). However, its implications and sustainability for improving health and well-being over time still remains to be explored in the subsequent chapters.

7.2.2 Reliability and validity of submaximal protocols

Chapter 5 consisted of the reliability and validity of submaximal exercise testing to establish the applicability of laboratory-based to field-based assessments of aerobic capacity in varying levels of MI. Previous studies have utilised the Chester Step Test (CST), Åstrand cycle test and Åstrand-Rhyming (A-R) nomogram technique to estimate aerobic fitness in healthy populations (Andersson, 2004; Buckley, 2004; Noonan & Dean, 2000). In this study, the A-R method overestimated true $\dot{V}O_{2max}$ by 10-15% but demonstrated moderate reliability (r=0.84) which is in agreement with studies in healthy individuals (Jessup et al., 1977; Jette, 1979) and in children aged 11-12 years old (Ekblom, 2014). Furthermore, estimated $\dot{V}O_{2max}$ from the CST exemplified a good correlation (r=0.81) with direct measurement of

$\dot{V}O_{2max}$ and may be a suitable test modality for field-based screening (Buckley, 2004; Stevens & Sykes, 1996) The A-R method can be reliably and straightforwardly used as a measurement tool to detect improvements in aerobic fitness across varying levels of motor skills and MI in youth, whereas the CST can only be confidently proposed for use in TD individuals from this study. A main component of the CST relates to stepping rhythm, which may be problematic for children with poor coordination. Further research should aim to quantify coordination and movement on using accelerometers, inertial measurement unit sensors while performing the CST or a stepping task with a metronome beat. Moreover, the recommendation for the A-R cycle test and CST to prescribe exercise intensities based on the association between heart rate and perceived exertion still requires further validation for its transferability to other activities (Buckley, 2004). Nevertheless, taking the limitations and age-correction factors into account, the A-R method is an appropriate submaximal alternative to the gold standard $\dot{V}O_{2max}$ test and the CST provides an innovative and entertaining fitness test for use in school settings.

7.2.3 Feasibility of targeted screening and gym intervention pathway

In Chapter 6, the findings from Chapters 2, 4 and 5 were applied to the design of a specialised screening process to identify adolescents (13-14 year olds) demonstrating lower fitness coordination (LFC) and movement difficulties. The second part of the pathway consisted of a group-based gym intervention to improve fitness components and longer-term engagement in PA and sport. As presented throughout this thesis, youth presenting with incoordination and MI, which affect the performance of motor skills, endurance, strength and power, often participate less in sports and PA. Correspondingly, given the rise in obesity and alarming risk profiles associated with falling activity levels in this target group, it was crucial to provide lifestyle and behavioural strategies. Moreover, as previously ascertained, there is a need to promote more participation and evaluation of vigorous-activity PA particularly in adolescents (Buchan et al., 2013; Collings et al., 2014; Janssen & Leblanc, 2010). Based on the results of Chapter 2, there was a moderate to inconclusive level of evidence pertaining to interventions targeting school settings. However, fully powered RCT with qualitative and quantitative outcome measures may improve the evidence and feasibility for supporting school-based settings. Additional research exploring the development, execution, implementation and feasibility of intervention pathways to improve fitness parameters in MI needs to be further addressed (Ekelund et al., 2007). Therefore, this final study was a proof-of-principle pilot study aiming to provide a pathway to engagement, participation, inclusion and confidence (EPIC) in sport and PA in adolescents with MI.

In the literature, most intervention studies on MI have focused on younger aged children (i.e., 6-12 years). However, this study solely targeted Year 9 Students (13-14 years old) who were identified with LFC and lower fitness performance relative to their class peers. The pathway was underpinned by recruitment and training theories (Capability, Opportunity, Motivation and Behaviour model; COM-B model) (Michie et al., 2011) in which we went into the school and motivated the students with a specialised circuit-style testing and follow-up with feedback of their performance. This unique approach involved PE teachers and parents with the recruitment process and emphasised engagement in a 6-week gym-based intervention to improve fitness, confidence building and perceived adequacy (Chapter 6). Furthermore, the opportunity to try new activities and exercises was important in the design of EPIC for increasing PA among adolescents. For most participants, the circuit-style gym sessions were considered a novel activity they have never tried before or had the opportunity to. Provided that, we wanted to incorporate a mixture of cardio and strength training exercises to improve skills and performance in MI based on the findings in Chapters 2 and 4.

In general, the screening tests and recruitment strategy of the EPIC study was a novel method for identifying young people presenting with LFC. Future work utilising this pathway as part of a RCT may allow researchers and clinicians to better target populations most in need of PA promotion. There were insignificant changes in fitness outcomes from pre- to post-intervention demonstrated during the 6-week intervention period. However,

however, the EPIC Club sessions were in its pilot phase and only one to two sessions were offered per week for 6-weeks. As revealed in Chapter 2, a minimum of 2-3 sessions per week for a period of 12 weeks is recommended for beneficial effects on aerobic fitness, body mass index and cardiometabolic markers (Buchan et al., 2013; Dobbins et al., 2013; Duppen et al., 2013; Verschuren et al., 2008). In addition, more research assessing the impact of school-based PA interventions and after-school programs on intensity levels, PA rates and personal development needs to be prioritised. Interviews and steering groups with participants, teachers and parents may better provide feedback and suggestions for improvements. Despite the limitations, findings from this feasibility stage supports the contention of designing interventions within school settings as demonstrated by the high adherence/attendance (90%) and participation rates throughout EPIC and post-intervention. Noteworthy, many students continued to attend the gym sessions up until the end of the 30 week time frame; highlighting the potential framework of EPIC as a long-term PA strategy in adolescents.

Overall, the gym sessions were well received and participants managed to achieve heart rate levels between 65-95% maximal heart rate throughout the cardio activities and strength training exercises during monitored sessions. The next phase of the EPIC pathway should incorporate a control group and different exercise intensity groups (i.e., HI training vs. endurance-training) for a longer training period to better elucidate the results in Chapter 4 in children and adolescents with MI. To further, although Sports Taster Days and 'Have-a-Go' events were organised by the Oxfordshire Sports Partnership to foster engagement with EPIC participants and the community, more opportunities enabling youth to try different sports and activities is encouraged.

7.3 Heterogeneity of MI

A common theme highlighted throughout this thesis was the substantial variability in the participants taking part. Due to the heterogeneity of motor skill levels, functional abilities and movement deficits presented in MI, the type of effective interventions may vary from child to child (Chapter 2). Therefore, a more ecological approach taking into account personal, contextual and environmental factors (Sugden, 2007) is crucial for exercise prescription and intervention design. Given that MI and movement difficulties (i.e., DCD) affects nearly 5-9% of children (Cairney et al., 2005), the EPIC study pathway feasibly identified 155 students out of 552 screened (28%) performing in the bottom fourth of their class (Chapter 6). Moreover, 30 students successfully took part in the EPIC Club gym intervention; accounting for 25% of the targeted recruitment. Interestingly, participants taking part in the exercise intervention were also predominately females, which, is in agreement with the gender-based disparity in PA among youth observed in the literature (Hallal et al., 2012; Telford et al., 2016; Trost et al., 2002). From a practical perspective, the screening process and feedback used for targeted recruitment and involvement with parents and PE teachers could be influential in public health policy.

Children and adolescents presenting with MI occur on a spectrum, however their reduced performance on exercise testing and lower fitness capacity (Chapter 4 and 5) in comparison to typically developing peers is consistent with findings in the literature. Children with DCD and high motor impairment have on average 11-22% lower $\dot{V}O_{2max}$ using lab-based assessments and 17-28% lower cardio-respiratory fitness on field-based tests (Faught et al., 2013; Morris et al., 2013; Rivilis et al., 2011) which was similar to the results in Chapter 4. In Chapter 5, the A-R submaximal test estimated and predicted $\dot{V}O_{2max}$ scores within a 10-15% range (Ekblom, 2014; Halicka-Ambroziak et al., 1975; Hartung et al., 1995; Noonan & Dean, 2000), however, a larger overestimation of 30% was demonstrated in 10 out of the 18 participants, possibly due to the lower aerobic fitness levels observed in MI. Furthermore, evidence from longitudinal studies suggests that the negative consequences of movement difficulties and poor motor proficiency tend to persist as children mature in age (Cairney et al., 2010; Haga, 2009; Hands et al., 2009; Rivilis et al., 2011). The studies stemming from this thesis are vital for evaluating the physiological and perceptual responses during acute exercise and the applications for chronic regular exercise in relation to MI.

7.4 Limitations and future directions

Alongside the specific limitations reported in the individual chapters, a number of general limitations throughout this thesis should be discussed and considered. Firstly, the sample size in Chapters 4 and 5 were underpowered resulting in distinct findings comparing MI and NMI groups. However, a larger sample size of 70-80 participants total (~35-40 in both MI and NMI) for study 1 (Chapter 4) is acknowledged to detect more robust differences between groups. This is also substantiated to better explicate the physiological and perceptual responses in MI in relationship to exercise intensity and tolerance. In Chapter 5, it was strongly encouraged that future studies conduct the repeatability of the A-R method and CST in a larger sample of children and adolescents across a range of motor skills in order to ascertain the suitability of these submaximal tests within research and clinical settings. Evaluating the applicability of these submaximal exercise tests in young people with MI was challenging due to the scope of motor skill abilities and inabilities presented. However, implementing the A-R cycle test and CST for use in MI served as a novel assessment of aerobic capacity in this heterogeneous population.

In Chapter 6, we could not determine the long-term applications of intermittent high-intensity exercise in comparison to continuous endurance-based exercise as presented in Chapter 4. Such limitations included short intervention time frame and lack of staffing to assist with monitoring exercise intensity during and across sessions. Whether either types of exercise can confer beneficial health benefits and improve fitness parameters and motor skill levels in MI remains to be explored. Allocating participants to different exercise intensity groups within the EPIC framework over a minimum of 10-12 weeks with 2-3 sessions weekly may better elucidate the long-term changes and improvements in fitness outcomes, fundamental movement skills and long-term health and well-being. Correspondingly, prior to commencing the next pilot phase/stage of the EPIC study, steering group meetings and discussions with EPIC participants, parents, headteachers, community members and coaches should be conducted to better inform and guide successful engagement and impact. Moreover, follow-up questionnaires or interviews with the participants regarding their PA participation, performance on activities of daily living and self-efficacy/self-competency may capture the motivation, enjoyment and sustainability of the proposed exercises and intervention designs.

7.5 Practical implications

The studies in this thesis have advanced the evidence base in young people presenting with MI regarding the potential efficacy of novel exercise and targeted screening process and gym intervention pathway to improve fitness and longer-term PA. The research findings presented may have practical implications for guiding exercise prescription, future experimental research, promoting health and fitness and informing public health policy and programmes in youth with MI. The suggested recommendations discussed in this section are based on the empirical findings in children and adolescents categorised with MI and movement difficulties on the BOT2- SF and not with a medical diagnosis of DCD or other conditions. Further work is required to establish the applicability of these findings to more diverse paediatric clinical populations (i.e., ethnicities, overweight/obese, comorbidities).

Strategies to promote a physically active lifestyle in youth with MI may improve fitness levels and stimulate healthy behaviours carried into adulthood. Different types of interventions have been proposed to improve PA and fitness with particularly emphasis on motor skill proficiency, functional performance and self-efficacy (Chapter 2). However, there is currently no consensus on the optimum exercise mode, intensity or duration of activity to maximise health benefits and influence fitness components in MI. The data presented here may be useful for future fatigue research that should examine acute and chronic interventions attempting to identify and examine the central and peripheral underpinnings to enhance exercise tolerance and movement economy in youth with MI. Because the cerebellum has been proposed as a potential dysfunctional area in movement disorders given its implication in motor coordination, postural control and execution/control of movements (Gomez & Sirigu, 2015), use of neuroimagery techniques (i.e., fMRI) (Zwicker et al., 2011) before and after exercise can provide more insight on brain activity in association with motor skill and fitness changes. The work and findings from this thesis have important applications and strategies for clinical populations as well as tackling exercise prescription and physical activity promotion in children and adolescents.

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Appendices

Appendix A

Search Terms

'Children', 'adolescents', 'youth', 'young persons/people' AND 'Participation' AND 'leisure activity OR recreation OR physical activity OR sports OR activities of daily living OR play OR exercise.'

Keywords used to perform the literature search included terms commonly used by researchers and service providers working with children and adolescents with motor impairment/physical disability: clumsy, clumsiness, developmental coordination disorders (acquired), DCD, probable DCD (pDCD), coordination disorder, incoordination, motor proficiency, motor competence, (perceptual) motor difficulties, (non-acquired) brain injury, ataxia, dyspraxia, motor delay, movement disorder(s), motor impairment(s) and sensorimotor difficulties. If the term DCD was used, it was defined either according to the criteria of the DSM-IV (American Psychiatric Association, 2000) or as a motor impairment not otherwise specified by a medical diagnosis, but examined with norm-referenced motor tests and standardised battery assessments confirming movement impairment. Furthermore, studies reporting on children with poor movement performance/low motor competency defined as 1 standard deviation (SD) below the mean, were also included but had to be described with standardised assessments (i.e., Movement Assessment Battery (MABC, MABC-2), the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2 SF), the Concise Assessment Method for Children's Handwriting, or the Test of Gross Motor Development-2 (TGM -2) (Smits-Engelsman et al., 2013). The five-level scale Gross Motor Function Classification System (GMFCS) used to describe current motor function in children and young people with CP was also accepted depending on the target population of interest. The second group of terms focused on the study population ranging from children to adolescents (child, youth, young person, young people, teens, students, boys, or girls) with a minimum age ≤6 years. As long as the average age of the participants were 6 years and older (with or without a control group), the study was accepted. The third set of terms aimed to identify the types of interventions employed in the studies and included variations of these terms: PA, exercise, sports, movement, motor activity, health behaviour, fitness, programmes and training. Lastly, the final group of mesh terms focused on the outcome measures of interest ranging from fitness components, physical activity level (PAL), motor control and variations of these terms: sedentary, inactive, aerobic, anaerobic, endurance, strength, flexibility, agility, power, body composition, overweight, body mass index (BMI), adiposity, body fat, cognition, academic performance, coordination and/or motor skills, sports, training, exercise, sedentary behavior/performance.

Keywords: trainability, youth, aerobic fitness, blood pressure, BMI, lipid oxidation, high-intensity interval training, high-intensity training, physical activity, exercise, play, cardio-metabolic, moderate-intense, moderate to vigorous, acute, chronic, physical fitness, cardiorespiratory endurance, muscle strength, endurance, flexibility, body composition, motor learning difficulties, movement skill, motor skill, movement difficulty, agility, speed, power, skill-related, health-related, participation, well-being, typically-developing, development, developmental coordination disorder, clumsiness, dyspraxia, difficulty

Appendix B

Review Title: Physical activity and exercise interventions in children and adolescents with Movement Impairment: A systematic review of the literature

Date: ___________________ Reviewer: FL/GB

RefmanID: First Author: Pub date:

Study Title:

Study Eligibility / Characteristics

	Review Inclusion Criteria	Study
Type of Study	RCT or CCT	Yes / No / Unclear WHERE
Participants	Children and adolescents >11 years old with DCD and/or low motor competency, movement difficulties	
Types of Intervention	Exercise Therapy Physical Therapy Physical Training Rehabilitation	
Types of Outcome Measures	Exercise parameters / QOL Physical performance (i.e. fitness, health markers, PAL) Psychosocial well-being (i.e. self-esteem)	

Include Exclude

Reason for exclusion:

Method Section	
Study design	
Total study duration	
Sequence generation	
Allocation sequence concealm ent	
Blinding	
Other concerns about bias	

OXFORD BROOKES UNIVERSITY

Appendix C

April 2014

Dear Dr. Easdale,

Re: Exploring the acute effect of exercise on recovery in children and adolescents

Your patient _________ is intending to participate in a study being run by the Movement Science Group at Oxford Brookes University. The study explores the response to and recovery from an acute bout of exercise in typically developing and children with movement impairments and physical disabilities aged 11-18 years. Testing will include maximal exercise testing and both high and low intensity acute cycling.

The study requires participants to visit the Movement Science Laboratory at Oxford Brookes University on three separate occasions. During the first session, baseline measures including a VO2 maximal exercise test on a cycle ergometer, a movement battery assessment and a short computer cognitive task will be measured. During the following visits, participants will be asked to perform exercise at either high or low intensity for 30 mins, a 1-rep max lift on a leg extensor chair and repeat the cognitive task. They will also be required to fill out questionnaires that include a physical activity, sleep and health audit, a self-reported physical disability measure booklet and a self-perception profile. The child will also be asked to wear a wrist accelerometer to measure day and night activity during the study.

Maximal exercise can result in feelings of discomfort and breathlessness. However, exercise is not without risk and although adverse reactions are rare, your patient will be ineligible to participate if he or she is not well enough to exercise. Participants must be able to walk independently and have no contraindications to maximal exercise.

Prior to taking part in the study, parents/guardians and the participants will have read the Participant Information Sheet regarding the eligibility to take part along with the risks involved. We have asked for the parent/guardian to determine whether or not they would be more comfortable obtaining medical clearance prior to their child taking part. We would ask for your written approval via a certificate or letter to ensure he or she would be suitable to partake if this is requested by the parent or if we feel GP approval is necessary. We would be grateful if you can provide medical clearance for your client to take part in this research project. A self-addressed envelope will be provided and/or return to parent will be appreciated. Thank you again for your time.

If you have any questions or concerns regarding the study please contact:

Francesca Liu at 12110172@brookes.ac.uk or 07598946401
Dr. Martyn Morris at mgmorris@brookes.ac.uk or 01865 488616

Yours sincerely,

Francesca Liu

GP Consent Form

Title of Project: **Exploring the acute effect of exercise on recovery in children and adolescents**

Principal Investigators: **Francesca Liu, PhD Student**

Dr. Martyn Morris, Supervisor **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 confirm that the child is suitable to take part in this study based on the information provided and the eligibility criteria. ☐

3. I confirm that I know of no contra-indications to the child's participation ☐

Notes/Comments:

__________________________ ____/____/____ _________________

Name of GP/ Paediatrician Date Signature

GP Practice Stamp

__________________________ ____/____/____ _________________

Name of Person taking consent Date Signature

Appendix D

OXFORD BROOKES UNIVERSITY

PRE-EXERCISE QUESTIONAIRE

Name ____**Date of Birth** ______________

Address ______________________________________

____

____**Postcode** ________________

Telephone number (day) _________________________**(eve)** ____________________

Doctors name_________________________**Telephone number** __________________

Referrers name _______________________**Telephone number** __________________

1. Has a doctor ever said that you have a heart condition?	**YES** ❑ **NO** ❑
2. Do you ever experience chest pain when you do physical activity?	**YES** ❑ **NO** ❑
3. In the past month, have you experienced chest or arm pain when you were not doing physical activity?	**YES** ❑ **NO** ❑
4. Have you ever lost your balance because of dizziness or lost consciousness?	**YES** ❑ **NO** ❑
5. Do you have a bone or joint problem that is made worse by physical activity?	**YES** ❑ **NO** ❑
6. Is your doctor currently prescribing drugs for your blood pressure or any heart condition?	**YES** ❑ **NO** ❑
7. Do you take medication for Diabetes?	**YES** ❑ **NO** ❑
8. Are you awaiting further surgery or medical treatment?	**YES** ❑ **NO** ❑
9. Do you experience asthma or any breathing difficulties when exercising?	**YES** ❑ **NO** ❑

Any other issues we should be aware of:

Appendix E

Headington Campus, Gipsy Lane, Oxford
OX3 0BP
Contact: Dr Martyn Morris Tel: 01865 488616
Email: mgmorris@brookes.ac.uk

Francesca Liu Tel: 01865 483272
Email: francesca.liu-2013@brookes.ac.uk

Research Project: Exploring the acute effect of exercise on recovery in children and adolescents

You are 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 to take part.

What is the study about?

Children and adolescents with movement difficulties (MD) and physical disabilities often demonstrate difficulties in the participation of physical activity and play. Reasons as to why may be related to how your body recovers and how you feel following exercise and physical activity. Gaining a better understanding about how youth like you respond and cope with different exercise intensities is important. The aim of this study is to explore the response to and following a short cycling session at different intensities (high and moderate). We hope you will find the sessions enjoyable and interesting and the measures are designed to help us find better ways to improve and develop longer term physical activity programmes for everyone.

Why have I been invited to participate?

You have been invited to participate because you are between 11-18 years old and you have been informed by a Headperson or Headteacher/coach about this study. You may also have showed interest in being involved in research projects being run at Oxford Brookes University or you may be replying to an advertisement for the study.

Are there any exclusion criteria?

Details on why you may not be able to participate in the study, is stated more in detail on the parent copy of the participant information sheet. A General Health Screen questionnaire must be completed by you if you volunteer to participate in this study. It would be great if you and your parent/guardian could determine together if it is okay for you to take part.

Do I have to take part?

You may take part if you are able to walk with or without support and are able to follow instructions safely. If you need assistance to mount onto the cycle, the researchers will help you to safely do so. It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep, time to think about it and to discuss with your parents/guardians if you are under 16 years old. With your interest to take part, we would as your parents/guardians to let us know and we can set a date. If you are under the age of 16 you will need to have a form signed by a parent/guardian stating you are allowed to take part. Any involvement in the study will not compromise any on-going or future treatment you may be receiving.

What will happen to me if I take part?

We would ask for you to visit the Oxford Brookes University Movement Science Laboratory on three separate occasions lasting approximately 1.5 hours each.

• During visit 1(Baseline) you will be asked to do the following:

-Go over health questionnaire

-Complete a physical activity questionnaire asking you about your physical activity over the past 7 days

-Take your height and weight

-Do a short computer game task called the Anti-Cue Cognitive Task (ACT) to look at how quickly you react

-Complete the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2 Short Form) which will include 8 mini tasks such as drawing, catching and throwing and balance

-Three maximal voluntary contractions (MVC) on the leg extensor chair to determine your muscle strength

-Have you do a 6 minute submaximal cycle test and a maximal fitness cycle test (VO_2 max test) to determine your fitness level during which we will monitor your breathing and heart rate

-Go over wrist activity monitor (similar to a watch and worn on the wrist for 24 hours a day but taken off when bathing or swimming) for seven days after both the first and second visits. We will ask you to wear this for the next 7 days until your next visit. This will help us to monitor your physical activity and sleep patterns.

• At visits 2 and 3 you will be asked to do the following:
-Go over health questionnaire
-Complete a self-perception (SPPA) questionnaire
-Perform either high (HI) or low (LI) intensity cycling for 30 min
-Immediately following and 5 min after you complete the cycling, you will perform 3 maximal voluntary contractions on the leg extensor chair so that we can see your muscle strength.
-Complete the ACT

The testing is safe and will be monitored by a trained tester to ensure that you are comfortable and confident with all tasks. You and your parent/guardian will also be asked to fill out questionnaires regarding your sleep patterns, physical activity and health and how you feel about yourself during the sessions. Travel expenses can be covered up to £10 per visit.

Is there anything I need to do before the sessions?

- We will ask you to complete several forms so that we are confident you are in good general health and will be able to complete the exercise tasks during the study.
- In the two hour period before arriving for the visits, we will ask you to refrain from eating, performing exercise or drinking caffeine (tea, coffee or coke). Snacks will be provided at the end of the sessions.
- We will ask you to wear a wrist activity monitor for 7 consecutive days to measure your physical activity and sleep following each visit.

What type of clothing should I wear?

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

What are the possible benefits of taking part?

The benefits of participating include performing exercise that mimics the high intensity and intermittent nature of daily play and physical activity. This study will focus on looking at how you recover following exercise and its impact on other aspects of your daily life. Furthermore, we get to hear from you directly about ways to improve physical activities to make them more fun and beneficial for their health.

Are there any risks in taking part?

There is a risk involved with any physical activity and some individuals may find exercising uncomfortable or unpleasant. However, all the activities in this study are conducted in a safe environment. If you do not regularly take part in physical activity your muscles might ache the next day after the session. This is perfectly normal and is a sign you have worked your muscles. The VO2 max test will require you to cycle as hard as you can until you are too tired and can no longer pedal. This maximal test may include risks of discomfort or pain, and usually lasts for a very short period and is likely to be avoided as long as you complete a period of cool-down. The researchers are fully trained first aiders and heart rate and breathing will be monitored throughout the test. If for any reason you do not want to do one of the activities you would be able to stop at anytime.

What will happen if I don't want to carry on with the study?
It is entirely up to you to decide if you want to continue with the study. You can withdraw from any part of the study but with yours and your parents/guardians permission we would like to keep your contact to let you know about any future events or projects going on.

What if there is a problem?
If you have any questions or concerns, feel free to talk with a member of the team.

What happens when the research study stops?
The study would end after completion of the visits. After this time you would still be free to contact any of the researchers with any question or concerns 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. Your continued participation in physical activity would be recommended and encouraged.

What will happen to the findings of this study?
The results from your performance and any data we collect will be kept in a safe place. Your name will not be used, but instead you will be given an ID number. All information collected will be retained in accordance with the University's policy on Academic Integrity and will be destroyed when no longer needed. The results of this study will contribute to an ongoing PhD research project. If you or your parents are interested in the results, we would be happy to send you a report sheet.

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

Francesca Liu, francesca.liu-2013@brookes.ac.uk, 07598946401
Dr. Martyn Morris, mgmorris@brookes.ac.uk, 01865 488616

Who is organising and funding the research? This study is organised by researchers in the Movement Science Group.

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 have your parent/guardian 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 E

Headington Campus, Gipsy Lane, Oxford
OX3 0BP

Francesca Liu Tel: 01865 483272
Email: francesca.liu-2013@brookes.ac.uk

Contact: Dr Martyn Morris Tel: 01865 488616
Email: mgmorris@brookes.ac.uk

Research Project: Exploring the acute effect of exercise on recovery in children and adolescents

You are being invited to take part in a PhD student research study. Before you make up your mind 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 to take part.

What is the study about?
Children and adolescents with movement difficulties (MD) and neurological disabilities often demonstrate difficulties in the performance of everyday movements. The underpinning physiological limits have not been fully explored along with the relationship between recovery following acute exercise and its impact on behaviour. Therefore, the aim of this study is to explore how quickly children physically recover following an acute bout of exercise of different intensities and how they respond to other aspects of their daily life. We hope volunteers will find the sessions enjoyable and the measures are designed to help us find better ways to improve and develop longer term physical activity programmes for everyone. We also hope healthy participants who are interested in their fitness will also take part.

Why have I been invited to participate?
You have been invited to participate because you have been informed by a Headperson or Headteacher/coach about this study and you showed interest in being involved in research projects being run at Oxford Brookes University or you may be replying to an advertisement for the study. The aim of the research is to explore the response to and following acute bouts of exercise of different intensities on physiological and non motor measures in children and adolescents between 11-18 years with and without disabilities. You may take part if you are able to walk with or without support and are able to follow instructions safely. If you need assistance to mount onto the cycle, the researchers will help you to do so safely. Your motor skill level will also be looked at, such as catching and throwing, balance and drawing. If you do decide to take part you are free to withdraw at any time without giving a reason.

Exclusion criteria
If you have sensory, sight or intellectual impairment it may not be suitable for you to take part. We must also exclude any individual suffering from muscular degenerative conditions or with uncontrolled epilepsy (must be stable epilepsy/on medication for greater than 12 weeks).

Do I have to take part?

It is up to you to decide whether or not to take part. Please take time, time to think about it, ask any questions or concerns you may have and to discuss with your parents/guardians if you are under 16 years old. If you do decide to take part you will be given this information sheet to keep. If you feel that it is necessary to receive approval from your GP/Physiotherapist prior to taking part, 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. We would then like to schedule a suitable date for the session and you would then be asked to sign a consent form. If you are under the age of 16 you will need to have the consent form signed by a parent/guardian stating you are allowed to take part. Any involvement in the study will not compromise any on-going or future treatment you may be receiving.

What will happen to me if I take part?

We would ask for you to visit the Oxford Brookes University Movement Science Laboratory on three separate occasions lasting approximately 1.5 hours each.

- During visit 1(Baseline) you will be asked to do the following:

-Go over health questionnaire

-Complete a physical activity questionnaire asking you about your physical activity over the past 7 days

-Take your height and weight

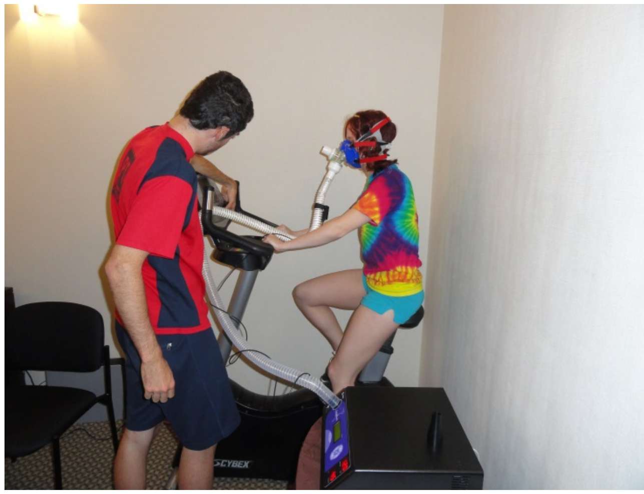
-Do a short computer game task called the Anti-Cue Cognitive Task (ACT) to look at how quickly you react

-Complete the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2 Short Form) which will include 8 mini tasks such as drawing, catching and throwing and balance

-Three maximal voluntary contractions (MVC) on the leg extensor chair to determine your muscle strength

-A Maximal fitness cycle test (VO2 max test) to determine your fitness level during which we will monitor your breathing and heart rate. The VO2 max test will involve cycling with the level getting harder each minute until you are too exhausted to continue. We will ask you to rate on a scale how easy or hard each level is and monitor your breathing and heart rate throughout the test to determine your fitness level.

-Go over wrist activity monitor (similar to a watch and worn on the wrist for 24 hours a day but taken off when bathing or swimming) for seven days after both the first and second visits. We will ask you to wear this for the next 7 days until your next visit. This will help us to monitor your physical activity and sleep patterns.



• At visits 2 and 3 you will be asked to do the following:
-Go over health questionnaire
-Complete a self-perception (SPPA) questionnaire
-Perform either high (HI) or low (LI) intensity cycling for 30 min
-Immediately following and 5 min after you complete the cycling, you will perform 3 maximal voluntary contractions on the leg extensor chair so that we can see your muscle strength.
-Complete the ACT
-Snack Break

The testing is safe and will be monitored by a trained tester to ensure that you are comfortable and confident with all tasks. You and your parent/guardian will also be asked to fill out questionnaires regarding your sleep patterns, physical activity and health and how you feel about yourself during the sessions. Travel expenses can be covered up to £10 per visit.

Is there anything I need to do before the sessions?

- We will ask you to complete several forms so that we are confident you are in good general health and will be able to complete the exercise tasks during the study.
- In the two hour period before arriving for the visits, we will ask you to refrain from eating, performing exercise or drinking caffeine (tea, coffee or coke). Snacks will be provided at the end of the sessions.
- We will ask you to wear a wrist activity monitor for 7 consecutive days to measure your physical activity and sleep following each visit.

What type of clothing should I wear?

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

What are the possible benefits of taking part?

The benefits of participating include performing exercise that mimics the high intensity and intermittent nature of daily play and physical activity and providing greater insight into the types of training, duration and intensity to benefit physiological and non motor measures. The proposed study will focus on assessment of recovery measures and its impact on quality of life in youth. Furthermore, we get to hear from you directly about ways to improve physical activities to make them more fun and beneficial for their health.

Are there any risks in taking part?

The procedures and tests in this study are routinely used for assessing people's health, fitness level and performance. However, exercising is not without risk and some individuals may find exercising uncomfortable or unpleasant. If you don't regularly take part in physical activity your muscles might ache the next day after the session. This is perfectly normal and is a sign you have worked your muscles. The VO2 max test will require you to cycle to exhaustion. However, the researchers are fully trained first aiders and heart rate and breathing will be monitored throughout the test. You would be able to stop at anytime without giving a reason.

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

It is entirely up to you to decide if you want to continue with the study. You can withdraw from any part of the study but with yours and your parents/guardians permission we would like to keep your contact to let you know about any future events or projects going on.

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. If you are harmed by taking part in this research project, there are no special compensation arrangements. If they are harmed due to someone's negligence, then you may have grounds for a legal action but you may have to pay for it. Regardless of this, if you wished to complain, you can use the mechanisms mentioned above.

What happens when the research study stops?

The study would end after completion of the three exercise sessions. 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 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 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 I have some more questions?

Francesca Liu, francesca.liu-2013@brookes.ac.uk, 01865 483272
Dr. Martyn Morris, mgmorris@brookes.ac.uk, 01865 488616

Who is organising and funding the research? This study is organised by researchers in the Movement Science Group.

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 F

Consent Form

Title of Project: **Exploring the acute effect of exercise on recovery in children and adolescents**

Principal Investigators:

Francesca Liu, PhD Student

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX2 9AT

Tel: 01865 483272, Email: 12110172@brookes.ac.uk

Dr. Martyn Morris

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX2 9AT

Tel: 01865 488616, Email: mgmorris@brookes.ac.uk

Study Number:

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

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

Please Initial Box

4. 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 ☐

5. I understand that my participation is voluntary and that I am free to withdraw them at any time, without giving any reason. ☐

6. I understand that in all instances where we disseminate the results my identity will remain anonymous and that all data will be treated as confidential (within the limitations of the law) ☐

7. I agree to take part in the above research study. ☐

	Y	N
8. 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 me to take part in the study. If the researchers cite any concerns, I give them permission to contact my GP or physio on my behalf to check that I 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 GP to check that there is no reason why I should not take part in the study and to let the researchers know if it is advised that I should not take part if I have any health/medical concerns.	☐	☐
8. I agree to my 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 GP/Physio:

____

__________________________ ____/____/____ _________________

Name of Participant Date of Birth Signature

________________________ ____/____/____ _________________

Telephone: _________________ Email: _______________________

Appendix F

Consent Form

Title of Project: **Exploring the acute effect of exercise on recovery in children and adolescents**

Principal Investigators:

Francesca Liu, PhD Student

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX2 9AT

Tel: 01865 483272, Email: francesca.liu-2013@brookes.ac.uk

Dr. Martyn Morris

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX2 9AT

Tel: 01865 488616, Email: mgmorris@brookes.ac.uk

Study Number:

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

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

Please Initial Box

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 ☐

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. ☐

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) ☐

I agree to take part in the above research study. ☐

Y N

I agree to the data collected for this being made anonymous and retained for use in other subsequent studies ☐ ☐

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. ☐ ☐

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. ☐ ☐

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

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

________________________ ____/____/____ _________________

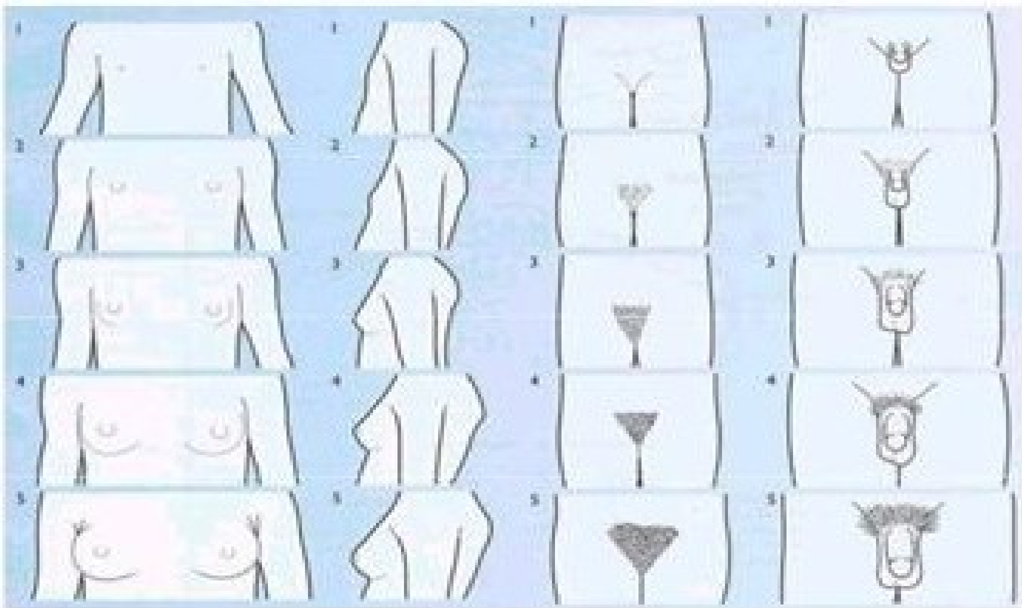
Name of Parent/Carer Date Signature

Telephone: _________________ Email: ________________________

Appendix G

TANNER SCALE

The 5-stage Tanner scale for males and females, is used to determine stage of sexual maturity. Please tick the box that most reflects your child's puberty level.



Pubic Hair

Stage 1: Prepubertal (can see velus hair similar to abdominal wall)

Stage 2: Sparse growth of long, slightly pigmented hair, straight or curled, at base of penis or along labia

Stage 3: Darker, coarser and more curled hair, spreading sparsely over junction of pubes

Stage 4: Hair adult in type, but covering smaller area than adult, no spread to medial surface of thighs

Stage 5: Adult in type and quantity, with horizontal distribution

Appendix H

ID: ___________

Visit: ______

D.O.B:_____________________

Age: ________

Weight: ___________________

Date: ________

Height: ____________________

BMI: ___________

MVCs

Bike Seat			
Leg Lever Length			
Chair Distance			

Cycling Bout

BP: ________________ Pre-HR: _________________

Start	HR	RPE	Watts
1			
5			
10			
15			
20			
25			
30			
P1			
P3			
P7			

Appendix I

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 in October 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)

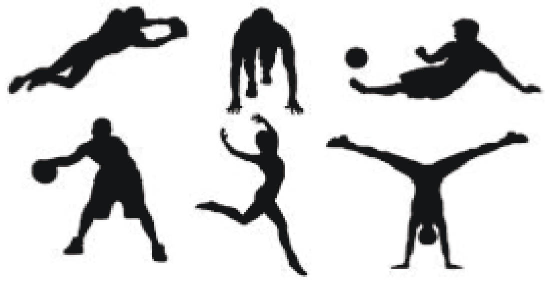
Parent/Guardian:………………………………………….(Name and signature)

From

The Movement Science Group

Appendix J

EPIC Screening Guide



Movement Science Group

SPORT ENGLAND
LOTTERY FUNDED

OXFORD BROOKES UNIVERSITY

Appendix K

Chester Step Test data sheet

Name: ………………………………………………… ID: ……… Age: ………Date of test: ………

Stage	I	II	III	IV	V
Heart rate recorded at each stage (bpm)					
Exertion level from RPE scale					

---

* N/A for participants

Tester's initials: ……… Step height for test: ……… cm Remarks:

Tick when checked

Readiness to exercise check: ………………

Contra-indications to exercise: ………………

Life style activity level check: ………………

Appendix L

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

Dear Parents,

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 Headteacher 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 on Monday 8th, December. 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

Contact: Francesca Liu Tel: 01865 483272678
Email: francesca.liu-2013@brookes.ac.uk
Contact: Dr Martyn Morris Tel: 01865 488616
Email: mgmorris@brookes.ac.uk
Headington Campus, Gipsy Lane, Oxford OX3 0BP

Appendix L

Movement Science Group

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

Dear Student,

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.

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 programme, 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.

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. Further details regarding the pathway and training programme 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 on **Monday, December 8th** at 2:00 p.m. at your school. This will be a great opportunity for us to meet you and for you to ask questions you may have. If you are interested in joining EPIC Club and would like to sign up please send us an e-mail (listed below)!

Kind regards,

Movement Science Group

OXFORDSHIRE SPORTS PARTNERSHIP

Headington Campus, Gipsy Lane, Oxford OX3 0BP
Contact: Francesca Liu Tel: 01865 483272678
Email: francesca.liu-2013@brookes.ac.uk
Contact: Dr Martyn Morris Tel: 01865 488616
Email: mgmorris@brookes.ac.uk

Appendix M

Consent Form

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

Principal Investigators:

Francesca Liu, PhD Student

Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX2 9AT
Tel: 01865 483272, Email: francesca.liu-2013@brookes.ac.uk

Dr. Martyn Morris
Oxford Brookes University, Gipsy Lane, Headington, Oxford, OX2 9AT
Tel: 01865 488616, Email: mgmorris@brookes.ac.uk

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

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

Please Initial Box

I confirm that I have read and understand the information sheet (version 1) for the above study and have had the opportunity to ask questions ☐

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. ☐

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) ☐

I agree to take part in the above research study. ☐

	Y	N
I agree to the data collected for this being made anonymous and retained for use in other subsequent studies	☐	☐

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. ☐ ☐

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. ☐ ☐

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

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: _______________________

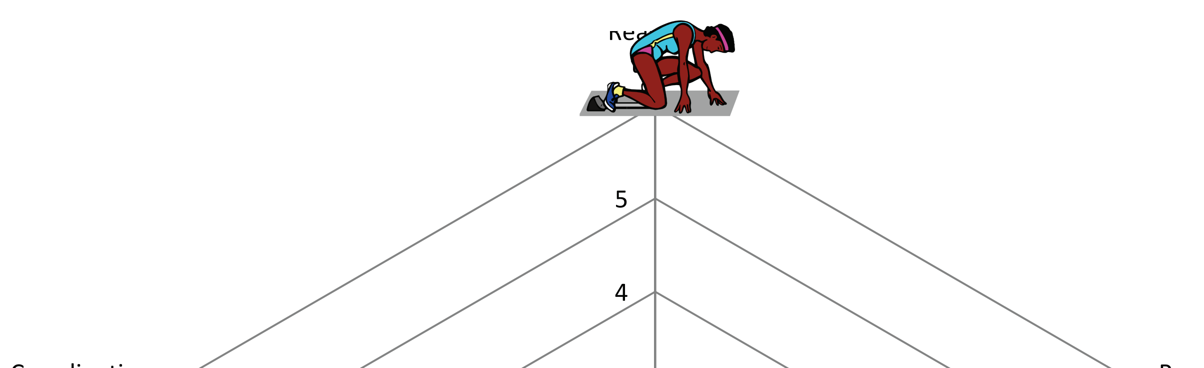
Appendix N

Physical performance feedback sheet

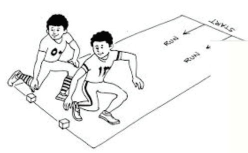
Name / school:

Date of test:

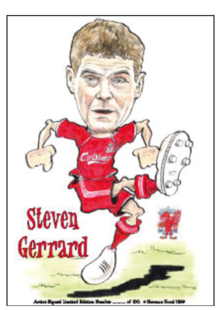
YOUR RESULTS



Your physical performance profile is similar this sport celebrity:



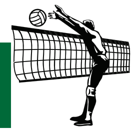
Andy Murray

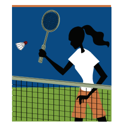


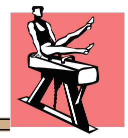
Michael

Jordan

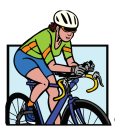
-We thought you would like to take part in sports like:

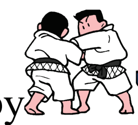
Basketball, netball, volleyball  

Racket sports 

Gymnastics or dance  

Sprinting  

Endurance events  

Martial arts or rugby  

Appendix O

Headington Campus, Gipsy Lane, Oxford

OX3 0BP

Francesca Liu Tel: 01865 483272

Email: francesca.liu-2013@brookes.ac.uk

Contact: Dr Martyn Morris Tel: 01865 488616

Email: mgmorris@brookes.ac.uk

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

You are being invited to take part in a PhD student research study. Before you make up your mind 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 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. Children and young people are recommended to participate in moderate to vigorous physical activity for at least 60 minutes a day but many students are not achieving this. Some children and adolescents with poorer coordination may have lower fitness levels and/or low levels of participation of physical activity. We are testing a new pathway to encourage 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 how participating in a training programme and trying different sports can impact your health and well-being in youth.

Why have I been invited to participate?

You have been invited to participate because you have participated in a fitness screening held at your school and you have showed interest in being involved in research projects being run at Oxford Brookes University. Following the fitness screening, it was not clear what activities would suit you best. Therefore, we would like to invite you to take part in an exercise training programme (EPIC Club) to work on improving your fitness along with building up your skills and confidence. This is also a great opportunity to receive personal training in a gym setting, meet new people and to try different sports and activities during 'Have a go days'. If you do decide to take part you are free to withdraw at any time without giving a reason.

Exclusion criteria

Details on why you may not be able to participate in the study are stated in detail on the parent copy of the participant information sheet. A General Health Screen questionnaire must be completed by you if you volunteer to participate in this study. It would be great if you and your parent/guardian could determine together if it is okay for you to take part and whether you would like to have GP consent prior to participating. However, if you have a muscular degenerative condition you will not be able to take part in the study. If you have asthma, diabetes and/or epilepsy, you are free to participate as long as your medication is stable. We would ask for you to bring your inhaler with you to the sessions if you do have asthma.

Do I have to take part?

It is up to you to decide whether or not to take part. Please take time to think about it, and ask any questions or concerns you may have. If you have any of the conditions stated above and are interested in participating, and/or any concerns, you may wish to discuss this with a parent and your 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 prior to starting. Safe participation is our top priority, therefore, if the research team also feels the need for you to be checked by the GP prior to testing, we would like to be able to tell you so. Once we have determined it is safe for you to take part, we would like to schedule a suitable day for you to start and you would also be asked to sign a consent form. Any involvement in the study will not compromise any on-going or future treatment you may be receiving or affect your progress at school.

What will happen to me if I take part?

The EPIC Clubs are designed to build confidence and skills in a fun environment so the young people succeed within their peer group and learn that sport can be fun and to develop foundations to be carried out for longer term and possibly into adulthood. You will be encouraged to attend 2-3 times weekly during or after school as pre-arranged with you and your school for 6 weeks. Each session (approximately 45 mins long) will involve cardiovascular exercise (i.e. cycling, treadmill running or a group warm-up) for 25-30 mins within a 65-90% target heart rate (HR) zone. Strength and resistance training will also be incorporated under the supervision of a qualified and experienced coach focusing on volume and intensity of resistance training based on your fitness level and abilities.

We would also ask for you to visit the Oxford Brookes University Movement Science Laboratory or the gym facility at your school on three separate occasions lasting approximately 1 hour each. The first visit will be prior to starting the training, the second will occur after the 6 weeks of training and the final one will just involve questionnaires 6 months after you finish the training programme. A t-shirt and prize badges will be given once the 6 weeks of training and assessments have been completed.

• During the assessments you will be asked to do the following:

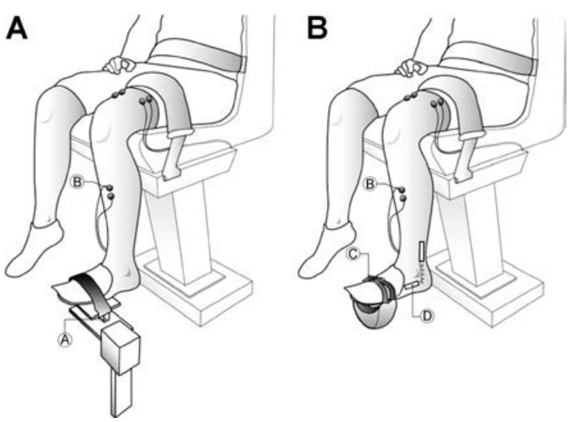
-Go over health questionnaire

-Complete a physical activity questionnaire asking you about your physical activity over the past 7 days

-Take your height, weight, blood pressure

-Do a short computer game task called the Eriksen Flanker Task to look at how quickly you react

-Three maximal voluntary contractions (MVC) on the leg extensor chair or torque transducer to determine your muscle strength and perform hand-grip strength



-A 6 minute submaximal cycle test (Astrand-Rhyming) to determine your fitness level during which we will monitor your heart rate. We will ask you to rate on a scale how easy or hard you find it throughout the test and monitor your breathing. Proper warm-up and cool-down will take place.

-A lateral step test in which you will step up and down a set of blocks as many times as possible in 15 secs.

The testing is safe and will be monitored by a trained tester to ensure that you are comfortable and confident with all tasks. We will also make sure you warm-up and properly cool-down before and after exercise. You will also be asked to fill out questionnaires regarding your sleep patterns, physical activity and health and how you feel about yourself during the sessions.

Is there anything I need to do before the sessions?

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

- In the two-hour period before arriving for the assessments, we will ask you to refrain from eating, performing exercise or drinking caffeine (tea, coffee or coke).

What type of clothing should I wear?

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

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 your physical activity. You will learn the proper techniques in strength and resistance training and undergo cardio training. We hope that this will also help build up your skills and confidence and also introduce you to sports and physical activities you may wish to undertake for longer-term participation. Therefore, during the study, you will also be invited to take part in 'Have a go day' Sports Taster days in which you can try different sporting activities offered and be in touch with local coaches. The focus of the study is to also look into the impact of exercise and training on mental and physical health and well-being. Furthermore, we get to hear from you directly about ways to improve physical activities to make them more fun and beneficial for your health and well-being.

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 you do 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 you have 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. The researchers are fully trained first aiders and heart rate and breathing will be monitored throughout the assessments as well as during training. You would be able to stop at anytime without giving a reason.

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

It is entirely up to you to decide if you want to continue with the study. You can withdraw from any part of the study.

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 after completion of the 6 week training programme and the three assessments. However the aim of the pathway is to promote long term physical activity and you would therefore be able to continue for longer if you please. We also hope to provide you with a connection to a sport or physical activity that you enjoy and for you 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 results from your performance and any data we collect will be kept in a safe place. Your name will not be used, but instead you will be given an ID number. All information collected will be retained in accordance with the University's policy on Academic Integrity and will be destroyed when no longer needed. The results of this study will contribute to an ongoing PhD research project. If you or your parents are interested in the results, we would be happy to send you a report sheet.

Who should we contact if I have some more questions?

Francesca Liu, francesca.liu-2013@brookes.ac.uk, 01865 483272

Dr. Martyn Morris, mgmorris@brookes.ac.uk, 01865 488616

Who is organising and funding the research? This study is organised by researchers in the Movement Science Group 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.

PARENT COPY

Appendix O

Headington Campus, Gipsy Lane, Oxford

OX3 0BP

Francesca Liu Tel: 01865 483272

Email: francesca.liu-2013@brookes.ac.uk

Contact: Dr Martyn Morris Tel: 01865 488616

Email: mgmorris@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 Headteacher/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?

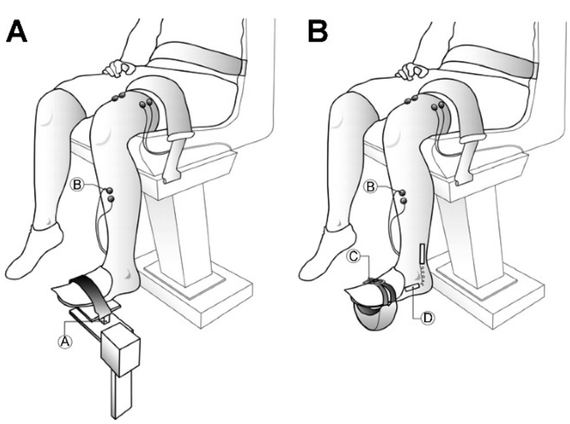
No, your child's participation is entirely voluntary. If you and your child are interested in taking part you will have the opportunity to discuss any questions or concerns you may have with the research team. If your child does have any of the conditions mentioned above and is interested in participating, 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 themself 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?

Francesca Liu, francesca.liu-2013@brookes.ac.uk, 01865 483272

Dr. Martyn Morris, mgmorris@brookes.ac.uk, 01865 488616

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 P

ID: ___________ Visit: _______

Age: ____________ Date: _______

D.O.B: _______

Height: ___________ (cm)

Weight: __________ (kg)

BP: ___________ Resting HR: ___________

MVICs (3x)

	Trial 1 (Nm)	Trial 2 (Nm)	Trial 3 (Nm)

Hand-grip Strength

	Trial 1 (cm)	**Trial 2 (cm)**	**Comments**
Dominant Hand (R or L)			

Balance Beam (30s) ___________

Astrand-Rhyming Submax Cycle Test

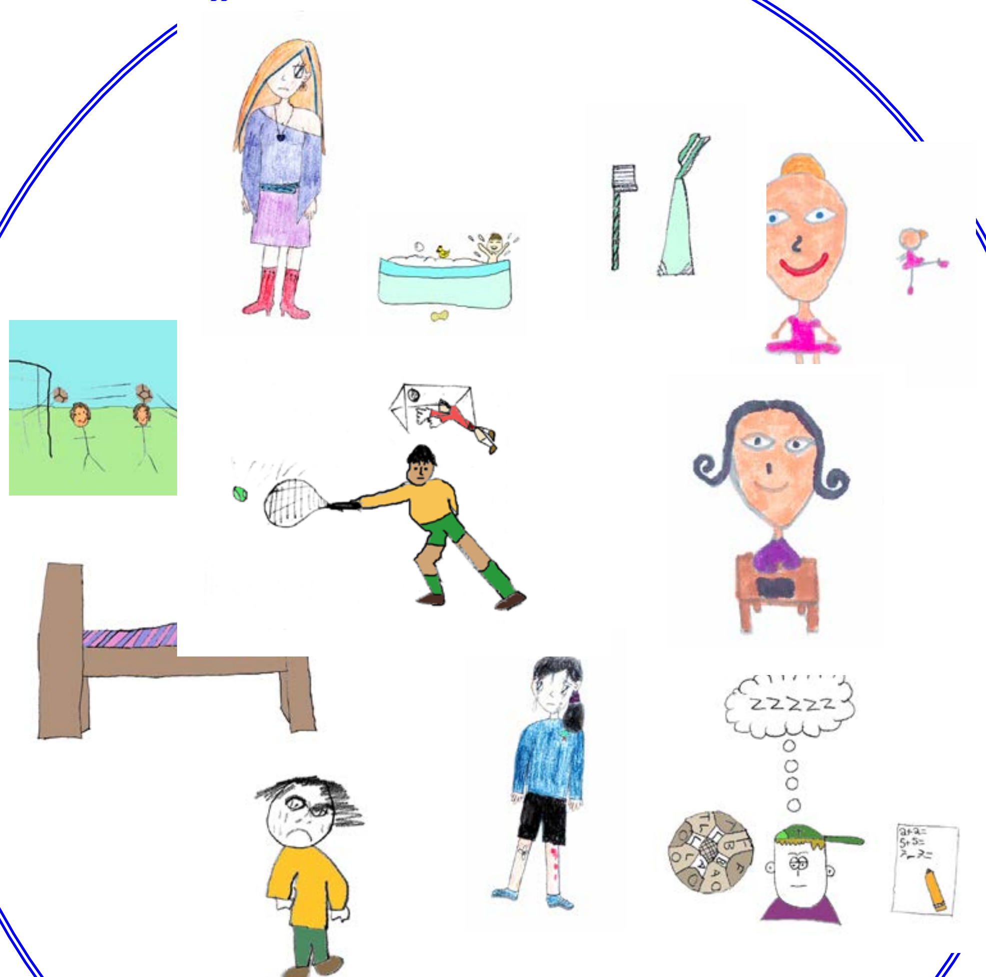
Time (min)	**HR (bpm)**	**Cadence (60rpm)**	**Watts**	**Weights**
Warm-up				
1:45-2:00 min				
2:45-3:00 min				
3:45-4:00 min				
4:45-5:00 min				
5:45-6:00 min				
Cool Down				

	Completed	**Not Completed**
Flanker Test	☐	☐
Survey Link	☐	☐
SPPA/PAQ-A	☐	☐

Appendix Q

The University Of Sheffield.

Child Health Utility 9D



Instructions

These questions ask about how your child is **today.** For each question, read all the choices and decide which one is most like your child **today**.

Then put a tick in the box next to it like this ☑. Only tick **one** box for each question.

<u>Example</u>

Today my child feels quite upset so I will tick this box.

Upset

- ☐ My child doesn't feel upset today
- ☐ My child feels a little bit upset today
- ☐ My child feels a bit upset today
- ☑ My child feels quite upset today
- ☐ My child feels very upset today

Now think about and answer the rest of the questions below

1. Worried

- ☐ My child doesn't feel worried today
- ☐ My child feels a little bit worried today
- ☐ My child feels a bit worried today
- ☐ My child feels quite worried today
- ☐ My child feels very worried today

2. Sad

- ☐ My child doesn't feel sad today
- ☐ My child feels a little bit sad today

- ☐ My child feels a bit sad today
- ☐ My child feels quite sad today
- ☐ My child feels very sad today

3. Pain

- ☐ My child doesn't have any pain today
- ☐ My child has a little bit of pain today
- ☐ My child has a bit of pain today
- ☐ My child has quite a lot of pain today
- ☐ My child has a lot of pain today

4. Tired

- ☐ My child doesn't feel tired today
- ☐ My child feels a little bit tired today
- ☐ My child feels a bit tired today
- ☐ My child feels quite tired today
- ☐ My child feels very tired today

5. Annoyed

- ☐ My child doesn't feel annoyed today
- ☐ My child feels a little bit annoyed today
- ☐ My child feels a bit annoyed today
- ☐ My child feels quite annoyed today
- ☐ My child feels very annoyed today

6. School Work/Homework (such as reading, writing, doing lessons)

- ☐ My child has no problems with their schoolwork/homework today
- ☐ My child has a few problems with their schoolwork/homework today
- ☐ My child has some problems with their schoolwork/homework today

☐ My child has many problems with their schoolwork/homework today

☐ My child can't do their schoolwork/homework today

7. Sleep

☐ Last night my child had no problems sleeping

☐ Last night my child had a few problems sleeping

☐ Last night my child had some problems sleeping

☐ Last night my child had many problems sleeping

☐ Last night my child couldn't sleep at all

8. Daily routine (things like eating, having a bath/shower, getting dressed)

☐ My child has no problems with their daily routine today

☐ My child has a few problems with their daily routine today

☐ My child has some problems with their daily routine today

☐ My child has many problems with their daily routine today

☐ My child can't do their daily routine today

9. Able to join in activities (things like playing out with their friends, doing sports, joining in things)

☐ My child can join in with any activities today

☐ My child can join in with most activities today

☐ My child can join in with some activities today

☐ My child can join in with a few activities today

☐ My child can join in with no activities today

Appendix R

By answering this questionnaire you will be helping us improve our understanding of how active children with physical difficulties in Oxfordshire are in their everyday lives. It doesn't matter if you do little or no physical activity at all, we still would like you to fill in the questionnaire. We would also like to know if there are things you would like to do but can't and the reasons for that. This will help us to make sure the things you want to do are made available if possible.

Physical Activity Audit

Age: __________
School year: __________
Gender: M / F

We are trying to find about your level of physical activity from ***the last 7 days*** (in the last week). These includes sports or dance that make you sweat or make your legs feel tired, or games that make you breathe hard, like tag, skipping, running, climbing, and others.

Remember:

There are no right and wrong answers - this is not a test.
Please answer all the questions as honestly and accurately as you can - this is very important.
Please fill in this questionnaire together with your parent.

- Physical activity in your spare time: Have you done any of the following activities in the past 7 days (last week)? If yes, how many times? (Please indicate **number of minutes** spent on activity next to activity and mark only one circle per row)

	No	1-2	3-4	5-6	7 times or more
Skipping………………………………	O	O	O	O	O
Rowing/canoeing…………………	O	O	O	O	O
Netball………………………………	O	O	O	O	O
Tag………………………………………	O	O	O	O	O
Walking for exercise……………	O	O	O	O	O
Bicycling………………………………	O	O	O	O	O
Jogging or running…………………	O	O	O	O	O
Aerobics………………………………	O	O	O	O	O

Swimming…………………………….	O	O	O	O	O
Baseball, softball, rounders……	O	O	O	O	O
Dance…………………………………	O	O	O	O	O
Football………………………………	O	O	O	O	O
Badminton…………………………	O	O	O	O	O
Skateboarding……………………	O	O	O	O	O
Rugby…………………………………	O	O	O	O	O
Street hockey…………………….	O	O	O	O	O
Volleyball……………………………	O	O	O	O	O
Hockey………………………………	O	O	O	O	O
Basketball……………………………	O	O	O	O	O
Ice skating…………………………...	O	O	O	O	O
Tennis…………………………………	O	O	O	O	O
Ice hockey…………………………...	O	O	O	O	O
Horse riding………………………...	O	O	O	O	O
Other, please state:					
___________________________	O	O	O	O	O
___________________________	O	O	O	O	O

- Are there any other children in your family?

Yes…………………………………………………. O
No, go to question 4………………………….. O

- Please list the sports they do

____

____

They do not participate in any sports…… O
If not, why?

____

____

- In the last 7 days, during your physical education (PE) classes, how often were you very active (playing hard, running, jumping, throwing)? (Check one only)

I don't do PE……………………………………… O
Hardly ever……………………………………….. O
Sometimes……………………………………….... O
Quite often……………………………………….. O
Always……………………………………………..... O

- In the last 7 days, what did you do most of the time *at break?* (Check one only)

Sat down (talking, reading, schoolwork) O
Stood around or walked around………….. O
Ran or played a little bit………………………. O
Ran around and played quite a bit………. O
Ran and played hard most of the time… O

- In the last 7 days, what did you do most of the time *at lunch* (besides eating lunch)? (Check one only)

Sat down (talking, reading, schoolwork) O
Stood around or walked around………….. O
Ran or played a little bit………………………. O
Ran around and played quite a bit………. O
Ran and played hard most of the time… O

- In the last 7 days, on how many days *right after school,* did you do sports, dance, or play games in which you were very active? (Check one only)

None…………………………………………........... O
1 time last week……………………………….. O
2 or 3 times last week………………………. O
4 times last week……………………………… O
5 times last week……………………………… O

- In the last 7 days, on how many *evenings* did you do sports, dance, or play games in which you were very active? (Check one only)

None……………………………………………….. O
1 time last week……………………………….. O
2 or 3 times last week………………………. O
4 times last week……………………………… O
5 times last week……………………………… O

- *On the last weekend,* how many times did you do sports, dance, or play games in which you were very active? (Check one only)

None……………………………………………….. O
1 time……………………………………………….. O

2 or 3 times ………………………………………… O
4 or 5 times………………………………………… O
6 or more times………………………………… O

- Which *one* of the following describes you best for the last 7 days? (Read *all five* statements before deciding on the *one* answer that describes you)

(A) All or most of my free time was spent doing things that involve little physical effort…………………………………………………. O
(B) I sometimes (1-2 times) did physical things in my free time (e.g. sports, running, swimming, bike riding)…………………………. O
(C) I often (3-4 times) did physical things in my free time……………………………………………………………………………. O
(D) I quite often (5-6 times) did physical things in my free time……………………………………………………………………………. O
(E) I very often (7 or more) did physical things in my free time……………………………………………………………………………. O

- Mark how often you did physical activity (like playing sports, games, doing dance, or any other physical activity) for each day last week. (Mark only one circle per row)

	None	Little bit	Medium	Often	Very often
Monday……………………	O	O	O	O	O
Tuesday…………………..	O	O	O	O	O
Wednesday………………..	O	O	O	O	O
Thursday………………….	O	O	O	O	O
Friday……………………….	O	O	O	O	O
Saturday……………………..	O	O	O	O	O
Sunday………………………..	O	O	O	O	O

- Were you sick last week, or did anything prevent you from doing your normal physical activities? (Check one)

No………………………………………………………… O

Yes………………………………………………………..   O
If yes, what prevented you?

____

- If you play sport please tell us how you found out about the most favourite sport you are performing?

School………………………………………………………   O
Physiotherapy……………………………………………   O
Friends and/or family…………………………………   O
Television/radio/newspaper………………………   O
Community service……………………………………   O
Other, please state:
_____________________________________   O

- Why do you enjoy doing this activity?

____
____

- Do you perform a second favourite sport?

Yes………………………………………   O
No, go to question 17……………   O

- How did you find out about the second most favourite sport you are performing?

School……………………………………………   O
Physiotherapy…………………………………   O
Friends and/or family……………………   O
Television/radio/newspaper……………   O
Community service……………………………   O
Other, please state:
_______________________________   O

- Why do you enjoy doing this activity?

____
____

- Most children in the UK do not reach the recommended amount of daily activities. If you don't participate in sport but would like to please tell us. What are the reasons for you not to participate in activities you would like to do? (Please tick all that apply)

Costs…………………………………………………………………………… O
Transport……………………………………………………………………… O
Facilities (accessibility, parking, changing rooms)………… O
Don't know where to go……………………………………………… O
Not feeling confident to participate…………………………… O
Feeling tired/lazy…………………………………………………………… O
Afraid to not fit in the group……………………………………… O
Do not like coaching, please explain: …………………………… O
____
Other, please state:
____ O

- What kind of sports would you like to try, if they were available for you?

____
____

- What do you think will help you participating in these sports?

____
____

- How often would you like to participate in these sports?

Never…………………………………… O
1 time………………………………… O
2 or 3 times…………………………… O
4 or 5 times…………………………… O
6 or more times……………………… O

- If you have had a good experience of attending a club or class that made you welcome and helped we would like to know

____
____
____

- Please tell us anything else that you think might be relevant

____
____

- What I am like (**Please pick which either the left statement or right statement and then tick which out of the two boxes on that side is more like you for questions 24-27**).

Really True for me	Sort of True for me				Really True for me	Sort of True for me
☐	☐	Some kids wish they could be a lot better good at sports	**BUT**	Other kids feel they are enough at	☐	☐

- What I am like

Really True for me	Sort of True for me				Really True for me	Sort of True for me
☐	☐	Some kids think they could do well at just about any new sports activity they haven't tried before	**BUT**	Other kids are afraid they might not do well at sports they	☐	☐

26. What

Really True for me	Sort of True for me				Really True for me	Sort of True for me
☐	☐	Some kids feel that they are better they than others their	**BUT**	Other kids don't feel can play as	☐	☐

27. What I am like

Really True for me	Sort of True for me				Really True for me	Sort of True for me
☐	☐	In games and sports some kids usually watch instead of	**BUT**	Other kids usually play rather than	☐	☐

Thank you!

If you have any questions, do not hesitate to contact:

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Appendix S

Strengths and Difficulties Questionnaire

For each item, please mark the box for Not True, Somewhat True or Certainly True. It would help us if you answered all items as best you can even if you are not absolutely certain or the item seems daft! Please give your answers on the basis of how things have been for you over the last six months.

Your Name .... Male/Female

Date of Birth...

	Not True	Somewhat True	Certainly True
I try to be nice to other people. I care about their feelings	☐	☐	☐
I am restless, I cannot stay still for long	☐	☐	☐
I get a lot of headaches, stomach-aches or sickness	☐	☐	☐
I usually share with others (food, games, pens etc.)	☐	☐	☐
I get very angry and often lose my temper	☐	☐	☐
I am usually on my own. I generally play alone or keep to myself	☐	☐	☐
I usually do as I am told	☐	☐	☐
I worry a lot	☐	☐	☐
I am helpful if someone is hurt, upset or feeling ill	☐	☐	☐
I am constantly fidgeting or squirming	☐	☐	☐
I have one good friend or more	☐	☐	☐
I fight a lot. I can make other people do what I want	☐	☐	☐
I am often unhappy, down-hearted or tearful	☐	☐	☐
Other people my age generally like me	☐	☐	☐
I am easily distracted, I find it difficult to concentrate	☐	☐	☐
I am nervous in new situations. I easily lose confidence	☐	☐	☐
I am kind to younger children	☐	☐	☐
I am often accused of lying or cheating	☐	☐	☐
Other children or young people pick on me or bully me	☐	☐	☐
I often volunteer to help others (parents, teachers, children)	☐	☐	☐
I think before I do things	☐	☐	☐
I take things that are not mine from home, school or elsewhere	☐	☐	☐
I get on better with adults than with people my own age	☐	☐	☐
I have many fears, I am easily scared	☐	☐	☐
I finish the work I'm doing. My attention is good	☐	☐	☐

Your signature .... Today's date ....

Thank you very much for your help