Children's Fitness and Quality of Movement

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Abstract

Introduction: Movement is essential to life and plays a key role in development throughout childhood. Movement can be assessed by its quantity and quality. Movement is important to measure as it can aid early intervention. Current research suggests that global levels of fitness are declining, with a lack of research surrounding children's natural fitness levels as they get older. Quantity of movement is commonly studied, however quality is becoming increasingly popular. A clear understanding of the methods of technology used to measure quality of movement is important as understanding this area will aid in designing appropriate interventions.

Methods: This thesis comprises of two experimental studies. Study one is a repeated measures design using previously collected Swanlinx data to investigate how components of children's fitness change over a one-year period. Study two is a scoping review investigating the measurement of quality of movement with technology in the form of MEM's devices, while aiming to gain clarity on the definition of quality.

Results: Study one revealed that children's fitness levels increase across a one-year period, in all components of fitness, except sit and reach. Boys performed significantly better in all fitness components, apart from sit and reach. Study two demonstrated the broad field that is included under the term of quality, showing clarity is needed in this area. A large number of devices, movements and populations are being observed, with multiple definitions of quality which is dependent on the metrics collected.

Conclusion: Study one concludes that children's fitness levels increase over one-year, with boys performing better than girls. This can be used to understand children's natural fitness levels and aid future interventions in participation. Study two concludes that there are multiple ways to assess quality of movement however a clear definition of the quality should be stated, aiding comparison of quality.

Declarations and Statements

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

Signed [redacted] (candidate)
Date 26.01.22

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended

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I hereby give consent for my thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available outside organisations.

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The University's ethical procedures have been followed and, where appropriate, that ethical approval has been granted.

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List of Tables & Figures

Glossary of Terms

Term	Abbreviation	Thesis Definition
Micro-electromechanical systems	**MEM's**	Micro-electromagnetic systems are used in small devices that combine mechanical and electrical components. These include accelerometers, gyroscopes, barometers, magnetometers, flex sensors, pressure sensors, and inertial sensors. These are devices that are portable and allow testing to take place in the field.
Accelerometer		A device that measures the acceleration of an object in counts, G.
Gyroscope		A device used for measuring or maintaining orientation and angular velocity.
Magnetometer		A magnetometer measures the direction and orientation in space.
Barometer		A device that measures atmospheric pressure.
Flex Sensors		A sensor that measures the amount of bending.
Pressure sensors		A sensor that consists of a pressure sensitive element to determine actual pressure.
Inertial Measurement Unit	**IMU**	A sensor that includes an accelerometer and gyroscope.
Inertial Sensors		A sensor that includes an accelerometer, gyroscope and magnetometer.
Swanlinx		A fun day that is run in Swansea primary schools to collect data on fitness measures.
Movement quality		How a movement is performed, how does someone walk or throw. What are the mechanics,
Movement quantity		How much does someone move, how much time do they spend being active.

Development Coordination Disorder	**DCD**	A condition that affects an individual's physical co-ordination.
Typically Developing	**TD**	An individual with no apart clinical conditions.
Duchene Muscular Dystrophy	**DMD**	A genetic disorder where there is progressive muscle degeneration and weakness due to alterations in a protein called dystrophin.
Idiopathic Toe Walking	**ITW**	Where an individual walks on their tip toes.
Gilles Tourette's Syndrome	**GTS**	Neuropsychiatric movement disorder, characterized by multiple motor ticks and vocal tics.
Down Syndrome	**DS**	A condition in which an individual has an extra chromosome, this alters the course of development.
Prader-Willi Syndrome	**PWS**	A genetic multisystem disorder characterized during infancy by lethargy, diminished muscle tone (hypotonia) and feeding difficulties.
Parkinson's Disease	**PD**	Brain disorder that causes unintended or uncontrollable movements.
Autism Spectrum Disorder	**ASD**	A neurological and developmental disorder that affects how an individual communicates, interacts with other and how they behave.
Movement Assessment Battery for Children (version 1 and 2)	**MABC or MABC2**	An assessment tool used to identify a delay or impairment in childrens motor development.
Körperkoordinationstest für Kinder	**KTK**	An assessment tool used to measure gross motor function.
Bruininks Oseretsky Test of Motor Proficiency (version 1 and 2)	**BOT or BOT2**	An assessment tool that measures childrens motor development.
World Health Organization	**WHO**	World Health Organization is the public health body.
Characterization		A way of what typically happens within that condition/movement.

Definition		A way of saying how something happens, how they have measured it.
20-metre Multi-stage Fitness Test	**MSFT**	A assessment tool of measuring cardiorespiratory fitness by running back and forth on a 20m course.

Chapter 1:

Introduction

Movement is a natural part of human life (Cools et al., 2009), is a crucial part of development and continues throughout the life course (Gabbard, 2021). During infancy the foundations for good movement are laid, however delays in movement development are possible (Landa et al., 2013). Movement can be measured in terms of its quantity or quality. Specifically, dimensions of movement such as, steps/day or total physical activity energy expenditure, provide insight into the quantity of movement over a specific period of time (Bassett et al., 2017). On the other hand, these metrics do not capture information on *how* that movement has been performed or what movements have been performed, in other words the 'quality' or movement (Hendry et al., 2022). It should be noted that there is contention around what is included under the term of movement quality. One interpretation is that it should only include *the way someone moves*, from the way they perform fundamental movement skills (e.g., running, rolling, throwing) or more complex sporting skills (a movement that requires processing several different decisions such as a tennis serve), i.e., a heavily biomechanical influenced perspective. However, dimensions of movement such as 'intensity' could be argued to provide insight into both quantity and quality of movement, because such dimensions could influence the outcome of the movement, such as changes in health, fitness and motor competence (Palomo-Carrión et al., 2020). Thus, there is some overlap between the two aspects of movement.

Physical activity is a process of movement; the outcomes of physical activity are physical fitness and motor competence (Blair et al., 2001; Hands, 2008). These three aspects of movement, activity, fitness and motor competence, interact with one another (Hands & Larkin, 2006; King-Dowling et al., 2020; Stodden et al., 2008). A child with low activity levels may not develop motor competence or achieve their genetic potential for physical fitness (Silventoinen et al., 2021; Stodden et al., 2008). In turn, a child with low motor competence may subsequently perform less physical activity (L. Barnett et al., 2008; Cairney et al., 2019; V. Lopes et al., 2011) and, in turn, this may affect their physical fitness (Hands & Larkin, 2006). Thus, consideration of physical activity, motor competence and physical fitness is critical to ensure that children thrive during their development (Robinson et al., 2015).

Being active during early infancy through play allows a child to explore their environment and in turn develop fundamental movement skills (Goodway et al., 2019; Hardy et al., 2010). The level at which children perform these fundamental skills is described as their motor competence (Haywood & Getchell, 2009; True et al., 2017). Fundamental movement skills include basic movements such as running, jumping, throwing, catching, kicking and hopping (Hands, 2012). Fundamental movement skills allow infants to develop and learn more sophisticated movement patterns, which can be the building blocks to more complex movements (Hands, 2012). There is no exact age that babies should be able to talk, walk or crawl, the same as there is no exact age that children should have developed good motor performance and fundamental movement skills, however there are age windows that these milestones fall into (Slentz & Krogh, 2001; World Health Organisation, 2006). While genetics impact movement development, the environment also has an effect (Miquelote et al., 2012), such as deprivation status (Venetsanou & Kambas, 2010). Some children will adapt and learn fundamental movement skills independently and from their environment, while others may need instruction, intervention and encouragement (Hands, 2012). Despite children being able to perform movement skills, some may not perform them with proficiency or good quality and may not develop full competence or mastery of the skill (Hands, 2012; Hardy et al., 2010; Huan Zhao et al., 2017). It is important that children learn skills the correct way and that a wide variety of basic skills are learnt to help them fully develop their fundamental skills (Gallahue & Donnelly, 2003). It is easier for children to learn and develop these skills earlier rather than later (Goodway et al., 2019). Indeed motor skills may be left unlearnt if they are not experienced and developed during infancy or childhood (Gallahue & Donnelly, 2003), which may ultimately affect the child's physical development, their participation in physical activity due to low motivation and their confidence (Biddle et al., 2018; Jaakkola et al., 2013) in addition to hindering their ability to reach a high level of skill (Gallahue & Donnelly, 2003; I. Janssen & Leblanc, 2010).

These children are at risk of suffering from developmental delay and, without early intervention, this may cause problems into later life (Gravem et al., 2012).
Similarly, children with motor disabilities or delays such as cerebral palsy may not use typical motor patterns to perform these skills (Capio et al., 2011) as their ability to control movements is affected (Bjornson et al., 2008) meaning they adapt to their unique needs (Sato & Haegele, 2017). Children with cerebral palsy and autism spectrum disorder focus on the outcomes of the task (Capio et al., 2011; Staples & Reid, 2010), rather than focusing on how to complete the task.

During childhood these fundamental and complex movements can be applied to sport (L. Barnett et al., 2016), these sporting skills may continue to develop through adolescence and into adulthood (Gallahue & Donnelly, 2003). Without these skills it can be difficult for children to participate and succeed in sports such as football (Gallahue & Donnelly, 2003). The development of these sport-specific movement patterns are called specialized movement skills or fundamental sport skills (Gallahue & Donnelly, 2003; Goodway et al., 2019).
A good level or mastery of the fundamental and complex movement skills allows a more active behaviour (Holfelder & Schott, 2014). The recommended amount of physical activity for children is 60min of moderate intensity activity per day (CDC, 2022; NHS, 2021). This recommendation is met by roughly 20% of the child and adolescent population (Guthold et al., 2020; NHS, 2017). Physical activity levels have, and are continuing to be impacted by a shift in societal norms towards environments encouraging sedentary behaviour (Alfonsin et al., 2019; Marteau et al., 2012; Morton et al., 2016). An active behaviour positively affects physical fitness (Bremer & Cairney, 2018), with Cattuzzo et al. (2016) reporting a moderate to strong association with motor competence levels and aerobic and anaerobic fitness levels during late childhood and adolescence. King-Dowling et al. (2018) has also found this during early childhood. Physical activity levels during childhood can predict future physical fitness levels in adulthood (L. Barnett et al., 2008, 2009; Rivilis et al., 2012), showing the importance of being active at a young age and continuing this into adolescence.

There are 11 components of fitness (Corbin et al., 2000) that contribute to developing a good level of physical fitness. These are split into 5 health related and 6 skill related components (Corbin & Pangrazi, 2008). The health related components are associated with good health while the skill components are associated with the performance of the movement (Corbin & Pangrazi, 2008). The health-related components are: Cardiovascular fitness, flexibility, muscular endurance, body composition and strength. The skill related components are agility, balance, coordination, power, reaction time and speed. A good level of physical fitness is important as it allows individual's to perform skills in daily life with ease, while also limiting the likelihood of chronic diseases in later life such as heart disease and obesity (Tomkinson & Lang, 2018). A good level of physical fitness has also been linked to positive cognitive affects with children who are more active performing better in school (Kao et al., 2017).

In an effort to promote the importance of movement to children and adolescents, physical literacy is often something that has been embedded in the school curriculum during recent years (Association of Physical Education, 2013; Shearer & Foweather, 2018). Physical literacy is discussed globally, with different interpretations and also differing definitions have been discussed (Roeter & Jefferies, 2014). Physical literacy is "the motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for maintaining purposeful physical pursuits/activities throughout the life course" (Whitehead, 2013). The concept of physical literacy applies to all individuals of differing ability levels across their lifespan with each individual experiencing the concept differently resulting in an individual physical literacy journey (Edwards et al., 2017). This journey can be seen as a continuum that will ultimately be influenced by experiences in life (Whitehead, 2013) and is something that needs to be developed, maintained and also embraced throughout the life course (Faigenbaum et al., 2018). Physical literacy encompasses physical skill development, knowledge surrounding physical activity, habits, confidence, the desire to continue participating in physical activity (Roeter & Jefferies, 2014), while also allowing individuals to understand the benefits and different types of physical activity (Shearer & Foweather, 2018). Physical literacy provides children with the tools to become competent and confident and therefore a greater chance of becoming active for life.

These positive and important consequences of movement, whether it be fundamental movement skills or physical fitness are important aspects for healthy child development. Due to the importance of movement, there have been multiple methods to assess it over the years, from observational assessments, subjective methods and there is also the use of technology such as accelerometers, gyroscopes and IMU's also known as MEMs devices. The most common assessment form has been observational, these have typically assessed movement with assessment batteries or the use of fitness assessments (Brown & Lalor, 2009; Wuang et al., 2012). There are challenges to this method of assessment such as bias, agreement between reviewers, time to complete the assessments and standardizing approaches during follow up.
Assessment can take place in laboratory environment or in the field, the common method in children's assessment is to utilize the field environment. This is due to a number of benefits such as available cohort size, cost and also the ability to conduct the assessments in a familiar environment such as a sports hall. This allows the data to be collected within context unlike in a lab environment.

In recent years, as technology has improved the use of MEMs devices has grown rapidly (Choudhary & Iniewski, 2017). These devices have been used for recording the amount of time spent in physical activity or sedentary behaviour (W. Lin et al., 2018; Lynch et al., 2019). As these devices have gained popularity and a greater understanding of what they have to offer their uses have become wider, such as the inclusion into toys. This allows the measurement of smaller movements in daily life to take place alongside their traditional use of measuring the amount of time spent moving. MEMs devices are beginning to be used to assess quality of movement in place of movement assessment batteries like the Movement Assessment Battery for Children -2nd edition (MABC-2) and Körperkoordinationstest für Kinder (KTK). These devices tackle some of the challenges that arise with observational assessments, they remove the subjectivity and bias, they can be used repeatedly and they decrease the time of data collection and analysis. The devices allow for movement to be assessed objectively, the method of collection and analysis will remain the same over time, which may not be the case during observational methods due to different assessors being present. This ensures that the changes in fitness or quality can be accurately tracked.

The assessment of both quality and quantity are important, it is useful to know the quality of movement performed (such as how they walk, run and throw) to understand whether a child is developing well or to predict future injury risk (Bennett et al., 2017). It is just as useful to know the amount of time (quantity) they spend moving and being physically active each day and subsequently how fit and active they are. Understanding the quality, quantity and trends of childhood movement and fitness is vital if successful interventions are to be implemented to improve and tackle the current decline in children's activity, movement competence and physical fitness. It is also important to fully understand how these aspects naturally change over time, across these key points of development.

The age group of 9-11 years is an important age group to assess, this is where gender differences in fitness levels begin to be captured (Golle et al., 2015). This allows appropriate future interventions to be applied as these children move into high school. There is a lot of change in this age group, from their growth to change in schools and all this may impact on their natural fitness levels.

The overall aim of this thesis is to understand the factors that contribute to a child's movement and activity levels, their physical fitness and their quality of movement.

This thesis will firstly consist of a literature review discussing physical activity, physical fitness, fundamental movement skills, the importance of these areas with the health benefits they bring. It will also contain a synopsis of the current measurement tools and assessment methods while discussing how this is developing with the use of technology.

Secondly will be the first study, which investigates the changes in fitness levels of 9–11-year-old children over a one-year period. The aim of this study is to explore the natural changes that occur in fitness levels, across a wide range of components and fundamental movement skills, over the school year in children aged 9-11 years and any aspects that may explain these changes.

The second paper consists of a scoping review, which will aim to gather information and understand MEMs devices and how they have been used to measure quality of movement. While also discovering how quality of movement has been described and defined. Lastly there is a synthesis to conclude the research.

Chapter 2:

Literature Review

What is movement?

Movement is fundamental to human life, enabling daily life activities and interactions with the physical and social environment (Davidson & Correia, 2002; Studd & Cox, 2019). Movement begins prior to birth and is considered vital when assessing children's development and for maintaining a healthy life. Movement includes physical activity, physical fitness and motor competence, these attributes provide good movement and health, all of these areas of movement are equally as important as the other.

Physical activity

Physical activity is "any bodily movement produced by the skeletal muscles that results in an increase in metabolic rate over resting energy expenditure" (Bouchard et al., 2012; World Health Organisation, 2020). Physical activity includes different intensities, with light activity typically including house chores, a slow walk or any activity that does not cause a substantial increase in heart rate. Moderate activity is where the heart rate and breathing rate increases but the individual is still able to talk (NHS, 2021), such as a brisk walk or riding a bike. Vigorous activity is where breathing is harder and faster and the individual will not be able to say more than a few words (NHS, 2021), such as running and swimming. It is recommended that children should spend 60 minutes per day being physically active in the moderate to vigorous intensity, (Hallal et al., 2012; World Health Organisation, 2020) while also including a variety of activities to help develop muscles, bones and their motor competence skills (NHS, 2021). The activity guidelines solely focus on the amount of activity that should be performed, there is little about the quality of the activity performed.

Despite the importance of physical activity a large amount of daily life is spent in sedentary behaviour, while physical activity levels are low (Verloigne et al., 2012). Over 80% of adolescents do not reach the physical activity target (Hallal et al., 2012; World Health Organisation, 2020).

In further detriment to these figures the Covid-19 pandemic saw a decrease in physical activity levels due to the restrictions that were placed across the world (Moore et al., 2020; Zenic et al., 2020) with 42% of children and 58.7% of adolescents in France reporting a decrease in their activity levels (Chambonniere et al., 2021). Similar results were also found in Chile (Aguilar-Farias et al., 2021), the Netherlands (ten Velde et al., 2021), Italy (Pietrobelli et al., 2020) and the United Kingdom (Hurter et al., 2022). Pietrobelli et al. (2020) reported 2.30 ± 4.60 hours a week decrease in time spent being physically active. While physical activity decreased there was an increase in sedentary behaviours and screen time. Xiang et al. (2020) reported an increase of 30 hours a week in screen time. Pietrobelli et al. (2020) supported this with findings of a 4.85 ± 2.40 hours per day increase.

It has been stated performing light activity is more beneficial than time spent being sedentary (Dohrn et al., 2018). However there is a decrease in time spent in light intensity, this is being replaced by sedentary behaviour (Owen et al., 2010). Sedentary behaviour is considered as “any activity while awake, where the individual is sitting or lying and their energy expenditure is low” (Tremblay et al., 2017) typically below 1.5 METS (World Health Organisation, 2020). Examples of this behaviour are sitting while commuting, working or in school, during leisure time such as watching the TV, computer or technology use (Owen et al., 2010). Children spend around 65% of their school day in sedentary behaviour (van Stralen et al., 2014) with time spent ranging between 300 and 500 minutes per day (Carson et al., 2015; Larouche et al., 2016; Van Ekris et al., 2020; Verloigne et al., 2012; Yıldırım et al., 2014). Sedentary behaviour increases as children get older (Harding et al., 2015; X. Janssen et al., 2016) with Van Ekris et al. (2020) finding an increase of 21.4min/day per year, potentially due to increases in school work and screen time, including watching TV, and the use of mobile phones and computers (Fennell et al., 2019; Park et al., 2020). The age that children are accessing mobile devices is decreasing (Graafland, 2018) with a recent Ofcom (2019) study reporting that 52% of 3-4 year olds are accessing the internet, in many cases before they are exposed to books (Hopkins et al., 2013). Of significant concern is that sedentary behaviour tracks from childhood into adolescence and adulthood (Biddle et al., 2010; Kirsten Corder et al., 2015). This is a particular worry given that children's physical activity levels are already low and sedentary behaviours are high, the concern also extends to future generations if this problem is not tackled. Despite the issues surrounding sedentary behaviour some physical activity time has been reduced in schools to spend more time on the 'core-subjects' (Sallis, 2010) with some teachers prioritizing these core-subjects over movement time (Routen et al., 2018). This means that children do not learn the importance of activity.

Another impact on children's physical activity levels are the people that surround them. It has been reported children complete 5 to 10 minutes additional physical activity for every 20 minutes (Garriguet et al., 2017; Petersen et al., 2020; Sollerhed & Hedov, 2021) and 8 to 15 extra minutes of sedentary time for each hour completed by their parents respectively (Garriguet et al., 2017). Children model themselves on the behaviours they observe (Granich et al., 2010; Minges et al., 2015). This is an issue as 40% of men and 35% of women spend 6 hours or more being sedentary on the weekends in the UK (NHS, 2017).

Physical activity levels have an impact on the physical fitness of children (Biddle et al., 2010; I. Janssen & Leblanc, 2010). To ensure good health it is important to promote physical activity. In order to influence the physical activity levels of children it is important to consider their environment, both at home and in school, as this can promote or hinder the amount of physical activity they participate in (Binns et al., 2009; Dobbins et al., 2008). Additionally sociocultural influences such as parents and peers and physical influences such as age and gender also have an impact (Dobbins et al., 2008). Psychological determinants such as confidence, enjoyment and perception in skill or fitness level are also important to consider (Dobbins et al., 2008). There are multiple factors that affect participation in activity and it has been recognized that schools are a key area to target to increase participation and promote physical activity, due to the time spent in that environment (Dobbins et al., 2008). This has meant that schools have been the location for multiple interventions trialed to promote physical activity and increase physical fitness (Dobbins et al., 2008, 2013; Ryde et al., 2018; The Daily Mile, 2022; Van Sluijs et al., 2008). These interventions target all components of fitness to have an impact on overall fitness levels.

Physical fitness

Physical fitness is made up of several components, both skill related and health related (Corbin et al., 2000). These include cardiovascular, muscular endurance, strength, power, flexibility, body composition, agility, balance, speed and coordination. The ability to perform well across all these components provides an individual with a good physical fitness that allows them to perform physical activity and also daily activities with ease.

Current literature suggests that children's fitness is decreasing in the UK (Boddy et al., 2012; D. Cohen et al., 2011), in Europe (Dyrstad et al., 2012; Venckunas et al., 2017), and also worldwide (Eberhardt et al., 2020; Morales-Demori et al., 2017). Especially in the components of endurance, strength and flexibility (Eberhardt et al., 2020; Masanovic et al., 2020). Tomkinson, Lang, & Tremblay. (2019), reported a 7.3% decline in cardiorespiratory fitness over a 33-year period, this included 19 high and upper middle-income countries. Muscular strength declined in English 10 year old children with a 1.6% decline between 2008 and 2014 (Sandercock & Cohen, 2019), while Slovenian boys aged 6-10 years had a 0.6% increase in muscular strength and girls a 4.4% decrease over the same time period (Đurić et al., 2021). However while both assessed muscular fitness Sandercock & Cohen (2019) used handgrip strength as an assessment while (Đurić et al., 2021) used bent-arm hang, this could explain the different trends.

A common theme in children's fitness research is to observe changes in fitness post intervention (Eather et al., 2013; Lai et al., 2014; Lotan et al., 2004), during changes in seasons (Augste & Künzell, 2014; Rowlands et al., 2009), or the trend over a number of years by looking at different cohorts (D. Cohen et al., 2011; Đurić et al., 2021; Venckunas et al., 2017). While this is providing an overall picture of fitness levels over different generations, or how an intervention affects activity and fitness levels, it is not explaining how a child's fitness level naturally change over a period of time. There is very little research into how fitness tracks in the same children, this repeated measures design, to examine variation in fitness is rare, especially in the age group of 9-11 years old, which is a key age for development and maturation. It is important to understand these changes to ensure a better understanding of natural growth while also gaining clarity on what areas can be targeted for intervention design. The few studies that have observed this natural change report moderate tracking with an improvement in physical fitness (Roth et al., 2018; Werneck et al., 2019). Roth et al, (2018) studied children's fitness over 4 years from age 6-9 and found that physical fitness levels increased significantly over time in all of the components measured except for flexibility, it was also stated that the tracking of fitness was lower in girls than in boys. Roth et al, (2018) reported that the timing and speed of adolescent growth spurt influenced the stability of physical fitness. While Werneck et al, (2019) assessed over 3 years (aged 9-11) and also found that physical fitness tracked moderately and an increase in body adiposity was associated with a reduction in physical fitness.

It appears that while the level of fitness from each generation decreases, children do get physically fitter each year due to growth and maturation, which theoretically makes sense and it is important to understand this. However, there is currently a lack of evidence into this.

<u>Outcomes of physical activity and physical fitness</u>

Physical fitness is an outcome of physical activity and there are benefits to a good level of physical fitness. Participation in physical activity is important for the general health of individual's as it has a number of positive health benefits both physically and mentally (Biddle et al., 2018; I. Janssen & Leblanc, 2010; Warburton & Bredin, 2017). Being physically active reduces the risk of obesity (Hills et al., 2011) and helps with the reduction of body fat, 150-180 minutes of moderate-high intensity activity provides a 0.4% reduction in body fat (Atlantis et al., 2006). Obesity has been linked to poor physical fitness and health (Hills et al., 2011; Sahoo et al., 2015). There has been research that has found that adolescents fitness tracks into adulthood (Cale & Harris, 2006), as does obesity (Sahoo et al., 2015). Therefore if children have low physical activity levels and are obese they are more at risk of future health complications such as cardiovascular diseases (Ruiz et al., 2009), osteoporosis (Ortega et al., 2008), and type 2 diabetes (Rush & Simmons, 2014).

A consistent relationship has been found between a higher intensity of physical activity, and positive health indicators, such as body composition, physical fitness and cognition/academic achievements, among others (Poitras et al., 2016). High intensity physical activity is also linked to higher scores during physical fitness assessments (Leppänen et al., 2016), this is not the case for moderate or light activity. While moderate and light intensity activity are beneficial to overall physical fitness, and contribute to an individual's overall physical activity levels, the positive effects to health are not as strong as higher intensities (Poitras et al., 2016). Replacing lower levels of activity and sedentary behaviour with 5 minutes of vigorous activity a day results in a better cardiorespiratory fitness and motor fitness (Leppänen et al., 2016). High intensity physical activity also has an impact on speed/agility and standing broad jump performance (Martínez et al., 2016).

There is a correlation between physical activity, fitness and children's cognitive functioning (Donnelly et al., 2016) with an effect on working memory and cognitive life skills (Álvarez-Bueno et al., 2017). Physical fitness increases academic success in children (Coe et al., 2006; Donnelly et al., 2016; Eldridge & Hutson, 2021), with suggestions that those who partake in exercise perform better in school (Howie & Pate, 2012). Being physically active with good physical fitness reduces the risk of suffering from depression (Kremer et al., 2014) and improves confidence (Hills et al., 2011; Holt et al., 2011) and self esteem (Wang et al., 2009). Being physically active allows children to perform better socially (Eime et al., 2013), with participation in organized sport allowing social benefits such as making friends, learning teamwork and developing relationships with others such as coaches (Holt et al., 2011).
Levels of physical fitness have been associated with physical activity, physical performance and positive health benefits (Wu et al., 2021).

It is important for children to have a high level of fitness but also important to maintain this fitness particularly at the end of primary school. As children transition to high school they encounter many changes that affect their participation levels, such as the environment their new school is in, whether it is possible to actively commute (Coombes et al., 2014; De Meester et al., 2014). A large number of adolescents, especially girls have a decline in their physical activity levels (Ridley & Dollman, 2019) and subsequently their fitness as they navigate through development and puberty. It is important to understand the period prior to this change to enable correct promotion of physical activity.

Children can participate in a wide range of activities to improve their physical fitness ranging from organized sport to playing outside with friends, this variety helps children improve all areas of physical fitness and health and increases participation (Landry & Driscoll, 2012). For example, playing tag can improve their cardiorespiratory fitness while skipping also improves this component, it additionally helps with bone density and muscular strength (Ghani & Rambely, 2010). All patterns of activity, whether sporadic or continuous, provide benefits to a child's physical fitness (Poitras et al., 2016). This variety in activity challenges children on how they use their physical space and helps them develop their motor competence and fundamental movement skills (Gallahue & Donnelly, 2003).

Motor competence

Motor competence is important for a child's development, physically, mentally and socially (True et al., 2017), their motor competence is linked with their physical activity level (Stodden et al., 2008) and physical fitness level (Robinson et al., 2015). Fundamental movement skills are learnt and developed during infancy and early childhood (Gallahue & Donnelly, 2003). These skills are learnt through a child's environment, by watching others, interacting and being taught and they form a child's motor competence. It is important for children to learn the correct skills early on as these are their building blocks for future development. These skills allow children to explore their environment, participate in physical activity and organized sport. These skills enable a good quality of movement and allow development of sport-specific and specialized movements (K. Cohen et al., 2014).

Fundamental movement skills have three types of movement; stability, locomotor and object control skills (Gallahue & Donnelly, 2003). Each of these three skills are important to develop and each child will develop them at different rates. Gallahue & Donnelly, (2003) refers to stability skills as a movement where the "body remains in place but moves around it's horizontal or vertical axis" and includes balance, rolling and stretching. Locomotor skills are the body moving from one place to another such as jumping, running, skipping. Object control skills require the control of an object

(L. Barnett et al., 2016), there are two types of object control, gross and fine motor manipulation (Gallahue & Donnelly, 2003). Gross motor refers to the act of throwing, catching and kicking. Fine motor describes the act of accuracy such as tying shoelaces (Gallahue & Donnelly, 2003). Most sports require skills from all three categories, so it is important that a child develops all three areas. Participating in a variety of activities can achieve this.

Despite their importance, motor competence proficiency levels are not meeting an adequate standard with less than one fifth of children aged 6-9 years having mastered the fundamental movement skills of run, jump, throw and catch (Duncan et al., 2020). This has been further supported by Foulkes et al. (2015). With motor competence levels low, there is no foundation for children to establish healthy active lives (Duncan et al., 2022; Roscoe et al., 2019).

A child or adolescent who possesses poor fundamental skills and in turn poor motor competence is less likely to partake in physical activity (Goodway et al., 2019; Lai et al., 2014; Loprinzi et al., 2015) due to confidence issues around their poor fundamental skills (McGrane et al., 2017). This then ultimately affects their physical fitness levels (Wu et al., 2021). A good level of motor competence will provide an individual with motivation to carry on being active with an increased enjoyment while partaking in physical activity (Hands, 2012). This will also affect their future participation in physical activity and organized sport (Hands, 2012). The better a child performs their fundamental movement skills the more they will engage in physical activity or sport, in turn providing them with additional skills. This increases the gap between the low and high motor competence children (Goodway et al., 2019). How the skill is performed is deemed as quality, thus the performance of fundamental movement skills can be considered as quality of movement. Therefore, quality of movement ultimately has an effect on the quantity of movement performed. However at a young age, low physical activity levels mean there are less opportunities for the children to develop adequate skills (Goodway et al., 2019), therefore being active at a young age is important to develop and improve their skills. This is supported by Stodden et al. (2008) whose model suggests that physical activity affects motor competence during early childhood, however as the child grows older their motor competence drives their physical activity participation.

Monitoring a child's motor competence level provides an indication on whether that child is falling behind in their development, with the ability to see if a child is suffering from developmental delays (Bisi et al., 2017; Hoyt et al., 2019). These delays can be indicators of conditions such as cerebral palsy or developmental coordination disorder (Hoyt et al., 2019; Mannini et al., 2017) and by monitoring their movement and detecting delays there can be early invention to help combat any difficulties in development (Serio et al., 2013). Monitoring this allows insight into whether the child is thriving in their development.

Sex differences in fitness and motor competence

Through monitoring it has been found that there are sex differences, girls are typically less physically active (Telford et al., 2016; Tucker, 2008) and less physically fit (Marta et al., 2012; Telford et al., 2016) than boys. In some areas of motor competence assessment such as object control, boys also perform better than girls (Bolger et al., 2018; Vedul-Kjelsås et al., 2013). It has been reported that girls are 19% less active than boys, with cardiorespiratory levels 18% lower and hand-eye coordination 44% lower than boys (Telford et al., 2016). These results show the importance of monitoring as it allows an understanding of the differences and therefore allows adequate interventions to be put in place. Something that works for boys may not work for girls.

Maturation is a process that affects a child's body, their organs, tissues and hormones are all affected in this development stage (Malina et al., 2004). Maturation happens alongside growth and they are closely related (Malina et al., 2004). Boys typically maturate later than girls do, as they get older they get stronger, faster and in turn fitter (Dorø et al., 2005; Papaiakovou et al., 2009), this creates a wider gap between boys and girls during the teenage years (Papaiakovou et al., 2009). Maturation can explain some of the gender differences in physical fitness with Quatman et al. (2006) reporting gender differences in vertical jump performance and ground reaction forces due to maturation. Maturation has also been found to have an impact on peak Vo_2 levels with Armstrong and Wellsman (2019) reporting that maturity status exerts a positive independent effect on peak Vo_2 in addition to that of age and body mass. However they report that the changes in free fat mass (FFM), with maturity status are the principal influence on the increase in peak Vo_2 in youth (Armstrong & Wellsman, 2019). There are small differences in FFM between boys and girls during childhood and early adolescents, however after the age of 14, boys have more FFM for the same stature as girls (Malina, 2004). The research showed that boys peak Vo_2 increases with age until 16-18 years, where the rate of change in growth decreases, this leveling off of progression was seen in the mid teens for girls, around 13/14 years of age (Armstrong & Wellsman 2019).

This increase in performance with maturation has also been seen with sprint performance, agility and lower limb-power, with Towlson et al (2018) reporting an increase in the performance of these components prior peak height velocity in boys. This was seen between the ages of 11.8 to 15.8 years, after which the trajectory decreased.

Typically in the age group of 9-11, a large number of girls have begun to mature, while many boys have not begun this process as they typically begin maturation 2 years after girls (Hauspie, 2002; Hauspie & Roelants, 2012). It is important to know how this natural development can impact on their fitness levels. Children’s fitness is commonly assessed but looking at their fitness over a time period during this process is rarely done.

Physical Literacy

Physical literacy teaches the children the importance of physical fitness, activity and motor competence (Silverman & Mercier, 2015). It can be described as “the motivation, confidence, physical competence, knowledge and understanding to value and take responsibility for engagement in physical activities for life” (International Physical Literacy Association, 2017; Whitehead, 2013). It allows children to understand the benefits of physical activity and promotes a positive attitude towards physical activity. It focuses on the development of fundamental movement skills to aid confidence and increase participation in physical activity. Children will carry these skills and knowledge through to adolescence where hopefully they will continue with physical activity (Whitehead, 2013). Children can progress and regress along their physical literacy journey if they are not challenged by their environment, physical or psychosocial factors (Faigenbaum et al., 2018). Physical literacy is a behaviour that needs to be developed and maintained through the life course.

Typically, during adolescence physical activity decreases, especially in girls and physical literacy aims to combat this, with late childhood being a critical period for physical literacy development (Longmuir, 2013). By being physical literate an individual will understand the importance of physical activity and will be able to help others acquire the necessary skills to continue with a physically literate lifestyle into adulthood.

Physical literacy helps the quality and quantity of movement, making sure that both are developed this is important to ensure a child has a well-rounded development.

Physical activity, physical fitness and motor competence provide information on how much an individual has moved but also how they have moved. Currently there is more focus on how much a child moves, have they met the physical activity guidelines rather than how they move during that time. More recently quality has become important, with research into motor competence and a focus in schools on physical literacy both quality and quantity are showing their importance and need for both to be measured.

Assessment methods

Physical activity, physical fitness and motor competence each require different methods to assess and understand the performance. Over the years there has been a multitude of different ways to gain insight into movement (Sylvia et al., 2014), these have ranged from observational techniques (Cools et al., 2009) and self-reporting questionnaires (Chinapaw et al., 2010) to the use of technology such as MEMs devices (H. Chen et al., 2016; Clark et al., 2018). In addition to the above, household technology such as tablet computers, have also been used in some fields to assess movement quality (Price et al., 2015; Huan Zhao et al., 2017).

A large amount of research in children has focused on the quantity of movement, the amount of physical activity that children should perform and how little they should be sedentary (Colley et al., 2011; Piercy et al., 2018). Over recent years the importance of quality is now also being considered (Hoogenboom et al., 2013; Myer et al., 2015) and the increasing interest has meant technology has evolved with screening tools and technology being developed (Bennett et al., 2019). All the information gathered from the different assessments allow for interventions to be developed that correctly target an area of weakness. There are two types of data collection, subjective, when an individual self-reports their activity and objective, when there is data surrounding the activity. There are benefits and limitations to both methods, of which are listed subsequently with the testing procedures.

Methods of Self-reporting physical activity

Self-reported questionnaires are a popular tool for collecting physical activity data (Sirard & Pate, 2001) and are the most common method for assessing quantity of movement (Castillo-Retamal & Hinckson, 2011; Dyrstad et al., 2014; Trost, 2007; Westerterp, 2009). These questionnaires are used to collect a variety of information, dependent on what questionnaire is used, from frequency, duration, intensity, type of activity and whether it was a leisure time activity (Sylvia et al., 2014). They give a researcher an overall view of how much the participant moves and sits. Whilst this form of data collection is low cost, can be used on a number of participants, and is completed by the participant with little effort (Sirard & Pate, 2001; Sylvia et al., 2014; Westerterp, 2009), there are limitations to this method. Responses to questionnaires can be influenced by what the participant thinks they should answer, which could lead to an overestimation of time in physical activity (Adamo et al., 2009; Basterfield et al., 2008). The questionnaires also required participants to recall their activity (Sylvia et al., 2014), this can be particularly challenging for younger children, especially when trying to recall the duration and intensity (Janz et al., 1995; Sirard & Pate, 2001). An additional aspect to questionnaires is having these questions asked by an interviewer. Although this method requires a trained interviewer and the data collection period potentially takes longer. Wallace et al. (1985) found a 75% agreement between a direct observation of physical activity and a 7-day recall when led by an interviewer. Indicating that this method of recall may be beneficial to the younger population or those who require assistance in completing the tool, such as older adults or individual’s where English is not their first language. The final type of self-reporting physical activity is the form of an activity diary, however there seems to be more limitations around this method with few studies using it due to the high amount of effort required by the participant (Sirard & Pate, 2001; Trost, 2007). Bouchards’ Physical Activity record (Bouchard et al., 1983) is the common activity diary used, however it requires the participant to record their movement every 15 minutes which is time consuming. While it has been found accurate and overcomes the limitations of recall error with the use of adults and teenagers (Van Der Ploeg et al., 2010), it has been suggested to not be used with children under the age of 10 (Sirard & Pate, 2001; Trost, 2007).

The issue that the questionnaire brings is the lack of context, understanding how an activity was performed, or in some cases what activity was performed. Quality is difficult to assess with this method. It does not gather information on how an individual uses space, speed or their intensity of activity.

Observational techniques

Observational techniques are an objective measurement and require an independent observer. Alternatively observation can occur indirectly from the use of a video (Hardy et al., 2013). This technique can be beneficial for the monitoring of children as it overcomes the limitations of children recalling their activities. This method allows context to be provided to the performance, it can be observed if a child is performing the amount and intensity of physical activity they report (Sylvia et al., 2014). However observation techniques are costly (Hardy et al., 2013; Trost, 2007) and require the need for trained observers to be present, which can cause issues with data collection. An additional limitation is the burden on the experimenter (Sirard & Pate, 2001), there is a lot of time observing and analyzing results (Trost, 2007). There may also be a reactivity by the participant (Sirard & Pate, 2001) as it may make them feel uncomfortable being observed, however Puhl et al. (1990) reported that only 16.6% of their participants aged 5 to 6 reacted to the observes. Observational techniques can take place in a wide range of environments (Sirard & Pate, 2001) and provide a greater understanding of how space is used, especially in comparison to questionnaires. However, it is challenging to use this technique over a long period of time due to the time commitments of the observers and the subsequent analysis of this.

Assessing physical fitness

Observational techniques are commonly used when assessing a child's physical fitness in the form of fitness batteries. Investigating physical fitness can provide information on the effects of physical activity, sleep, diet and lifestyle factors on an individual's overall fitness level. There are multiple batteries that are used to monitor health (Ortega et al., 2008) and focus on most of the components of fitness such as

Eurofit, PREFIT, FITNESSGRM and the ALPHA (Council of Europe, 1983, 1988; Ortega et al., 2015; Plowman & Meredith, 2013; Ruiz et al., 2011). It is important that all the components are assessed, as only observing one or two will not provide an overall and true picture of an individual's physical fitness (Marques et al., 2021). Physical fitness assessments provide a result for each fitness component, which subsequently can be used to classify the performance and indicate physical fitness level. This is common across all components with normative data allowing comparisons between countries and across years (Catley & Tomkinson, 2013; Tomkinson, Carver, et al., 2017; Tomkinson, Lang, et al., 2017).

There are several different assessments used for each component. Cardiorespiratory fitness is the "ability of the circulatory and respiratory systems to supply oxygen to the skeletal muscles during sustained physical activity" (Armstrong & Welsman, 2019; Corbin et al., 2000). This component of fitness is the most commonly researched component and is typically assessed with the 20-metre shuttle run or 1 mile run/walk (Marques et al., 2021). The 20-metre shuttle run, also known as the multi-stage fitness test (MSFT), being the most popular field measurement tool (Tomkinson, Lang, et al., 2017). All these assessments are validated and have proven to be reliable (Mayorga-Vega et al., 2015; McSwegin et al., 1988). They are excellent for use in schools due to the low cost, little equipment required and the high number that can be assessed at one time. From these field tests the maximum aerobic capacity of a child can be predicted however there are major concerns around this estimation (Armstrong & Welsman, 2019; Welsman & Armstrong, 2021) with belief that potentially comparing laps, stages or time is more beneficial and provides a clearer picture (Marques et al., 2021). It has been stated that the MSFT should only be used as an indicator of cardiorespiratory fitness. It is possible to measure cardiorespiratory fitness in the lab with a Vo2 max test, this is a gold standard test however it is expensive and does not allow a great number of participants to be assessed (Armstrong & Welsman, 2019).

Agility is a skill based component and relates to the "ability to rapidly change the position of the entire body in space with speed and accuracy" (Corbin et al., 2000). This component is typically measured in the field with the 10 x 5m shuttle

(Tomkinson et al., 2018) and has been found to be valid and reliable (Booney et al., 2019).

Flexibility is a health component, it relates to “the range of motion available at the joint” (Corbin et al., 2000). In the field, the sit and reach test is used, it is easy to use and has been proven to be a reliable (Baltaci et al., 2003) and valid assessment of hamstring flexibility (Mayorga-Vega et al., 2014; Patterson et al., 1996). However there is a little validity when assessing lower back flexibility (Jackson & Baker, 1986). There is a concern that the sit and reach assessment does not consider leg length of the participants (Castro-Pinero et al., 2009).

Muscular fitness is a component that is commonly assessed and includes different aspects such as strength, power and muscular endurance. This area of assessment requires little equipment and is easy to complete in a field environment such as a school (Marques et al., 2021). Strength relates to the “ability of the muscle to exert force” (Corbin et al., 2000) and is typically assessed with dynamometers that measure handgrip strength (Marques et al., 2021). This has been proven both valid (Castro-Piñero, Artero, et al., 2010) and reliable in children (Gąsior et al., 2020). Power is the “ability to exert muscle force quickly (Corbin et al., 2000). Power can be assessed with the standing broad jump or vertical jump (Marques et al., 2021). Castro-Piñero, Artero, et al, (2010) reported that there was limited evidence utilizing these assessments and therefore there are still questions around their validity. However he has also reported that standing long jump may be considered as a general index of muscular fitness (Castro-Piñero, Ortega, et al., 2010). Rahman et al. (2021) and Bulten et al. (2019) have reported validity and reliability for the standing broad jump to assess leg power.

These assessments can be completed in a laboratory environment however this is costly and time-consuming meaning there is a limitation on the number of participants that can be assessed per session. The field environment allows a larger number of participants to be assessed while still providing valid and precise results. A larger cohort allows for a greater understanding of what is happening to fitness levels within that cohort. This information provides researchers with the knowledge of what the current levels of fitness are and what happens when there are changes in physical activity and movement levels. It allows an understanding of whether interventions have been successful. However physical fitness assessments can be impacted by the motivation of the children and the effort they put in (Wiersma & Sherman, 2008), especially when observing cardiorespiratory fitness and the 20-metre shuttle run due to the assessment requiring the child to work until exhaustion (Tomkinson, Lang, Blanchard, et al., 2019). A laboratory environment may create a decrease in motivation due to the unfamiliar environment and could be daunting for children, this may cause a decrease or change in performance level (Razak et al., 2010). An environment such as a school playground can impact how children behave as they feel more at ease in familiar settings (Xu et al., 2006), it's possible to learn more about their natural behaviours (Razak et al., 2010).

Initiatives such as Swanlinx and SportLinx have been used to allow physical fitness assessment to be more enjoyable, as physical fitness assessments have been seen to have an impact on a child's motivation to participate in physical activity. Low physical fitness scores may potentially decrease a child motivation, enjoyment and confidence to participate (Rice, 2007; Wiersma & Sherman, 2008). However Jaakkola et al. (2013) found that children had a higher level of intrinsic motivation during fitness assessments compared to physical education lesson potentially due to it offering more of a challenge and that positive experiences can increase their perceptions of competence. Despite this finding Jaakkola et al. (2013) also found that the fitness assessments promote a negative motivational experience, which has been suggested that this was due to them creating fatigue and therefore a negative experience, which is in line with Rice, (2007).

Physical fitness assessment has allowed an overall picture of children's fitness levels globally to be assessed and has provided great insight into fitness trends. However, looking at the same children year on year is less commonly seen, as is research into natural changes. This study aims to gather this information using the above methods.

Micro-electromechanical devices (MEMs)

Micro-electromechanical devices (MEMs devices), are technology (Liu et al., 2022; Migueles et al., 2017; Sylvia et al., 2014) that include a wide number of devices, such as accelerometers, gyroscopes, magnetometers, barometers and inertial measurement units (IMU's). They are small structures (Dadafshar, 2014) and are wearable devices that are used to monitor activity (Esfahani & Nussbaum, 2018).

Accelerometers are electromechanical devices that measure acceleration forces and linear acceleration along an axis (Dadafshar, 2014). Acceleration is directly proportional to the force acting on the object to move it (Williams & Rawat, 2008). To begin with, accelerometers were predominately used to measure the amount of time and intensity that an individual was moving (Westerterp, 2009). Accelerometers have difficulty measuring dynamic movements and have a limited ability at assessing low-intensity activities and sedentary behaviours (Esfahani & Nussbaum, 2018). Gyroscopes provide additional information as they measure the rotation and angular velocity of an object, allowing a clearer understanding of the body in space (Dadafshar, 2014; Geen & Krakauer, 2003; Passaro et al., 2017). Over the years, as technology has improved there has been an increase in the use of inertial sensors and inertial measurement units. Inertial sensors include both accelerometer and gyroscopes allowing a greater range of information to be collected and provide more accurate kinematic measures when combined (Esfahani & Nussbaum, 2018). While it is possible to assess quality with an accelerometer, inertial sensors have made this task a lot easier as it is possible to understand the acceleration alongside the mechanics of a movement from the gyroscope as an accelerometer does not provide orientation information (Luinge & Veltink, 2005). IMU's occasionally include the addition of magnetometers which increases the accuracy of orientation estimation in the vertical axis (Esfahani & Nussbaum, 2018). IMUs have provided new insight into movement by moving past linear acceleration only to include acceleration in 3 directions alongside the rotational acceleration (rads/sec2) of the gyroscope.

There are several benefits to the use of MEMs devices, they allow the recording of data to be collected with minimal bias (Bardid et al., 2018) as well as take place in any environment (Bardid et al., 2018; Bastian et al., 2015). The environment in which data collection takes place can impact a child's movement characteristics (C. Newman et al., 2013) as an unfamiliar environment such as a laboratory will not reassure the child. It has been suggested that automatic classification tools developed within a lab may not perform as successfully as when the data from free living is used (Bastian et al., 2015).

Another benefit of the devices is their large memory capacity (K. Chen & Bassett, 2005), which allows for prolonged periods of time to be assessed (Bardid et al., 2018; Troiano et al., 2008; Westerterp, 2009). Finally the devices are small and light (Troiano et al., 2008) which allows them to be used on infants as well as not impacting the movement of the individual that wears them (Gravem et al., 2012). MEMs devices have been found to be a valid assessment method (C. Newman et al., 2013; Nooijen et al., 2015; Requena et al., 2012).

However, there are limitations to MEMs devices, particularly their validity when measuring activities such as weight lifting, cycling and rowing. Typically levels of physical activity are underestimated in these activities (Lagerros & Lagiou, 2007). This is due to the movements not being clear enough and the acceleration and force traces looking similar to other movements such as sedentary behaviour.

A large limitation of MEMs devices is the human and device noise that is present during data collection. This could be from the rattle of the device to the measurement of other movements not intended to be recorded such as steps prior to a throw. Device and human noise should be taken into account when analyzing the results (Mohd-Yasin et al., 2010). If an individual is wearing the device all day to measure energy expenditure, a movement such as rowing may be classed as sedentary behaviour, the devices provide little context to the activity.

The devices are expensive and while relatively easy to distribute and use, the analysis and interpretation of data can be more complicated with technical expertise required (Ward et al., 2005). There is a lot of data provided from these devices however not all of the data is being used (Liu et al., 2022).

MEMs for Physical activity

Typically, accelerometers have been the most commonly used device to measure physical activity, this is due to the nature of the movement. An accelerometer can measure how much time one spends moving from the acceleration force. This is measured in movement counts and gravitational unit (G). This information is then converted into valuable information that is biological, such as energy expenditure or related to their physical activity patterns such as time stationary (Freedson et al., 2005). Accelerometers can measure a wide range of data from steps in a given time period to time spent sedentary, standing or walking (Sylvia et al., 2014). This

information allows researchers to know how much and what activity participants are engaged in.
Accelerometers allow physical activity to be measured without bias, in comparison to physical activity questionnaires. Dyrstad et al. (2014) found that there was a variation in self-reported time for vigorous activity and sedentary time compared to the accelerometer devices. There is poor agreement between accelerometers and physical activity questionnaires (Dyrstad et al., 2014).

When assessing physical activity, accelerometers are typically placed on the ankle (Crouter et al., 2018; Duncan et al., 2020), wrist or hip (Boerema et al., 2014; Fairclough et al., 2016; Routen et al., 2012). There have been multiple studies looking into what placement is best (Boerema et al., 2014; Fairclough et al., 2016; Routen et al., 2012). Wrist worn accelerometers tend to have more wear compliance with children (Fairclough et al., 2016; Routen et al., 2012).

When assessing physical activity gyroscopes are not commonly used due to the fact that most information can be gathered from the accelerometer. However, gyroscopes and IMUs provide additional information such as how the space is used. The device used is often dependent on the outcome of the study.

MEMs for quality of movement

Assessing quality requires additional information in comparison to measuring time spent in physical activity. Gyroscopes are commonly used in the field of quality due to the information they provide about range of movement, space and angular velocity (Dadafshar, 2014).
IMU's include both accelerometers and gyroscopes, which allows both the quality and quantity to be assessed simultaneously. Quality of movement with MEMs devices can be assessed in a wide number of populations such as Parkinson's disease (Brognara et al., 2019), cerebral palsy (Carcreff et al., 2017), infants (Chen et al., 2016) and also typically developing children (Clark et al., 2017).

Assessment of quality with MEMs devices has not been as common as the research surrounding quantity. There may be different reasons for this such as difficulty surrounding the assessment process, and the additional cost of a gyroscope.

Currently there appears to be a disagreement in what is deemed as quality of movement (Bisi et al., 2017; L. Lopes et al., 2019). Using MEMs devices to assess quality has allowed an opportunity to observe and compare different clinical conditions to typically developing cohorts. This has allowed a greater understanding in the differences in movement, which in turn allows a more specific intervention to take place. Brégou Bourgeois et al. (2014) found that children with cerebral palsy had a shorter stride length, a decreased foot strike and lift off angle when compared to typically developing children. The devices allow for a greater understanding of the small nuances in movement, for example understanding the smaller details that are difficult to see by the eye. Such as observing lower accelerations of the thigh during frog jumping in children with DCD suggesting poorer muscle strength and efficiency while performing the movement (Ricci et al., 2019; Sahoo et al., 2015).

Studies have begun to utilize MEMs in creative ways to limit the perception of being assessed, such as Rivera et al. (2016) who placed an accelerometer into a cube. The information they gained from this was an understanding of how the child placed and stacked the cubes, and the accuracy of their movement (Rivera et al., 2016). Similarly Moradi et al. (2017) placed an accelerometer in a toy car, this helped recognize and distinguish movement patterns between typically developing children and those with autism spectrum disorder. This has thus far been successful and provides an additional avenue to measure quality of movement during natural play. However this method does bring up issues regarding the structure and materials of the devices used (Serio et al., 2013). For example when using a toy it should be interesting to the child and they should not perceive they are being assessed or the presence of the devices (Serio et al., 2013).

When assessing quality of movement MEMs devices can be worn in numerous places on the body depending on what is being assessed, such as wrist, ankle, hip, and thigh (Sylvia et al., 2014). This allows the assessment of a wide range of topics of movement such as gait, postural control, upper limb movement and spontaneous movements in infants. It is also becoming increasingly common to see MEMs being used in creative ways to measure the quality of movement such as within objects (Moradi et al., 2017; Rivera et al., 2016).

Over the years there has been a greater understanding of device placement and utilizing the devices (Anwary et al., 2018). MEMs devices allow assessment to take place in the field, this allows children at play or infants spontaneous movements to be assessed without the need for constant observation.

By utilizing MEMs devices successfully, a new perspective on both quality and quantity of movement can be provided. The devices allow for movement to be understood, which in turn allows correct, effective and tailored interventions or support to take place. Each individual, despite performing the same activity will have a slightly different movement pattern and a different quality of movement (Raket et al., 2016). To help target and improve individual's movement it is important to tailor interventions to their skill levels. There is little research into how these devices are used to assess quality and the scoping review in this thesis aims to interpret the currently published research in this area to provide a clearer synthesis of the research.

Other quality assessments

Prior to the use of MEMs devices to assess movement quality, assessment batteries were the commonly used tool (Jaikaew & Satiansukpong, 2021). These movement assessment batteries are an observational method. A video camera is occasionally used to re-visit a movement, as some smaller movements or the technique of a movement can be missed in real time (L. Barnett et al., 2014). This method requires trained qualified assessors to score how the movements are performed (Bardid et al., 2018). Occasionally there can be disagreements in the assessors scoring the movement, as the testing process is subjective, the inter-rater reliability is important to consider and ensure that the rater effect is minimal to ensure the assessment process is reliable (Gwet, 2014). Inter-rater reliability is the degree of agreement among observers while assessing the same subjects (Walter & Tsiberidou, 2019).

These assessment batteries can be time consuming both in the implementation but also the data assessment (Bardid et al., 2018), the batteries investigate the product and process measures. The product assessments measure the outcome of the movement, for example, did the child catch the ball. While the process score focuses on the quality of the movement and how it was performed (Bardid et al., 2018), for example did the child perform the overarm throw with a straight arm?

There are multiple assessments that measure the product outcome such as the Körperkoordinationstest für Kinder (KTK), the Bruininks Oserestsky Test of Motor Proficiency (BOT) and the Movement Assessment Battery for Children (MABC), there are also other versions of these tests such as the MABC-2 and BOT-2 (Darsaklis et al., 2013; Wuang & Su, 2009). The KTK assessment battery (Kiphard & Schilling, 1974) has a high evidence of inter-rater reliability at 94% (Rudd et al., 2016), however it does not specifically assess the fundamental movement skills and does not include object control (Bardid et al., 2018). The MABC (Henderson & Sugden, 1992) has mixed evidence for its validity and reliability, while its inter-rater reliability is strong (Eddy et al., 2020) although it does not measure locomotor skills. The BOT assesses all three fundamental components with good reliability and good evidence for inter-rate reliability (Eddy et al., 2020), however it is a costly and time consuming assessment (Eddy et al., 2020). TGMD measures the process of movements and is the most reliable and valid tool (Eddy et al., 2020), although it does not assess stability (Ulrich, 1985).

The Dragon Challenge is a recent development that is used to assess both the process and the product for all three fundamental areas, it also includes the assessment of complex movement skills (Tyler et al., 2018). This method is a dynamic assessment, rather than the static approaches of the previously mentioned tools (Tyler et al., 2018). The Dragon Challenge has also been proven to be a valid and reliable tool for the assessment of children's movement competence who are aged 10 to 14 years (Tyler et al., 2018).

An assessment tool that measures all three fundamental movements is important due to most sports requiring all three movements to perform successfully, each movement on its own is also equally important as they each contribute to overall movement (Dobell et al., 2020). Assessing all three gives a more comprehensive assessment of the child's motor competence and current skill level. It is possible for a child to achieve the product score without the skill being performed correctly and therefore this may have an influence on their overall motor competence level, such as an overarm throw being performed without a step forward with the opposite foot to throwing arm but still hitting the target.

More recently there has been the inclusion of MEMs devices alongside the testing batteries (Bisi et al., 2017) to allow for an overall assessment and better efficiency (Bardid et al., 2018). It reduces the subjectivity of the batteries while also providing a greater insight into the small details of movement. By combining the assessment of both quality and quantity a greater understanding of movement will be present.

This thesis aims to collect information on MEMs devices and how they are used to measure a child's quality of movement. It is important to gain an overall view on what areas are measured and how, while also understanding how quality of movement is defined. This will create a clear picture for future research to work from.

Future application and importance of such work

All of the above methods of assessment are beneficial in monitoring a child's fitness level, their physical activity and their motor competence. While there are limitations in all methods, the information collected provides the opportunity to identify issues. Once these issues are identified it is clear to see what areas need to be targeted, the next step from here is the development of interventions that target the issue. These interventions could tackle issues such as poor skill performance or low activity levels which could be targeted by implementing schemes such as walking buses or the daily mile, which are completed at school. Interventions could also target a specific cohort such as getting more girls into sport or specific skills such as working on fundamental skills. Not all interventions are 100% successful but they help give an understanding on what promotes change and development in children. By using the assessments post intervention, it provides an insight into whether the issues have been targeted efficiently.

Aside from interventions a greater understanding of physical activity, fitness and motor competence allow relationships such as that between quality of movement, fundamental movement skills and motor fitness (Wu et al., 2021) to be explored. Wu et al. (2021) reported that 60.5% of children with excellent fundamental movement skills and 59.6% with high QOM had good motor fitness. Over recent years there has been a decrease in the quantity of movement; physical activity levels, while there has also been a decrease in the quality of movement; fundamental movement skills and motor competence. By understanding that both of these affect one another and how natural growth also has an impact, a greater understanding of how to tackle the issues may be present, thus allowing the design of more effective interventions.

Concluding statements

Movement is a vital aspect of life with physical activity, fitness and motor competence all contributing to a healthy life both physically and mentally. There are clear benefits of a high level of fitness and motor competence shown with the relationships with cognitive performance and future health. However, both fitness and motor competence in the global population are decreasing year on year. Interestingly there is a lack of research understanding what happens to a child's fitness level as they grow older. Is it possible that children increase their fitness as they grow older due to maturation and growth, however overall fitness is decreasing generation by generation due to the changes in lifestyle influences? A clear picture of natural changes is important to understand how best to target children's fitness and this is currently lacking in the literature.

Additionally, is it time to begin to understand the impact quality has on their performance and how to assess this quality effectively with the use of technology. There is growing research in the area of children's quality of movement with MEMs devices, however there currently seems to be no structure to the reporting. Quality of movement is important because it promotes a healthy and active life, provides children with the ability to participate in activity while reducing the likelihood of injury. By understanding both quality and quantity there is the likelihood of a more successful intervention and development of children's fitness, activity and motor competence levels.

Chapter 3:

Study 1:

One-year changes in motor fitness in 9–11-year-old children

3.1 Abstract

There is evidence that children's fitness levels have declined over the last 20-30 years. However, these conclusions have been largely based on comparisons of independent observational studies and there are few examples of longitudinal studies tracking natural changes in components of fitness in children. The purpose of this study was to investigate 1-year changes in field-based measures of fitness of 9-11-year-old girls and boys. Participants included 575 children (277 boys, 298 girls; aged 9.96 ± 0.32 in year 5, and 10.94 ± 0.31 in year 6) from 14 schools across south Wales. Each participant completed a battery of field-based fitness tests including the 20-metre multi-stage fitness test (MSFT), handgrip strength (GS), sit and reach, speed bounce, standing broad jump and 10x5m agility run, on two occasions separated by approximately 1 year. With the exception of sit and reach, there were mean improvements in all components of fitness over the 1-year period. With the exception of speed bounce performance, these improvements persisted even after adjusting for changes in BMI (z score), the number of days between the fitness tests and baseline performance.

All components except for grip strength had a significant main effect for gender, when adjusting for the covariates, the result was unchanged for grip strength, 10x5m and sit and reach. While there was a change in significance for multi-stage fitness test, speed bounce and standing broad jump, which, all became non-significant.

On the other hand, there was a significant difference in the change scores of boys and girls for sit and reach and speed bounce performance (both $p<0.05$); the increase in speed bounce performance was more pronounced in girls compared to boys whereas the decrease in sit and reach performance was more pronounced in boys. Together, these findings suggest that many components of fitness improve naturally over the course of a 1-year period in 9–11-year-old children and to an extent that is greater than would be expected by growth alone.

3.2 Introduction

Children's physical fitness is influenced by a number of factors, including physical activity, sedentary time, genetics, socio-economic status and parental behaviour (W. Chen et al., 2018; Garriguet et al., 2017; Marques et al., 2015; Marta et al., 2012; Pavón et al., 2010; Silventoinen et al., 2021). There are 11 components of fitness, 5 of which are defined as health related and 6 that are defined as skill related (Corbin & Pangrazi, 2008). Sufficient levels of fitness are important for children and their development; indeed, high levels of fitness in children are associated with numerous positive physical and mental health benefits (Tomkinson & Lang, 2018) and provide the foundations for physical activity related skill development and sporting success (Ceschia et al., 2016; Tomkinson & Lang, 2018). Furthermore, cardiorespiratory fitness, speed-agility, motor coordination, perceptual-motor skills and body mass are associated with academic performance (Donnelly et al., 2016; Kao et al., 2017; Rauner et al., 2013; Ruiz-Ariza et al., 2017; Torrijos-Niño et al., 2014).

Fitness levels in childhood track through to adulthood (Tomkinson & Lang, 2018); indeed, low fitness in childhood increases the risk of obesity (Dwyer et al., 2009; Ortega, Artero, et al., 2011), stroke (Tomkinson & Lang, 2018) and cardiovascular disease (Hills et al., 2011) later in life. Despite the known benefits of maximizing fitness levels in children, cross sectional studies on children's fitness suggest that both muscular strength and cardiorespiratory fitness have been decreasing over the last 20-30 years (Boddy et al., 2012; Moliner-Urdiales et al., 2010; Sandercock & Cohen, 2019; Stratton et al., 2007). However, the cross-sectional nature of these studies is a key limitation and there are few examples of studies where fitness components have been tracked over time in the same cohort of children using a repeated measures design.

The few studies that have used longitudinal designs have only measured fitness at 1 time point after an intervention (Watson et al., 2019), or have only included a few select components of fitness (Butterfield et al., 2008; Werneck et al., 2019). There is a gap in the literature of research assessing all components of fitness at once to ensure an understanding of overall fitness levels. Other studies that have observed fitness changes have researched the impact due to factors such as seasonal change (Hjorth et al., 2013). These studies have also not been completed in the UK (Roth et al., 2018; Werneck et al., 2019) and it is possible that different policy implementation in different countries could impact the findings (Masanovic et al., 2020). Monitoring the natural changes in fitness without interventions is not common and this study aims to fill the gap in the current literature. It is vital to understand the growth and development of children alongside understanding the factors that are associated with poor fitness (Boddy & Stratton, 2020; Ortega, Labayen, et al., 2011). This is important as it provides insight into the natural changes that may occur due to genetics, lifestyle behaviours such as physical activity or sport participation, or maturation. However, it must be noted that natural interventions such as changes in school year/schools can also have an impact. Understanding natural changes in fitness in children can help guide policy and interventions by highlighting the areas of fitness that require help. Interventions can be created by the government, local council or the schools themselves (Chesham et al., 2018; Innerd et al., 2019; Pate et al., 2013). While regular fitness assessment can help detect any development problems the children may have, ensuring that early spotting means early treatment and additional support for those who need it (Harris & Cale, 2006).

Theoretically due to maturation and growth (Bohannon et al., 2017; Malina et al., 2004; Meyers et al., 2016; Towlson et al., 2018), children's fitness levels (or at least performance in fitness assessments) should track through to adulthood (Werneck et al., 2019) where it will once again decrease with older age. Maturation is a process that affects the whole body, including tissues, organs, hormones and functions (Malina et al., 2004). Maturation will typically affect performance in strength, speed and power components (Malina et al., 2004). Therefore it is expected that handgrip strength performance will increase, Bohannon et al. (2017) has previously reported that maturation affected changes in strength. The improvement in speed has also been reported on previously (Meyers et al., 2016; Towlson et al., 2018). This being said we would expect to see an improvement in the performance of handgrip strength, 10x5m shuttle run, standing broad jump and potentially speed bounce. While it is expected to see an increase in performance, there is also an expectation that there will be an increase in BMI (Bohannon et al., 2017; Meyers et al., 2016; Roth et al., 2018; Towlson et al., 2018).

When looking at how girls and boys fitness levels differ it appears that boys fitness improves at a faster rate than girls during the teenage years (Ortega, Labayen, et al., 2011; Thomas et al., 2020; Tomkinson et al., 2018), with boys typically performing better in all components apart from flexibility (Dumith et al., 2010; Lisowski et al., 2020). There is a difference in boys and girls fitness levels due to their maturation process, the age group of 9-11 is important because this is typically the age maturation begins for girls with boys beginning this process later. Although there is no set age to begin the process and some children will start earlier or later than the "norm". This transition may affect their fitness levels and there is a need to understand this change to aid future interventions and tackle child health levels. While also allowing an understanding of how fitness tracks differently in boys and girls, as their development and growth are not identical (Marta et al., 2012; Ventura et al., 2009).

The primary aim of this study was to investigate natural changes in components of fitness over a 1-year period in 9-11-year-old primary school children. A secondary aim was to compare changes between girls and boys.

3.3 Methods

Participants and settings

This is a repeated measures, secondary analysis of the data from the Swanlinx project, including health lifestyle and field-based fitness measures from 3924, 9-11 year old children in South Wales between 2013 and 2018 (Sheldrick et al., 2018; Tyler et al., 2015). The data were first collected in school year 5 (aged 9-10) with follow up measures repeated on the same children a year later in school year 6 (aged 10-11). Fourteen schools were involved including, 277 boys and 298 girls. The 14 schools were located in a wide range of deprivation areas, with 6 schools based in the 50% least deprived areas in Wales and 2 schools in the 10% most deprived (Welsh Government, 2014). The characteristics of the sample are shown in **Table 3.1.** Informed parental consent and participant assent were provided for each child prior to participation. Ethical approval for the study was granted from the institutional research ethics committee (project ref: 2020-023).

Table 3.1 - Participant characteristics

	Boys (n=277)		Girls (n= 298)		All (n=575)	
	Year 5	**Year 6**	**Year 5**	**Year 6**	**Year 5**	**Year 6**
Stature (cm)	138.6±6.5	144.0±6.9	139.0±6.7	145.4±7.1	138.8±6.6	144.7±7.0
Body Mass (Kg)	34.6±8.6	38.9±10.1	36.2±8.9	41.3±9.4	35.4±8.8	40.1±9.9
BMI (Kg/m^2)	17.9±3.4	18.7±3.7	18.6±3.6	19.5±3.5	18.3±3.5	19.1±3.6
Decimal Age	9.96 ± 0.31	10.92 ± 0.30	9.96 ± 0.32	10.95 ± 0.32	9.96 ± 0.32	10.94 ± 0.31
Change in BMI Z-score	0.0491		0.1252		0.0871	

Data are presented as mean ± SD unless otherwise stated.

Instruments & Procedures

Swanlinx data collection took place during 'Fitness Fundays' on an annual basis. The Fitness Fundays included anthropometric measurements of stature and body mass to the nearest 0.01m and 0.1kg, using a portable stadiometer (Seca 213 portable stadiometer, Hamburg, Germany) and electronic weighing scales (Seca 876, Hamburg, Germany) respectively. This data was then used to calculate BMI (weight(kg)/square of height (m^2) (World Health Organisation, 2021) that were subsequently converted to z-scores using the BMI UK1990 reference standard (Pan & Cole, 2012). Change in BMI z score was used as a covariate rather than height or weight due to being more indicative of growth rate, we wanted to consider both aspects and therefore BMI encompasses this. Additionally, we did not want to overload the model with too many covariates. We needed to be aware of the potential co-linearity between covariates.

The field-based fitness battery included: 10x5m shuttle run, 20-metre multi-stage fitness test (MSFT), standing broad jump, speed bounce, sit and reach and handgrip strength. These assessments measure a wide range of components of fitness, which gives us an overall general fitness overview. Children completed the assessments in an indoor athletics facility. The assessment procedure followed the SportLinx and Swanlinx protocols that have been published elsewhere (S. Taylor et al., 2004; Tyler et al., 2015). A description of each assessment is provided below. No verbal encouragement was provided during each assessment.

Multi-Stage Fitness Test

The multi-stage fitness test is a 20m shuttle run (Leger & Lambert, 1982) which assesses cardiorespiratory fitness and is commonly used in the field to estimate maximal aerobic capacity (VO_2 max) in children, this is due to its practicability to use in physical education classes (Van Mechelen et al., 1986). It has been shown to be a feasible test to use in a school setting and is both valid and reliable (Ruiz et al., 2011; S. Taylor et al., 2004; Van Mechelen et al., 1986). The activity took place in a sports hall with the 20m court marked out with cones. The children ran between the cones until volitional exhaustion. An audiotape including the multi-stage fitness test soundtrack was played; the children started each 20m shuttle on a beep and had to complete the shuttle before the next beep. The time between repeated beeps became shorter as the assessment progressed. The children were allowed to miss one beep, if they then missed the next one, they were asked to drop out and the number of shuttles they had completed was noted. The children were allowed to drop out when they deemed they had reached exhaustion. The children were allowed to re-enter to help motivate the children who remained in the assessment, however their score was not counted when they re-entered.

10x5m

The 10x5m shuttle assesses children's speed and agility (Council of Europe, 1983). Following a '3, 2, 1' countdown, each child ran back and forth 10 times as quickly as possible between two cones that were spaced 5 metres apart. This was timed with a stopwatch to the nearest millisecond and each child completed the test once only.

Speed Bounce

The speed bounce assessment is designed to assess children's muscular endurance of their legs (S. Taylor et al., 2004). The equipment needed for this activity was a speed bounce mat and hurdle (Eveque speed bounce, Northwich, UK), both of which are soft to limit the possibility of injury. The children were asked to jump over the hurdle, from one side to the other as many times as possible in 30 seconds. For a jump to be counted towards their total score their feet had to completely clear the hurdle (i.e. if they clipped the hurdle the jump was not counted) and they had to land with two feet. The children performed the test twice and their highest score was taken forward for analysis.

Standing Broad Jump

Standing Broad Jump measures the explosive power of the legs (Ruiz et al., 2011; S. Taylor et al., 2004). The equipment needed for this activity was a tape measure. The children were asked to perform a long jump from a standing start, they stood with their feet together behind the start line and then jumped as far as they could. Arm swing was permitted. To be counted they had to land steadily, with jump distance measured in meters from the heel of the foot closest to the start line. Each child was allowed three attempts and their best score was recorded. This test has been found to be valid and reliable (Fjørtoft et al., 2011; Latorre Román et al., 2015).

Sit and Reach

Sit and reach is a common measure of flexibility and specifically measures the flexibility of the lower back and hamstrings (S. Taylor et al., 2004; Wells & Dillon, 1952). The children were asked to sit at the end of the sit and reach block (Eveque, Northwich, UK), on the floor, with their feet flat up against the apparatus and legs straight. No shoes were worn during the assessment. The children had to reach as far forward as they possibly could with both hands, and hold this position for a second. The distance they reached is recorded to the nearest (cm). Each child had two attempts with their best score recorded.

Grip Strength

There is a strong correlation between handgrip strength and overall muscular strength (Wind et al., 2010). A hand grip dynamometer (Takei Corp Ltd., Tokyo, Japan) is used to measure grip strength (Ruiz et al., 2011; S. Taylor et al., 2004). The children held the dynamometer above their head with a straight arm. As they brought their arm down to their side, they had to squeeze the grip with maximum force for 5 seconds. The test was performed on both their left and right hands, each child was allowed two attempts on each hand and the best scores were recorded. For analysis the average from the left and right hand scores were calculated and score was recorded in Kg.

Design & Analysis

All statistical analysis were completed using SPSS, version 26 (IBM SPSS Statistics Inc., Chicago, IL, USA). The distribution of all variables were analysed using histogram plots and Levene's statistic, with a significance level of 0.05, key normality assumptions were checked and the appropriate tests were used. Linearity of the covariates was deemed appropriate, as was the homogeneity of regression slopes. Missing data were removed and only complete pairs were analysed for the repeated measure test. All data for the ANCOVAS were mean centered, this had an effect on the results of the change in fitness over the year (main effect) for multi-stage fitness test as the result became significant, all other fitness tests did not change overall significance level, however their score did change. Descriptive statistics, including means and standard deviations (mean ± SD) were calculated for all anthropometric and fitness measures.

A two-way repeated measures analysis of variance (ANOVA) was used to determine changes in fitness over time and whether these changes differed by gender. Delta BMI (z scores), the time between fitness tests (days) and baseline test scores were entered as covariates to investigate whether they had an impact on the change in fitness. Alpha was set at 0.05 and data are presented as mean ± SD (including tables) unless otherwise stated. Partial Eta^2 was used to provide a measure of effect size with thresholds of 0.01, 0.06 and 0.14, indicating a small, medium or large change respectively (J. Cohen, 1988).

3.4 Results

Changes in Fitness from Year 5 to Year 6

Raw scores for each of the fitness assessments in year 5 and year 6 can be seen in **Table 3.2**, whilst the change of fitness from year 5 to year 6 based on gender is illustrated in **Figure 3.1.** There was an increase in performance from year 5 to year 6 for standing broad jump (η^2 *=0.194)*, multi-stage fitness test (η^2 *=0.106)*, handgrip strength (η^2 *=0.404)*, 10x5m shuttle (η^2 *=0.034)* and speed bounce (η^2 *=0.119)*, whilst performance decreased for the sit and reach test (η^2 *=0.024)*, (all $p<0.001$ for main effect of time). Adjustment for change in BMI z-score, the number of days between the fitness tests, and the baseline score together did not alter the result for 10x5m (η^2 =0.229, $p<0.001$), multi-stage fitness test (η^2 =0.012, $p<0.05$), handgrip strength (η^2 =0.130, $p<0.001$), standing broad jump (η^2 =0.035, $p<0.001$) or sit and reach performance (η^2 =0.020, $p<0.05$). On the other hand, there was no longer a significant change in speed bounce performance over time (η^2 =0.001, $p>0.05$).

Table 3.2. Raw data of the fitness test results for Year 5 and Year 6.

	Year 5	Year 6	N
Multi-stage fitness test (no. of shuttles)	29.7±16.4	34.0±18.0	501
10x5m shuttle run (s)	20.2±2.3	19.7±2.4	527
Speed bounce (no. of jumps)	38.0±11.2	41.7±12.6	521
Grip strength (kg)	15.1±3.7	17.6±3.8	536
Sit & reach (cm)	19.1±6.9	18.3±7.7	535
Standing broad jump (m)	1.3±0.2	1.4±0.2	532

Data are presented as mean ± SD.

The main effect for sex was significant for all assessments except for grip strength. While the sex x time interaction was insignificant for multi-stage fitness test, 10x5m shuttle run, standing broad jump and grip strength performance (all $p>0.05$), indicating boys and girls were changing at the same rate in these components. Whereas there was a significant sex x time interaction for sit and reach and speed bounce (both $p<0.05$). There was a significant increase in speed bounce performance in girls compared to boys (mean of 4.74 jumps in girls versus 2.80 jumps in boys), whereas the decrease in sit and reach performance was more pronounced in boys (mean of -1.22cm in boys versus -0.33cm in girls).

After controlling for delta BMI z scores, the days between fitness assessments and the baseline score all together, the sex x time interaction remained non-significant for multi-stage fitness test performance (η^2 =0.007), handgrip strength (n^2 =0.001) and standing broad jump performance (η^2 =0.005), all p>0.05. The sex x time interaction for sit and reach performance continued to be significant with an increased effect size (η^2 =0.024). There was a change in sex x time interaction for speed bounce performance, which became insignificant (η^2 =0.000, P>0.05) whilst a significant sex x time interaction for 10x5m sprint performance emerged (η^2 =0.031, P<0.001). Meanwhile the main effect for gender changed the significance level from significant to non-significant for multi-stage fitness test (η^2 =0.006), speed bounce (η^2 =0.000) and standing broad jump (η^2 =0.004). While both 10x5m (η^2 =0.028) and sit and reach (η^2 =0.025) remained significant and grip strength non-significant (η^2 =0.001). All of the above had a decrease in effect size.

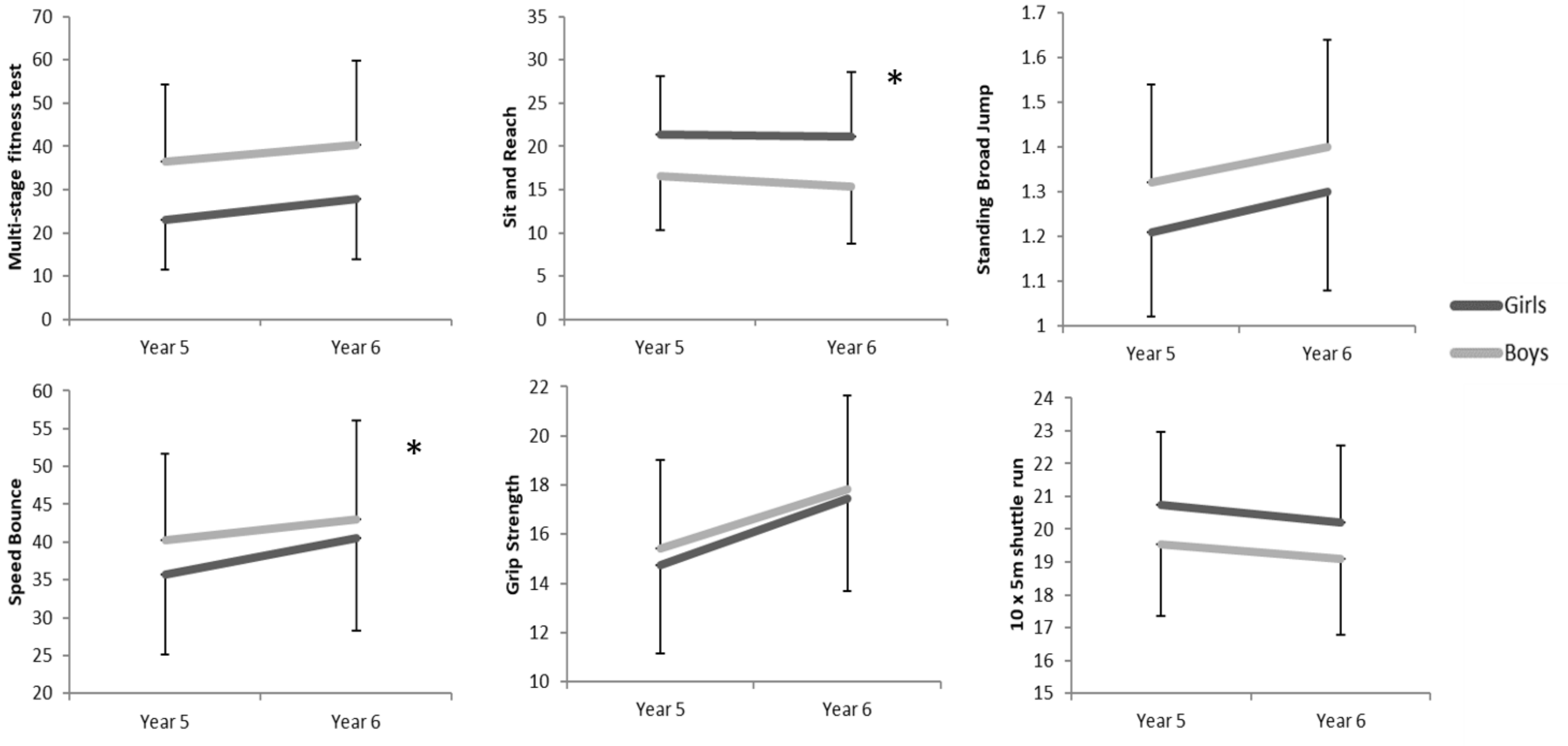

Figure 3.1: *Showing the change in fitness assessment results from year 5 and year 6 for Girls and Boys. Showing raw scores and standard deviation, statistical significance between the change scores is shown with* *

3.5 Discussion

The purpose of this study was to investigate changes in children's natural fitness levels from school year 5 to school year 6 and to understand the differences between boys and girls. Similar to other studies (Đurić et al., 2021; Roth et al., 2018), we found a significant increase in all components of fitness with age, with the notable exception of flexibility performance, which declined. We also found that boys performed significantly better than girls in the multi-stage fitness test, 10x5m shuttle, speed bounce and standing broad jump. Boys had a higher mean score in grip strength at both time points, however this was not significantly better than girls. Meanwhile girls performed significantly better than boys in the sit and reach assessment. Whilst boys performed better on average across both time points, girls demonstrated greater mean improvements over the one-year period across all components except for sit and reach. While there was a decline in sit and reach performance, boys had a significantly larger decrease than the girls. Meanwhile the change in speed bounce performance was significantly better in girls. When controlling for all of the covariates together; change in BMI z-score, days between fitness tests and baseline scores, the significant effect of time persisted for all components apart from speed bounce performance. Taken together, the data from this experiment suggests that children's cardiovascular fitness, strength, power and agility naturally improve, and flexibility naturally declines over a 1-year period in both boys and girls.

This study controlled for the change in BMI to establish whether fitness has changed more than would be expected by growth. It was important to control for the change in BMI as it is clear that BMI can affect performance levels for some components such as the multi-stage fitness test (Boddy et al., 2012; He et al., 2011; Moran et al., 2017) and also negatively impact power and flexibility (Ding & Jiang, 2020). We adjusted for the change in BMI to try to account for the effect of growth on fitness over a 1-year period. When adding the covariate of change in BMI z score to the ANCOVA on its own, there is no impact on the overall effect of time with all results remaining significant for all components of fitness (all $p<0.001$ except for flexibility at $p<0.05$), with an increased effect size for multi-stage fitness test, Grip Strength and Standing broad jump performance. This indicates that the increase in aerobic fitness, strength, power, flexibility, agility persisted after adjusting for the change in BMI z scores.

The change in BMI covariate also had no effect on the main effect of gender, all components except for strength remain significant with an increased effect size, while strength remained non-significant. All sex x time interactions were non-significant, with speed bounce and sit and reach having a change in their results from significant to not. This indicates that boys and girls change at the same rate when adjusting for the change in BMI.

BMI should increase slightly from 9-11 years old and therefore it is expected to see an improvement in performance alongside growth. This improvement in performance due to growth is expected to affect multiple components, an increase in leg length positively affecting running speed while an increase in trunk and arm length will increase sit and reach performance (Kohl III & Cook, 2013). During growth there will be an increase in heart size and stroke volume, alongside an increase in lung size which can all positively effect cardiovascular fitness (Kohl III & Cook, 2013). However, while BMI is an indicator of growth, it is not clear what is driving this change in BMI and therefore there are limitations to its use in this study. It is unknown what proportion of the increase or decrease in body mass is down to a "healthy" gain of lean/muscle mass or instead due to changes in fat mass (Kyle et al., 2003). BMI does not give any information on the body fat distribution (Kok et al., 2004). While an increase in skeletal muscle mass would be expected to have a positive effect on performance, an increase in fat mass would typically be expected to have the opposite effect. Despite the lack of clarity, BMI is still an indicator of growth and it is apparent that despite controlling for it there is still a natural change in fitness over the year of observation. This indicates that there is an intrinsic effect that is causing the change and that fitness is changing more than would be expected by growth alone.

The study controlled for the number of days in between the two fitness assessments as, due to the nature of the data collection, different schools had different numbers of days in between the two time points, and in some cases this difference was marked 252 days vs 482 days. A greater amount of time in between the assessments could be hypothesized to allow greater changes and *vice versa*, due to effects of, for example, growth or the effect of exercise training. It is apparent from the results that some parameters are affected by the differences in time between the assessments. For changes in 10x5m shuttle, sit and reach and standing broad jumps performance, the main effect for time became non-significant after controlling for time between assessments. This indicates that the number of days between these assessments has an impact on the change score. This may indicate that some components of fitness see a change quicker than others, for example a change for aerobic fitness may be seen in 200 days while 400 days are needed to see the same improvement in flexibility. While the covariate of days between intends to focus on the days between the fitness tests it does indirectly also represent each school. Therefore, this may impact the results as some schools may have specifically worked on flexibility and therefore that school is linked with a certain number of days. Therefore, it is important to consider that there may be a hidden affect within this covariate. The days between covariate does indicate that this is something to consider for some parameters but it is not important for all and that the variation of days and when we test, persist the natural rate of change.

The covariate of baseline score was included because we were interested to see whether the score initially received, impacts on the second assessment. Adjusting for this covariate ensures that an understanding of the effect of the first assessment is clear and can inform on whether those who are fitter in year 5 have a smaller change in their performance over the year. Alternatively, it could also be explained by measurement errors that may be present across the time points which can potentially manifest into a “regression to the mean effect” (A. Barnett et al., 2005). This measurement error can be intrinsic to the test methodology but could also arise due to change in participant motivation on the day of testing. For example, a participant with low motivation during the baseline assessment, resulting in an erroneously low baseline score for that particular outcome, has a greater potential for a large change to be observed over time (if motivation is higher during the second assessment). Familiarisation or a learning effect could also affect the change in performance, as it has been reported that familiarisation prior to fitness assessments has a positive impact on the result and it limits the likelihood that the change seen is down to a learning effect (Moir et al., 2005). Participants in this study were allowed several practice attempts prior to the assessment for all except for the 20-metre shuttle run, this is due to the length of time to complete and also the need to run until volitional exhaustion. However, there is data showing that 20-metre shuttle run performance is independent of test familiarity and prior practice (Tomkinson, Lang, Blanchard, et al., 2019). From this perspective it is worth noting that the more complex the task, the more repetition and familiarisation can have an influence on the learning process (Katic et al., 2012) and therefore outcome of the results (Vrbik et al., 2017). Thus, a familiarisation effect may be unlikely to affect the 20-meter multi-stage fitness test. Similarly tests such as the standing broad jump are simple to execute and the performance is mainly determined by physical ability (Vrbik et al., 2017). Indeed, Vrbik et al. (2017) found that there was only a significant difference between the first and sixth fitness test, which could argue that the improvement was not down to learning the skill, but to a training or growth-related effect. The need for running familiarity attempts prior to the assessments is down to test difficulty, participant age, previous fitness assessment experience or performance of some motor skills by default in daily life (Vrbik et al., 2017). A more active participant may play more sport and be motivated to participate in fitness assessments while also potentially having more experience in performing fitness assessments, therefore this may provide a truer example of their fitness during baseline indicating less change over time. This could also be an indication of a ceiling effect, where children who had a high score in the first time point will not increase their performance levels as much as someone with a lower baseline score due to their being less room to improve. Therefore, their change may be less but they still perform better. This topic has not been widely researched, however Taylor and Baranowski (1991) suggested that low adiposity children reached a ceiling effect and that the level of physical activity was not vigorous enough to further enhance their fitness. While Eather et al. (2013) implied that during their research on the feasibility and efficacy of an intervention to improve physical fitness, the student attitudes towards fitness testing may have been affected by a ceiling effect, as high scores were found at baseline. Therefore, controlling for this covariate is important, as there can be several different factors affecting a baseline score which ultimately affects the change seen.

When looking at the change scores over time (prior to controlling for covariates), there was a significant difference between the change scores for boys and girls in the sit and reach and speed bounce. It can be seen from the results that in both of these time points girls have a significant improvement in their performance, or in the case of flexibility performance a significantly smaller decrease in comparison to the boys. In the sit and reach assessment for flexibility, girls performed significantly better than boys over both time periods as their performance levels drop from year 5 to year 6. The change is more pronounced in boys with a decrease of -1.22cm in performance while there was a -0.33cm decrease in girls. This is in line with previous research where typically boys flexibility performance decreased more than girls and their levels of performance were poorer (Castro-Pinero et al., 2009; De Lima et al., 2019; Štefan et al., 2019). De Lima et al. (2019) reported for each cm girls performed the boys were 2.94cm less. There are several potential reasons why sit and reach performance may decline less in girls compared with boys. One possible reason is a higher concentration of estrogen and collagen fibres, which means greater joint and muscle range resulting in higher levels of flexibility (De Lima et al., 2019). However it should be noted that sit and reach may not be the most accurate assessment for hamstring and lower back flexibility due to leg length difference not being taken into account (Castro-Pinero et al., 2009).

The decrease seen in flexibility performance from year 5 to year 6 is contrary to some previous research (Mikkelsson et al., 2006), with Castro-Pinero et al, (2009) reporting that children aged 13-17 have higher levels of flexibility than children aged 6-12 years. Despite this Štefan et al. (2019) reported a decrease in performance from 1st grade (age 6/7 years) to 4th grade (9/10 years), which is more in line with our age group. It is suggested that the decrease may potentially be down to an increase in sedentary time as children get older (Harding et al., 2015). Spending a vast amount of time sitting has the possibility of making the child adapt poor postural habits (Dutta & Dhara, 2012). In turn this could cause the shortening of the hamstring muscles which in turn would reduce sit and reach performance (Vadivelan & Priyaraj, 2015). While an increase in sedentary time would possibly lead to a decrease across the other components of fitness (Chinapaw et al., 2011; Mitchell et al., 2013), it is likely that the cause of this decrease is a lack of stimulus specific enough to improve flexibility. Liyanage et al. (2020), found a weak positive correlation with physical activity and hamstring flexibility and suggests that the physical activity being completed is not specific enough for flexibility.

In the speed bounce boys performed significantly better over both time points however girls had an increase of 4.74 jumps while the boys had a significantly smaller improvement of 2.80 jumps. There is minimal research within the speed bounce fitness assessment, however a study using a similar test involving jumping sideways over a wooden rod for 15 seconds reported that boys significantly outperformed girls (Adriyani et al., 2020; Vandorpe et al., 2011).

Boys are consistently performing significantly better than girl in all components except for flexibility and strength, which while they perform better in strength, this result is not significant. It has been previously documented that boys perform better than girls apart from during balance and flexibility assessment (Dobosz et al., 2015; Marta et al., 2012; Ploegmakers et al., 2013). This gap in performance between girls and boys has been found apparent as young as 4 years old in grip strength (Ploegmakers et al., 2013). During adolescent growth this gap increases as they go through their adolescent growth spurt. Dorø et al. (2005) reported that from 14-16 years old there was a clear differentiation in lean leg volume and cycling peak power. This is believed to be due to girls having an increase in lower-limb fat during puberty whereas boys have an increase in their lean body mass (Dorø et al., 2005). Other contributing factors to this greater performance include body composition (Goswami et al., 2014), motivation (Domangue, 2009), perceived identity based on society norms (Fisette, 2011), and influences on physical activity at home and school (Telford et al., 2016).

Interestingly across all of our results girls are having a higher change score than boys, while this is only significant for speed bounce and sit and reach performance a higher change is present across all components. This is interesting that despite boys performing significantly better in aerobic fitness and power for example, girls are closing the gap between them during the year 6 assessment. This change may be present for a number of reasons, it may indicate that maturation is the cause due to girls starting the process before boys. Girls start their adolescent growth spurt on average 2 years earlier than boys (Hauspie, 2002; Hauspie & Roelants, 2012) and it has been found that jumping performance increases during growth (Temfemo et al., 2009), which may explain the significant change score by girls in the speed bounce. It would be interesting to see if this larger change is consistent in other age groups, especially after maturation. It could also highlight the potential of a ceiling effect (Eather et al., 2013), that due to the girls performing at a lower level there is more room for improvement or that girls have partaken in activities that develop this movement such as netball.

When controlling for all three covariates together there is no change to main effect of time results expect for speed bounce, which becomes non-significant. Interestingly when controlling for the covariates separately there was no impact on speed bounce performance indicating that all three together are having an impact. With the remaining components all having a significant result this indicates that there is still a change in performance despite controlling for these covariates.

The sex x time interaction shows a change when controlling for all three, 10x5m has changed to have a significant interaction, while speed bounce has changed to have a non-significant result. When running all covariates separately the sex x time interaction for speed bounce was affected by all covariates.

It appears that the change in fitness is intrinsic and exceeds natural growth or score at baseline. However, some parameters appear to be affected by the number of days between each fitness assessment. Boys perform significantly better than girls, although girls have a higher change score, this may be down to the baseline score received or the fact that girls have begun maturation at this age and boys have not.

Limitations

While the field tests used are valid and reliable, they may be affected by external factors such as motivation, peer pressure and also skill level/familiarity with the test. Motivation is a factor that can affect both time points and therefore the change we see. It has been suggested that motivation and the ability to tolerate discomfort affects the performance of the multi-stage fitness test as well as the ability to judge pace and effort can affect the results (Tomkinson, Lang, Blanchard, et al., 2019). Self-efficacy towards physical activity and fitness also has an impact on results (Cairney et al., 2008). Motivation is not something that was assessed prior or post completion of the fitness Fundays and this is a limitation due to not knowing whether a score has increased or decreased due to this factor. In the future, including motivation assessment or heart rate assessment alongside this repeated measures design, could be introduced to minimize the effect of motivation and understand the effort that was given and the affect this would have on the repeated design results. Peer pressure also falls into this category, some individual’s will not perform 100% as they have a fear of failing in front of their peers or they also do not want to stand out as a top performer, this is especially true in the multi-stage fitness test (Harris & Cale, 2007). There is also an increased level of anxiety during fitness assessments for children (Huhtiniemi et al., 2020) while fear of failure has been found to have a negative association with fitness scoring (Correia & Teixeira, 2017). These factors have an impact on the overall fitness levels of children and would have affected both time points. This being said caution should be taken with the change scores as there was no measurement of how factors such as motivation may affect the results. There was also a lack of measure for maturation as BMI does have its limitations; this may provide a clearer understanding on the affect that this process has on the results.

Future work

For future work it would be valuable to measure motivation and how that may impact the result, alongside completing the study for longer to gain a better understanding of the change with a larger cohort of children. It would also be valuable to gain an understanding of whether ceiling fitness impacts children as this could explain the effect of the baseline score covariate. A key question to be answered is although the children’s fitness levels increase, have these fitness levels increased compared to what they used to be in the general population? Are we seeing that children’s fitness increases as they grow however each generation is getting progressively less fit than the previous generation? A study incorporating both of these elements would clarify an important question.

3.6 Conclusion

To conclude it is apparent that children's fitness tracks positively from aged 9-11, it appears that this increase is above what is expected of growth, and outside of the effect of baseline assessment. Day between fitness assessments may be important for some parameters but not all. Boys' performance levels are higher than girls, expect for sit and reach performance, however girls change scores are higher across all components of fitness. Future research can help decipher whether this is a natural cause or down to factors such as motivation.

Chapter 4:

Study 2: The Measurement of Quality of Movement in Children using Micro Electromechanical (MEMs) Devices: A Scoping Review.

4.1 Abstract

The purpose of this study was to investigate how quality of movement in children is measured with the use of MEM's devices. A key aim of the review was to determine if MEMs devices are indeed being used to their full potential. Given the differing views surrounding the definition/scope of quality of movement, this study also aimed to gain an understanding of how quality of movement has been defined and measured in children's research to date. Studies published between 2010 and 2020 that measured quality of movement in children with MEM's devices were included in the review. The search and data extraction was performed by two reviewers (EW and HB), the data extracted included study year, study population, MEM's device, movement assessed and whether there was definition of quality of movement. Three databases were searched and a total of 124 records matched the inclusion criteria. The number of published studies increased from 2015 onwards, with infants and typically developing children being the two most studied populations (both with n = 31 respectively). Cerebral palsy only and cerebral palsy and typically developing as a control were the next most researched populations (both n = 21 respectively). The most common devices used were Inertial Measurement Units (IMUs) (n = 56) and Accelerometers (n = 49), while most research focused on gait (n = 39). The data from MEMs was used in a variety of ways, including the raw trace to inform modeling of gait and activity, to the extraction of statistically significant features. A

large number of studies did not include a clear definition of quality of movement and among those that did there was a lack of cohesion. The findings of this scoping review outlines the range and direction of current research on movement quality in children measured using MEMs devices and includes directions for future research.

4.2 Introduction

Movement is an essential component of everyday life, promoting health and wellbeing for all (Chaput et al., 2014; Storey et al., 2016). Movement can be measured quantitatively or qualitatively (Levac et al., 2010) and both are important to assess and understand in children. However to date movement quantity has been the focus of the vast majority of research in children (Chaput et al., 2014; Myer et al., 2015).

Children's movement competence, the way they move and therefore their movement quality, is a key component of sound growth and development. This is an area that is receiving increased attention by researchers using MEMs devices to investigate movement quality in healthy children (Clark et al., 2018; Zuzarte et al., 2019), as well as those experiencing motor development delays (Bisi et al., 2017) such as cerebral palsy (Gravem et al., 2012; Machireddy et al., 2017). These approaches also have significant potential in assisting with the development of effective interventions (Bisi et al., 2017) that focus on the quality of movement (Cain et al., 2013; Olesen et al., 2013). Quality of movement is important to consider as a poor movement quality can affect children's participation levels in activity. A poor quality can also lead to injuries while performing activities, or could be a sign of a developmental delay condition. Therefore, monitoring quality, especially with MEMs devices can provide an important insight into a child's development.

Quality of movement appears to not be commonly defined in terms of child cohorts and is unclear, it is referred to by several different terms such as motor competence (L. Lopes et al., 2019), movement competence (Bisi et al., 2017) or gross motor function (Thieme et al., 2010) among others. Some researchers use terms with subtle differences in terminology such as motor competence or movement competence, however while similar these terms also have important differences. Bisi et al. (2017) reported movement competence is defined as "the development of sufficient skill to assure successful performance in different physical activities". While motor competences is generally used to describe a person's proficiency in a wide variety of actions and motor skills (gross and/or fine) (Silva et al., 2019). Logan et al. (2018) has previously commented on the need of clarification for terms used to describe motor competence as there are a number of terms used to describe different levels of movement. While these terms and definitions are similar, they are used interchangeably which can cause confusion, especially when trying to find all the relevant research in a certain field. This broad use of terms creates confusion around what is quality of movement and what research is included. This may even lead to important work being missed, highlighting a need for a general term which should be clear and easy to search the breadth of the research.

The need for a clear definition of quality is important to allow comparison between studies and providing the opportunity for quality over time to be compared. Terms such as motor competence and fundamental movement skills and their accompanying assessment methods are often used to discuss and measure quality of movement. Alternatively quality of movement is more clearly defined in the field of adult assessment with Niewiadomski et al. (2019) defining quality of movement as; "how well a motor activity is performed, and includes several aspects such as postural control, coordination and balance". However, this definition may not be suitable for direct application to the study of cohorts of children due to the challenges children bring, such as differences in their movement and how unstructured their movement is. For the current study a working definition that encapsulated all studies that researched movement quality amongst children was desired. Therefore a broad approach was taken when considering quality of movement, this could be anything from comparisons between individual's, to comparisons with a gold standard, a large number of terms were assessed to ensure nothing was missed. Quality of movement was deemed as research understanding how a movement was performed. Any study that was only looking at the quantity side (time spent sitting, moving or standing etc.) was not included.

In light of the definition offered above quality of movement can be assessed in several different ways, such as movement assessment batteries like the Koordinations test fur Kinder (KTK) and Movement assessment Battery for children (MAB-C) (Logan et al., 2018). These assessment batteries have been commonplace when assessing children's movement competence (L. Lopes et al., 2021). However, the availability of improved technology around MEMS devices has meant an increase in the variety of devices used within the field of children's movement assessment. There is a wealth of literature using accelerometers and MEMs devices to assess the quantity of physical activity, energy expenditure and sedentary time in children (Cain et al., 2013; K Corder et al., 2008; Olesen et al., 2013). This is typically seen as a measurement of quantity of movement due to identifying the time spent performing an activity. Accelerometers are no longer the key sensor, others such as IMUs, flex sensors and pressure sensors are more commonly found now than in 2010 (H. Chen et al., 2016), this expansion is opening up opportunities to assess quality of movement (Clark et al., 2018; Clark, Barnes, Summers, et al., 2017; Clark, Barnes, Swindell, et al., 2017) in a variety of settings. This development of new devices and the development within the technology has changed MEMs and we aim to understand how are they now being used and are they being used to their full potential. To understand if the advancement in technology has impacted on the data that has been collected and whether this has impacted any definition or ideology that the community of researchers have around quality.

It is possible to see the benefits of using MEMS devices to measure quality of movement as they have the opportunity to observe a wide range of movement patterns from gait to hand gestures (Brégou Bourgeois et al., 2014; Pande et al., 2014). They also provide the opportunity to assess quality in real-life settings outside of the motion lab due to their size and portability. MEMs devices are able to provide unique insight into the movement that the human eye may not see, meaning they would be useful when observing quality as they can offer a full objective comparison between individual’s or with a gold standard (Kaittan et al., 2020; Smith et al., 2015). MEMs devices have been found to be reliable when assessing movement patterns (Bisi et al., 2017; Mannini et al., 2017). The devices reduce the time spent scoring movement competence assessment batteries and the need for trained operators to ensure reliability (Bisi et al., 2017). This is making assessment of movement more accessible and quicker, this being said there are still a number of studies that use video alongside the data collection process to enable better context to the data.

The current issue is that it has been reported that MEMs devices are yet to be utilized to their full potential in the field of children’s movement quality (Hongyu Zhao et al., 2019). Full potential meaning, is the current researching utilizing all that MEMs devices have to offer, for example when looking at gait are they only observing number of steps or are they also observing the different gait phases, joint angles and ground reaction forces. It would be interesting to know whether this is due to a lack of clarity as to what MEMs have to offer or has the advancement in the technology come quicker than the understanding of how to handle this data. This paper aims to explore this question of whether the devices are being used to their full potential, and how exactly are these devices being used. Over time the definition of MEMs devices has grown, with the improvement in technology both software and hardware it is interesting to gain an insight into how the use of the devices has developed.

An initial pilot search would suggest that the use of MEMs devices has a limited research evidence base in child motor control potentially down to the difficulties of using these devices within this population, such as the size of devices has improved since the first accelerometer used (H. Chen et al., 2016). There appears to be a stronger literature base on MEMs devices for diagnostic investigations in special and clinical groups. These include cerebral palsy (CP) (Singh & Patterson, 2010), Autism Spectrum Disorder (Goncalves et al., 2012), Developmental Coordination Disorder (DCD) (Speedtsberg et al., 2018) and Injury (M. Newman et al., 2020).

In the field of movement quality there is no clear consensus on what constitutes as quality of movement and there are a large range of assessment methods. It is unclear whether MEMs devices are being used to their potential and what areas can utilize these devices. This review aims to provide information and understanding on what MEMS devices are being used and how the data obtained by these sensors are summarized to assess quality. A secondary aim to this review is to observe whether there is a general consensus in the way that quality of movement is defined. This review will be important to make this area of movement assessment with MEMs devices clearer for future work to ensure there is a consistent framework for further research.

4.3 Methods

As the aim was to assess the size, scope and quality of the existing literature, a scoping review was chosen (Munn et al., 2018), as it was best suited to the broad topic and ambiguity of the term 'Quality of movement' and also best suited to identify existing gaps in the literature. The methodological framework proposed by Arksey & O'Malley (2005) was followed. PROSPERO was searched for existing reviews on this topic and none were found at the time of the search.

Research Question

The aim of the research was to determine how MEMs devices are being used to assess quality of movement and whether these devices are being used to their full potential. The desire to understand the definition of quality of movement and whether there were any trends in the data that would impact this. While considering the research question we did not want to rule out certain study designs as it was understood from an initial pilot search that a wide range of papers and topics were included in this research. The initial intention was to perform a scoping review of MEMs and movement quality across both children and adults. Due to the volume of papers returned during pilot searches and moreover, movement amongst children presenting a unique set of challenges, it was decided that a focused investigation into this child cohort was warranted.

Search Strategy

To define the search terms, an iterative approach was employed, current relevant literature was searched and a list of terms used to describe quality of movement and MEMs devices were collated. These terms were based on our own working definition of quality of movement and expertise within the team. The list included 31 terms ranging from movement, stability, motor co-ordination, movement patterns, accelerometers and sensors among others. These search terms were piloted in each database and based on the outcome, the final terms for the search strategy were decided. There was a desire to ensure that there were enough terms to try and maximize hits and ensure the full breadth of the research was captured, however find a balance with too many terms. Flow diagrams were created to view the effect of adding limits to the search field. After scoping the current research, a gap in the literature of MEMs devices assessing children's movement was found and therefore this study focused on children specifically.

The databases used for the scoping review were Scopus, Web of Science and SportDiscus. These databases were chosen as Scopus includes all life, social, physical and health sciences, Web of science is multidisciplinary, while SportDiscus is the most comprehensive source of journal article for sports and sports medicine.

The searching process was completed from July 2020 until August 2020, with the following terms used to complete the search: "Quality of movement", "Profiling movement", "Movement pattern", "Motor control", "Movement quality", "Motor competence", Movement* AND Accelerometer*, Sensor*, "Inertial sensor*", "MEMS device*", alongside Child(ren), Kid(s), Adolescents, Infant(s), Youth, School, Pre-school. These combinations were used across all the databases and searched in the title, abstract and keywords.

Due to the volume of original research papers revealed by the search, it was decided not to supplement the database search by reviewing the reference lists of the original research articles. However, the reference lists of relevant review articles that appeared in the search were reviewed.

Study Selection

Inclusion criteria for the selection paper were as follows: papers included in the review were those that include MEMs devices to measure quality of movement, MEMs devices include accelerometers, gyroscopes, magnetometers (this includes inertial sensors), barometers and sensors. Lab-based motion capture papers were excluded due to this not falling under the umbrella of MEMs devices as they are not wearable. However, studies where 3D motion-capture and standard videos were used when in conjunction with MEMs devices, especially for validation purposes were included. Papers published between 2010-2020, that included participants between the ages of 0 and 18 and were written in English were included in the review. There were no restrictions on the types of study design eligible for inclusion in the study.

Papers were excluded from selection if MEMs devices were used to measure the amount of time spent in physical activity, sedentary behaviour or sleep, as based upon the background research these would be linked to quantity. Any papers that did not provide a metric capturing quality of movement were also excluded. Some studies contained both quality and quantity metrics and these were included. Studies that used motor competence or movement assessment batteries without the support of MEMs were not considered alongside virtual gaming, unless used for validation purposes. Previous reviews were also excluded although reference sections in the reviews were searched and relevant papers included.

Once the search was completed the papers were compiled using Rayyan (Rayyan, 2022). To initially review the papers the titles and abstracts were searched and clearly irrelevant papers were excluded. The remaining papers were reviewed by full text. Two researchers completed the full text search, this was done blind to not influence each other. If there was a disagreement a third researcher was used.

Charting the data

Two researchers (EW and HB) extracted the data from the studies and then input it into a database. The data collected included the year of publication, type of MEMS device, study population, aim and area of study, the main findings and a definition of quality of movement (if present). When extracting the metrics derived that described quality 4 categories were used;

1) Models – models included detailed biomechanical models such as the inverted pendulum model for gait.

2) Machine Learning – Included a wide range of techniques from SVM to Morkov with the aim of classification of movement and regression.

3) Papers that extracted a metric that overlapped with quantity - This includes the use of activity counts and intensity of performance.

4) Feature extraction – Feature extraction was further split into 5 sub-categories due to the large number of papers in the category. The sub-categories were speed, angular, range, patter and frequency features. Speed focused on speed, acceleration of movement and general reactivity. Range includes distance such as step length or reaching length. The Angular group was explained as the angle of joints and position of joints. Pattern was defined as papers that considered raw (or filtered) trace in

totality, comparing this to a gold standard or to others in the cohort. The papers used pattern to recognize activity or for the purposes of comparison. Finally, the sub-category of frequency features included information related to frequency such as stride frequency, frequency analysis such as spectral purity, Root mean square (RMS) and Fast Fourier Transform.

When charting the data related to the definition of quality of movement, a discussion around the definitions of quality took place as there were many ambiguous and unclear terms. It was decided there would be three categories; definition, characterization and no definition. The definition category includes papers that stated a definition of movement. The characterization category included papers that did not define what their interpretation of quality of movement to be, however they characterized a typical movement behaviour such as stating crouched gait is a characterization of cerebral palsy. The category of no definition included papers that did not state a definition or characterize a movement. While all these papers implied they were observing quality of movement from the metric output and their methods they did not define or characterize. The reason these papers with no definition were not excluded is due to the current paper aiming to gather knowledge firstly on how quality of movement is measured with MEMs devices and how do people define quality of movement.

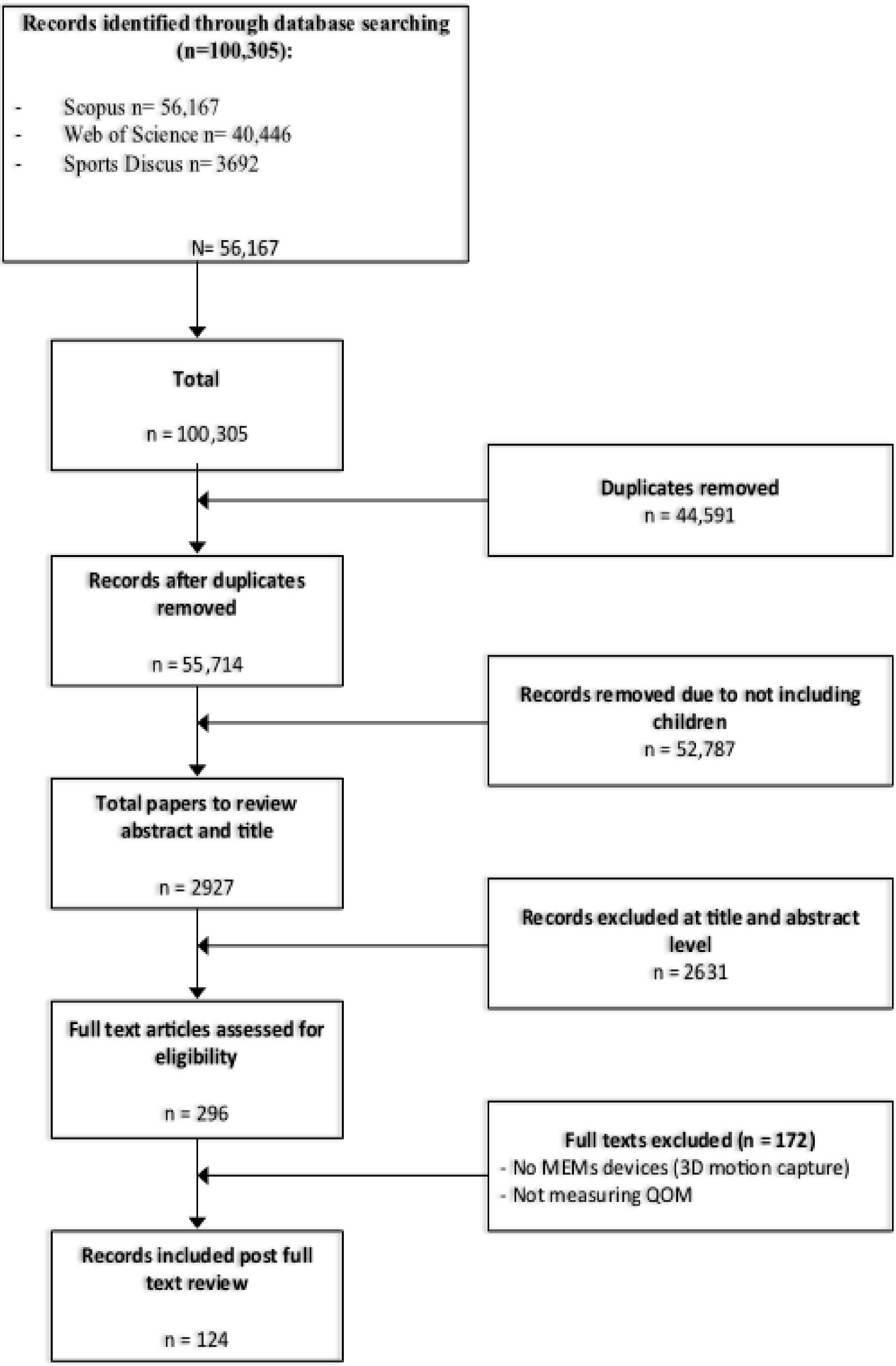

Figure 4.1: PRISMA Flow diagram showing the number of papers found at each stage of the search.

4.4 Results

A total of 100,305 studies were located in Scopus (56,167), Web of Science (40,446) and Sports Discus (3692). First duplicates were removed leaving 55,714 records, then records that were not related to children were removed leaving 2927 records, after further review of the abstract and title, based on the criteria, 2631 records were excluded leaving 296 records for full text assessment. Final checks left 124 records that matched the inclusion criteria and these were then included in the data extraction. A flow chat with the selection studies is illustrated in **Figure 4.1.**

Year of Publication and Study Population

The papers included were more commonly found from 2015 onwards, with 91 of the 124 papers being published after this date. 2019 (n=21) had the largest number of published papers with 2017 just behind (n = 20). It should be noted that the search was completed halfway through 2020, which explains the lower numbers for this year. It is also thought that COVID-19 may have had an affect on some of the research due to be published throughout 2020 and into 2021. The number of papers for each year can be seen in **Table 4.1.**

The papers covered a wide range of population groups with studies observing children with cerebral palsy only (n = 21), cerebral palsy and typically developing children (n = 21), typically developing children only (n = 31) and studies including newborn children/infants under the age of two (n = 31) being the most common. As time has progressed the inclusion of other populations have been apparent with 14 studies from other populations being included since 2017 (from a total of 19 studies). These other populations included developmental coordination disorder (n= 3), ADHD (n= 3), Duchene Muscular dystrophy (n= 1) and autism spectrum disorder (n= 4). Thirty-seven of the papers included typically developing children in comparison to clinical conditions. **Table 4.2** shows the breakdown of studies in different populations.

Table 4.1: Including the year of publication and number of papers.

Publication year	Number of papers (n)
2010	7
2011	3
2012	9
2013	6
2014	8
2015	9
2016	10
2017	20
2018	17
2019	21
2020	13

Data showing the number of papers published for each year.

Table 4.2: Containing all the study population groups and number of papers.

Study population	Number of papers (n)
Cerebral palsy	21
Typically developing (TD)	31
Cerebral palsy & TD	21
New-born infants (under 12 months)	31
Autism Spectrum Disorder & TD	4
Idiopathic toe walking & TD	2
Developmental coordination disorder & TD	3
Autism Spectrum Disorder	1
ADHD & TD	3
Down syndrome, Prader Willi Syndrome & TD	1
Duchene Muscular dystrophy & TD	1
Duchene Muscular dystrophy	1
Tourette's & TD	1
Idiopathic toe walking	1
Traumatic brain injury & TD	1

Data showing the populations that have been researched.

<u>MEMs devices & research area</u>

There was also a range of MEM's devices used, the most popular being an Accelerometer (n =35), followed by the use of Inertial measurement unit and inertial sensors (n=33). The use of video alongside the MEMs devices was fairly common with thirty-five papers using videos and 3D motion capture such as Vicon for purposes of validation. Some papers included a 5-minute filming period to help validate the results, these studies have not been included in the video category due to the filming process not taking place through the whole data collection period. The studies using video cameras were used infrequently until 2016 where after the use of IMU and video was consistent every year after. The general pattern of MEMs usage were that IMU's and accelerometers were used every year (bar 2011 for IMUs & 2013 for accelerometers), typically numbers were low to begin with until 2017 where there was in increase in their use. The number of papers using alternative MEMs such as force or pressure sensors also increased around 2017. Detailed results of what devices were used are in **Table 4.3.**

Table 4.3: Different MEMs devices used and the number of papers for each.

MEMs device	Number of papers (n)
Inertial measurement unit (IMU) and inertial sensors	33
IMU, Inertial sensors and Vicon	7
IMU, Inertial sensors and video	15
Accelerometer	35
Accelerometer and video	13
IMU versus Accelerometer	1
Other	11
Force and pressure sensors	6
Flex Sensor	2

Data showing the MEMs devices used.

The most common topic to be assessed was gait with n = 39, secondly were studies that analyzed upper limb movements such as reaching and grasping (n = 22). Other topics in the studies included posture (n = 4), lower limb movement (n = 12), Fundamental movement skills (n = 14) and daily living assessment (n =9). Further topics can be seen in **Table 4.4.**

Table 4.4: What categories are the papers observing and the number of papers.

What are the studies assessing	Number of papers (n)
Posture	4
Gait	39
Fundamental movement skills	14
Upper limb	22
Daily activities	9
Lower limb	12
Infant general movement	16
Other	7

Data showing the topics of movement that have been assessed.

The metrics that were extracted from the data can be seen in **Figure 4.2**. There were multiple papers (n = 93), which included information from more than one of the categories shown, this is out of a total of 123. There were 7 papers that included models as part of their data extraction, the models used were the inverted pendulum model (n = 2), Human dynamic model (n = 1), extended Kalaman filter model (n = 1), while the remaining 3 papers fell under the overall umbrella of modeling but focused more on the stability of movement. The feature extraction category had 107 papers, which meant 5 sub-categories were included; the largest was speed with 74 papers, while pattern only included 16.

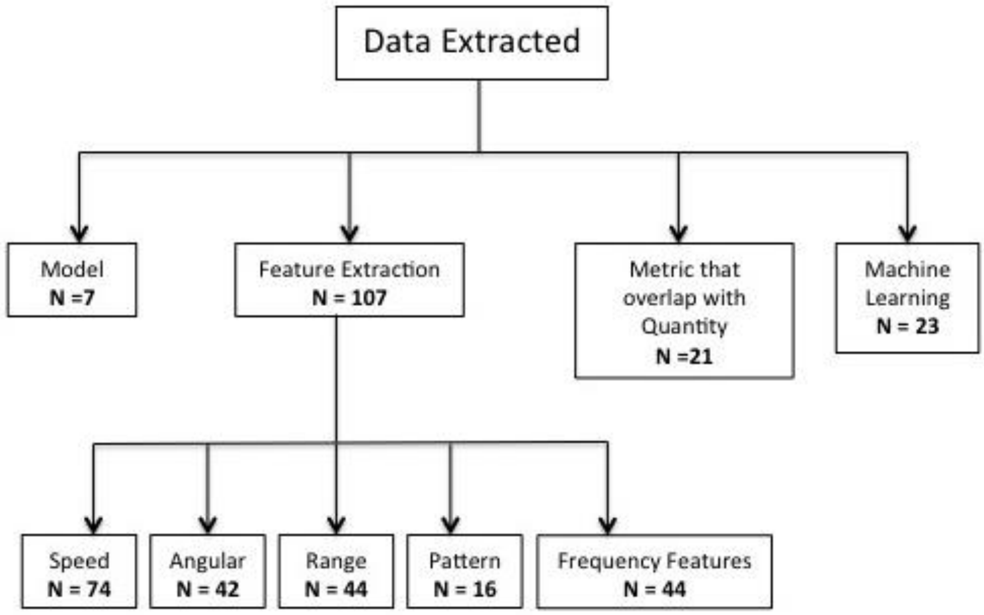

Figure 4.2: Data metrics that have been extracted from the papers. Papers may appear in more than one category.

There is no clear trend over the years in terms of data extracted however there seemed to be a clear pattern of use of machine learning in the infant category with 8 papers using this data extraction metric. There are only 23 papers altogether that use machine learning and therefore 34% of the machine learning papers focus on infants. The category of ADHD and typically developing children only has 3 papers and all three-use machine learning. This is not unusual due to the sporadic and more complex features of infant movement, machine learning can collate the data and look for subtle features and differences amongst individuals in this difficult to observe category. The category of model is most popular in populations that include typically developing children such as, typically developing (n= 2), Infants (n =2), CP & TD (n= 1), DMD & TD (n= 1) and DCD & TD (n= 1). This is also similar in the pattern extraction; this may be due to the wider amount of research in this field and the links of comparing to adult populations. For example, the inverted pendulum model is something that can be used in a typical adult population however not with children with developmental conditions such as cerebral palsy, due to the variety of ways such individual's deviate from the standard gait pattern. There is not currently a similar model for children with CP and therefore models will not be typically used in this cohort. It is difficult to see if there is a trend by population outside of the main categories of CP, CP & TD, Infants and TD as the number of papers in the other populations are low, therefore a trend cannot be assumed.

When looking at the trend based on devices, the machine learning data is being extracted more commonly from the accelerometers rather than the IMUs (n= 6 for Accelerometers and video, n = 7 for accelerometers, n = 4 for IMU). The same can be said for the quantity category with 16 of the papers using quantity measures such as intensity and are feeding into quality of movement. This category shows the cross over between quantity and quality.

This trend in devices may be down to the data that is available to capture from the devices for example the gyroscope within the IMU makes it much easier to measure the angular category, with 27 of the papers from this category coming from IMU devices.

When observing the trend of data metrics and the field of measurement it is possible to see that the angular metric is more commonly found when observing the lower limbs, such as during gait or the lower limb category (n =22), while the quantity extraction is more common in the upper limbs field of measurement (n = 7). The field of infant measurement (n=7) and gait (n=6) commonly use the metric extraction of machine learning, while in gait the extraction of model is also high (n=5). The field of fundamental movement skills show a wide range of data metrics extracted with all categories of extraction apart from model used. While finally the field of daily living is typically using the extraction metric of machine learning, this is potentially due to the randomness of the activities performed by the children throughout the day.

It seems that the use of the data is a clear indication of how quality is being interpreted, even when a definition is not offered. These metrics often depend on the type of devices used and cohort under consideration. As a result, we can see that these factors also guide each researchers working definition of quality of movement.

Definition of quality of movement

While these papers observed and assessed quality of movement a large number of the papers did not include a definition or alternatively did not characterize the movement they were investigating (n = 76). The remaining papers (n= 47), included a definition of movement (n = 13), or characterized the movement (n = 34). An example of a definition and a characterization can be seen in **Table 4.5.** The definitions provided have been broad with different terms used such as movement competence and motor development indicating an inconsistent approach to quality of movement.

The papers marked as characterization were ambiguous with no definition of quality of movement however, they did list common themes likely to be found within quality. They described something that you may see performed. For example discussing the longer reach time found in children with cerebral palsy, how their path to the target is less efficient and their velocity on touch is greater than a typically developing child (Cahill-Rowley & Rose, 2018). They have described how their movement differs but they have not described how the movement will be performed.

The need for two categories of characterization or definition shows the requirement for a consistent definition due to the broad topics, responses and opinions surrounding a definition of quality.

The papers included within the definition category describe what a movement was, what was meant by a term such as movement competence. Within the 13 papers that included a definition only 2 of these papers included infants, 21 infant papers were in the category of no definition. Within the definition and characterization papers the remaining populations were cerebral palsy only (n= 4), typically developing only (n= 4) and typically developing and cerebral palsy (n= 3). Interestingly there were no other clinical conditions included here, however 11 of the 19 papers with other clinical conditions were in the characterization group, the remaining 8 were in the no definition.

The earliest definition was in 2013, which indicates that overtime the knowledge has grown.

There was no trend in the devices used and the definition given, the definition category included a mixture of devices (IMU n= 3, IMU & Video/Vicon n= 4, Pressure sensors n= 1, Flex sensors n= 1, accelerometers n= 3 and one paper from the other devices category).

Table 4.5: Showing the different definitions and characterizations of movement.

Definition/ Characterization	Author	Year	Definition
Definition	Bisi et al	2017	Movement competence is defined as the development of sufficient skill and ability to assure successful performance in a variety of physical activities.
Definition	Bisi, M.C & Stagni, R.	2016	Motor development has been defined as the adaptive change towards competence implying that adjustment, compensation and changes to reach or maintain competences continue throughout the lifespan.
Definition	Clark.C.C.T et al,.	2017	Quality may be a nebulous term, one operational and measurable definition is; The purity of the fundamental frequency spectra (or signal during human movement.
Characterization	Cahill-Rowley, K & Rose, J.	2018	Children with Cerebral palsy have longer reach times, less efficient paths to the target object and higher velocities at contact with the target object than typically developing children.
Characterization	Ricci, M et al	2019	Children with developmental coordination disorder act with poor coordination, poor postural control and/or fine or gross motor clumsiness.

4.5 Discussion

This scoping review provides a summary of the literature investigating how quality of movement has been measured in children with MEMs devices. The use of MEMs devices has been growing in popularity over the last several years, it should be noted that the year of 2020 has a small decrease in the number of papers, this is due to the data collection taking place halfway through the year. It is also possible that the COVID-19 pandemic may have affected some research that was also due to be published during that time.

New technology has led to a change in MEMs devices, this change has seen gyroscopes and accelerometers being used alongside each other to enable a greater range of measurement to be studied. The development of IMUs has allowed a wide number of topics to be studied from the spontaneous movements of infants (Gima et al., 2011) to the grip strength of children (Kaittan et al., 2020) or the gait of an individual with cerebral palsy (Aycardi et al., 2019).

Over the years the populations measured has increased from the four main populations including typically developing children, children with cerebral palsy, infants and finally cerebral palsy and typically developing children as a control group, to include conditions such as ADHD, Autism Spectrum Disorder, Duchene Muscular Disorder, Down Syndrome and Developmental Coordination Disorder. This increase is important to gain a better understanding of movement across a spectrum of populations and conditions, it allows an understanding of different qualities of movement and how that may change from individual to individual. Each individual has a different level of movement ability despite overall activity being comparable and even when completing the same activities, the way an individual moves differs from person to person (Clark et al., 2016). When considering developmental level, children of the same age group can have different developmental levels (Masci et al., 2013) with external factors such as motor experience playing a role in their developmental skill level (Grimpampi et al., 2016) as well as their maturation rate. With standards of quality differing such as the difference in gait between a typically developing child and one with cerebral palsy, it provides difficulty when trying to set a clear definition on quality of movement and therefore the research purpose may impact on the definition of quality. The inclusion of a large number of populations does warrant a proposal that a more flexible definition of quality would be more suitable to account from this wide range of movement qualities. It is important to create something that is suitable and specific for the population being studied (Albert et al., 2020). This is where the use of MEMs devices is beneficial, enabling measurement across different populations and understanding the smaller differences in their quality.

There are a wide range of MEMs devices in use, allowing children of all abilities to be assessed for their quality of movement without the need of going to an unfamiliar environment of a lab. The devices are low cost, enable a greater number of children to be assessed and provide the option of continuously monitoring their movement (Pan et al., 2020).

A number of studies (n = 35) include the use of video cameras or Vicon alongside the data collection process to aid with classifying movements. These video cameras recorded the whole assessment and provide context to the assessment. For example Patel et al, (2019) used a video recording to code the movements seen. Spontaneous movements are not observed when an infant is asleep, fussy or crying and therefore Patel et al, (2019) used the video to discard the data that was not relevant to their study. The video aid helped ensure that only the active durations and relevant conditions were coded for investigation (Patel et al., 2019)

Bisi et al. (2017) & Lander et al. (2020) have shown that MEMs devices are a valid tool for movement measurement and can be used in replacement of video analysis in the field. Bisi et al. (2017) found a 73% agreement between the automatic assessments of the TGMD-2 with the use of IMUs, in comparison with the standard assessment. MEMs devices further add to the practicality of movement assessment by allowing assessment to take place outside of a laboratory environment, it simplifies assessment by not requiring a trained assessor and can reduce the time spent during the data collection/analysis (Bisi et al., 2017; Lander et al., 2020). It reduces time due to the automatic assessment rather than assessors manually scoring video analysis post data collection, Bisi et al. (2017) reported a decrease in average time spent assessing each participant from 15 minutes to 2 minutes due to automatic assessment. Using MEMs devices in comparison to video analysis has less ethical constraints, making the process easier for researchers (Everson et al., 2019).

However, there are limitations currently with the accuracy of measurement of some movements. While movements such as side step are receiving 100% accuracy during classification, other movements such as a hop or jump, are receiving an accuracy as low as 80% (Bisi et al., 2017; Lander et al., 2020). Noise associated with sensors may impact the ability to use for comparative purposes. This indicates there is some improvement required before MEMs completely replace the way child movement assessment is performed. Another issue to be mindful of is the shape and position of the motion sensors, this can affect the efficiency of the sensor (Cho et al., 2020) and occasionally there can be a discrepancy seen between the results of different measurement units (Hayward et al., 2016).

<u>What have MEMS devices been used for?</u>

The definition of MEMs over time has developed along with the technology that has led to these devices being used in a number of different ways. Something that has become apparent while observing the trends in the results is that since 2017 there has been an increase in the use of MEMs in daily life to measure quality of movement during free play and living. This is interesting and positive as it is clear MEMs are not only being used to measure the quantity of activity performed by children, but are also observing quality of that movement over a day or during a free movement play session. Some examples of key research in this daily living category are Muñoz-Organero et al. (2019) using machine learning techniques on the data collected on children with ADHD (both medicated and non-medicated) and typically developing children. They wore inertial sensors on their wrists and ankles for 24 hours, the children were in school during this time. The research found after assessing their movement patterns, that non-medicated participants had significant differences in their data at medium intensity, in comparison to the control group. Interestingly the movement patterns of medicated participants were better predicted by the movement patterns of the control group. This measurement of daily movement is beneficial as it gives a greater understanding of how movement is performed in an uncontrolled setting and how the results may vary from a more staged testing approach that we see in laboratories. It has been found that in order to walk over force plates or fit within a walkway that the participants alter their gait pattern, Rastegarpanah et al. (2018) found that the first step of gait, when targeting a force plate was on average slower and shorter than their non-targeting step. There is also the possibility of children's movement patterns being affected in the laboratory setting with the presence of assessors (C. Newman et al., 2013; Serio et al., 2013) and therefore assessment in a familiar environment may provide more accurate results. These assessments in daily life are also being completed over the course of a day and sometimes even multiple days, this is allowing a better understanding of the typical movement of an individual rather than the short assessment times that are seen in laboratory settings. This has so far been found to be successful with MEMs devices showing reliability over long periods of time and showing promise for understanding detailed movements in these uncontrolled settings such as school or at home (Abrishami et al., 2019; Hoyt et al., 2020; L. Lin et al., 2020).

A topic that is very common over the years is the analysis of gait and infant movement. The study of gait is more commonly utilized with children who have clinical conditions and how they walk, these are also including typically developing children as a comparison (Belluscio et al., 2019; Ganea et al., 2012; C. Newman et al., 2013). These studies have noted the differences in gait between clinical conditions and typically developing children (Ganea et al., 2012; C. Newman et al., 2013), while Belluscio et al. (2019) also discussed the differences between two clinical conditions (Prader Willi Syndrome and Down Syndrome). Belluscio et al. (2019) found that children with PWS and DS had an altered gait compared to the control group, both had reduced stride length, increased stride frequency however children with DS had greater attenuation of the accelerations from the pelvic to the sternum in comparison to the children with PWS.

The studies involving infants are used to predict and assess movement, to enable early intervention in conditions such as cerebral palsy (Rahmati et al., 2015; Redd et al., 2019). The studies discuss how MEMs devices have provided a way to track infant movement, such as spontaneous movement. Patel et al. (2019) report that spontaneous movements are more active while the child is not being held or moved. These movements are a precursor to reaching skills and are predictive of neurological disorders (Patel et al., 2019) and therefore understanding when and how to observe is key. MEMs devices provide the information of all movements unlike video cameras that may miss a movement when the camera is obstructed (Patel et al., 2019), however Machireddy et al. (2017) found combining both video and IMU

sensors provided a new method of estimating depth and found that 84% of fidgety movements were classified correctly. MEMs are also being used in toys to help with stimulation but also assessment, this allows monitoring to take place remotely and has been used in preterm infant cohort (Rihar et al., 2016).
MEMs devices have allowed a method of detecting movement, which can be important precursors to typical motor development and in turn aids the identification of conditions such as cerebral palsy (Cecchi et al., 2010; Fry et al., 2018). These studies are discovering movements that are very difficult to be seen by the eye and are therefore allowing an earlier diagnosis to take place (Rahmati et al., 2015). Early diagnosis is important for allowing early intervention and therefore providing an improved quality of life for the children and their families (Heinze et al., 2010; Rahmati et al., 2015).

Although there are some challenges the use of MEMs present in the field of infant movement assessment, and there are important factors to be considered, such as external forces on their limbs while being carried or moved (Cecchi et al., 2010; Kwon et al., 2019; Rahmati et al., 2015) and the devices should not impact the movement of the infant (Rahmati et al., 2015; Serio et al., 2013).

Posture is a topic that is not as commonly researched; this may be down to the fact that force plates are seen as the gold standard for measurement in this area with both children and adults (Shieh et al., 2020; Sun et al., 2018). However it is possible to measure postural sway with MEMs devices and it has been found to be a valid and viable alternative method in both children (Shieh et al., 2020) and adults (Sun et al., 2018). The use of MEMs rather than force plates allows the research of posture to be completed by a wider audience as MEMs devices provided a cheaper alternative (Kim et al., 2018).

MEMs devices while having many benefits and uses do pose challenges and there are important things to consider such as device noise and placement. The devices are not being fully utilized and some data is being left unreported. Whilst they are being used across a larger spectrum of cohorts and measuring new fields, there is still a long way to go before they are used to their full potential.

Definition

A large number of the studies found did not define quality of movement and provided no definition of the movement or skill they were observing. Other papers refer to the movement and define the characteristic of the movement that they are observing. These are typically employed by papers considering specific clinical groups.

The scoping review revealed that a number of groups have differing opinion on what quality of movement means. There is no consistency around this topic as can be seen by the return in paper results. Having a broad definition or near to no definition can cause some confusion (Jacquey et al., 2020) and means that the findings of different studies cannot necessarily be compared. Moreover, a clear definition is required for a high reliability of movement quality assessment to be achieved and allow changes to be tracked over time. However, one definition for every child population is difficult and potentially unrealistic. One definition would exclude some individuals from achieving good quality due to the movement patterns they perform. The question to be asked is can there be one overarching definition that is also flexible to include multiple populations.

A number of terms are used to describe how someone moves from motor competence (L. Lopes et al., 2019), motor control to quality of movement (Niewiadomski et al., 2019). This broad use of terminology was reflected in the wide range of search terms however people still interpret these terms differently. The term ‘quality’ can be defined as something that is good or bad, it can also be used to describe a high standard or particular characteristics of an individual (Collins Dictionary, 2022). This is where the confusion around the term of quality of movement may come from, due to some people discussing the optimal way to perform and what is required to perform a skill to perfection while others may be stating how an individual actually moves regardless of it being good or bad quality and this may explain the broad return of papers and results found. Moreover, a definition of good quality may not be appropriate for some clinical groups and whilst a single definition has many advantages it may not be realistic. The review has highlighted that there are multiple measures of quality that can be taken; it can be measured by assessing acceleration, force and step count or by observing how someone moves biomechanically during a specific skill. The term can also vary between different areas of research; how a biomechanist may define quality may be different to someone in the health and fitness field. It appears that the definitions are usually dependent on the objectives of the research. The measure of quality is not restricted to qualitative or quantitative tools, this is where MEMs devices can be helpful as they take out the bias from assessment and the unpredictability of observing movement.

There does not seem to be a trend in the definition of quality of movement over the years, even during the earlier years there is a distinct lack of definition and over the years with additional populations and forms of assessment this appears to have increased the problem.

This definition stated by (Clark, Barnes, Summers, et al., 2017) is a clear definition of quality of movement; "Quality may be a nebulous term, one operational and measurable definition is; the purity of the fundamental frequency spectra (or signal) during human movement." While Bisi et al., 2017 also stated a definition using the term movement competence once again showing the confusion and inconsistency with terms used; "Movement competence is defined as the development of sufficient skill and ability to assure successful performance in a variety of physical activities".

The other definitions presented discuss the characteristics of a movement or condition similar to the following definition presented by Iosa et al. (2013); "Gait stability can be defined as the capacity to minimize upper body oscillations and absorb jerks, bumps, shakes and fluctuations, despite the broad and fast movements of the lower limbs during locomotion."

Creating one definition for quality of movement is quite difficult due to the broad population and skills covered. Therefore, a definition should be broad and covering all abilities, ensuring that a good quality of movement is when an individual performs a skill to the best of their ability with efficiency. After scoping the current research in the area, it is clear that the definition is not a one size fits all, the standards of movement vary and this should be reflected in a definition. Children with Prader Willi Syndrome and Down Syndrome are often treated with the same intervention approach despite the children adopting different motor strategies (Belluscio et al., 2019). While Contini et al. (2019) reports that individuals had different responses to two different orthotic solutions. This shows the importance of personalized treatment and a personalized definition of quality of movement. Each individual has a different efficiency and some will not be able to perform certain skills however this does not necessarily mean they have poor quality of movement. Then, there can be a degree of ‘good’ quality of movement for each individual skillset.

4.6 Conclusion

To conclude there is a wealth of research surrounding children's movement with a large number of papers characterizing and measuring quality of movement. Quality of movement can be measured qualitatively and quantitatively with MEMs devices becoming an important tool for measurement. MEMs devices have numerous benefits surrounding cost, ease of use and time spent analyzing the data. Despite some of the challenges they pose such as differences in placement, size for infant measurement, they are becoming popular and useful in this field. The area of research is growing with multiple cohorts now being assessed which is important to understand overall development but also aid in gaining a clearer picture on quality. The definition of quality of movement has proved confusing with numerous interpretations. The large number of devices, cohorts and areas of research has led to an unclear picture. It does seem as if an overall definition of quality is difficult due to the wide range of movement even within the same cohort. There is not a one size fits all definition. However future research should aim to clearly state what they interpret a good movement quality to be, this will create a comparable tool for everyone looking at quality of movement.

Chapter 5:

Synthesis

The aims of this research were to gain a better understanding of both the quality and quantity of children's movement. This thesis aimed to understand what happens to children's fitness levels from school year 5 to year 6, while looking at the gender differences, if any, that occur during the change in fitness. To gain a better understanding of the quality of movement, the study aimed to understand how technology in the form of MEMs devices are used. We aimed to explore trends with the devices and areas of research while also considering the definition of quality of movement. Quality of movement in children's research is not clear and this study aimed to seek clarity.

Movement is vital to functioning and daily life, it provides children with the opportunity to explore, play and develop. Movement is essential from the simplest tasks to complex skills that can be used in sport. Movement can be discussed in terms of quality and quantity with both measures as equally as important to children's movement (Janssen et al., 2012). Quantity can include the time spent being active, how much time an individual spends sitting, the intensity of the activity, while quality of movement includes how to walk, run, jump, the mechanics of a movement and how it is performed.

The aim of study 1 was to quantify changes in fitness levels from school year 5 to year 6 in boys and girls. While research indicates that global levels of fitness are decreasing (Boddy et al., 2012; Moliner-Urdiales et al., 2010; Sandercock & Cohen, 2019; Stratton et al., 2007) the current study did not follow this trend, indicating the need for more research to understand natural changes in fitness. However over a one-year period, in this study children improved their fitness levels in all components except for flexibility, this is in line with current literature (Đurić et al., 2021; Roth et al., 2018). This being said there are mixed conclusions on flexibility performance.

Mikkelsson et al. (2006) reports that an increase in sit and reach performance is seen from adolescents to adulthood, while Castro-Pinero et al. (2009) reports a greater performance in children aged 13-17 in comparison to 6-12 years old. This being said Roth et al. (2018) and Štefan et al. (2019) have reported a decrease in performance. Flanagan et al. (2015), is a study that is similar to the current study in design and concept and interestingly while they found that girls flexibility decreased by 32.4%, boys' flexibility increased by 105%. This indicates that it is unclear what trend flexibility follows and what is to be expected with the result, as there are multiple findings.

Differences in fitness between girls and boys were evident with boys having superior scores to girls with the exception of flexibility which is in common with the current literature. On the other hand, changes in fitness between girls and boys produced more noteworthy results. For example while boys performed significantly better than girls (Dobosz et al., 2015; Marta et al., 2012; Ploegmakers et al., 2013), girls performance increased at a higher rate over 12 months for all components (except for sit and reach performance), although only 2 (speed bounce and sit and reach) achieved significant change in comparison to boys. The reasons for the narrowing of gender difference is not absolutely clear but is probably driven in part by the onset of the adolescent growth spurt. Flanagan et al. (2015) reported a greater improvement in grip strength performance over a year in girls and attributed this to the earlier growth spurt that we see in girls. This may explain the greater improvements across all components of fitness and it is apparent that the changes in fitness in boys and girls is not similar. This being said, controlling for the covariates of change in BMI Z score, days between and baseline score did not seem to have a large overall effect on results, and it appears that some parameters (10x5m shuttle, sit and reach and standing broad jump) are slightly affected by the number of days between, however not all.

A limitation to this study is the lack of maturation measurement that could potentially explain whether this is the cause of the greater change seen by girls, while the change in BMI informs us on growth it is not possible to know whether this increase in BMI is down to a healthy or unhealthy mass gain. The studies on children's fitness are increasing and the current results from this study confirm that boys perform better than girls, and children's fitness increases over a one-year period. Additional research could focus on whether girls continue to improve at a greater rate than boys in different age groups, or whether this result is purely seen due to girls beginning their maturation before boys do. Understanding this will allow a clearer picture of the effects of growth on physical fitness, while also understanding any relationships that may be present with fitness and will aid research or interventions that target this population.

While the quantity of movement is important to ensure a child is moving enough to stay physically fit, the quality of movement can impact the confidence to move. Therefore quality and quantity impact one another. Research in quality is not as common as quantity. The aim of the scoping review was to explore how MEMs devices are used to assess quality of movement, what devices are used, what metrics are extracted and what areas of movement are being observed. A secondary aim was to create clarity on the term of quality of movement and provide guidance on future work.

The use of MEMs devices has increased over the last decade and their use to measure movement quality has increased over the years. It has also been noted that MEMs devices have allowed a greater inclusion of clinical conditions in movement quality assessment such as Down Syndrome, Duchene Muscular Dystrophy and Autism spectrum disorder (Belluscio et al., 2019; Ganea et al., 2012; Naito et al., 2019). MEMs devices have developed and decreased in size, which has also meant that they are being more commonly used in infant assessment (Rahmati et al., 2015; Redd et al., 2019). It is important to understand how an individual moves to allow adequate intervention but also to measure for the potential of developmental delays. Quality of movement is not only being measured in set movement patterns such as throwing (Wedyan & Al-Jumaily, 2017) but has also expanded to include the assessment of free living and daily life (Clark et al., 2019).
One of the main challenges surrounding quality of movement assessment is the lack of consistency. Assessing movement quality is problematic due to the lack of consistency in the devices used, metrics extracted, populations studied as well as the definitions of quality provided. This means it is difficult to compare studies within this field of measurement.

For example when observing gait Zhang et al. (2014) used machine learning techniques while Aycardi et al. (2019) extracted features such as cadence, speed, stride length and pelvic angle. In this sense MEMs devices are not always being used to their full potential as there is some data that is not reported from movements. The device or the metrics extracted drive the study and the quality observed. Another challenging aspect to quality of movement research is the lack of a consistent definition of quality. There are studies that do not state what they intend by a good quality of movement or what they aim to see in the results. Multiple papers characterize a movement and explain what the movement looks like by eye, for example "Toe walking, foot drop and walking manipulations are some of the walking disorders that can arise due to cerebral palsy" (Pitale & Bolte, 2018).
However, few report on data signals and patterns that illustrate quality of movement, neither are there the analytics that standardize data extraction and interpretation. Some studies such as Iosa et al. (2013) have started this process with their clear definition of gait stability; "Gait stability can be defined as the capacity to minimize upper body oscillations and absorb jerks, bumps, shakes and fluctuations, despite the broad and fast movements of the lower limbs during locomotion. An upright gait is stable when upper body accelerations are minimized and smoother and have a harmonic distribution that is in accordance with natural step by step repetition." They followed this definition with measurement of gait smoothness, harmony, symmetry as well as the common feature extractions of gait speed.
There is a potential that 'quality' can be interpreted in different ways by different researchers and while this is beneficial, as it expands knowledge in this area it can also make comparison of findings difficult. For some researchers' quality may include a measure of intensity, the intensity of a performance may affect how the movement is performed and therefore is also a factor of quality to consider, while others do not include intensity in their ideology of quality.

That being said setting one definition for quality of movement is difficult due to the broad scope surrounding the topic. It would need to cover movements such as walking, lifting arms, posture, all while encompassing different clinical conditions from typically developing to children with developmental delays. Ideally there would be a definition for each condition and each movement to ensure that a good quality is achievable for all individuals.

A limitation of the study is that papers were included in line with a working definition, this may have excluded some studies in other areas. Future research should aim to create consistency by clarifying the studies interpretation of quality of movement, what methods and data extraction will be used. Over time this may create a clearer base, which may allow a definition to be created in the future and also a comparison of quality to be made. Future research could bring together a group of academics to consider this and work towards a common goal and scientific programme of work. The results from the scoping review are promising, as it highlights that the importance of quality is being recognized and technology is being used to help gain a better insight.

All together this thesis has highlighted the importance of movement, both quality and quantity and provided a deeper insight into trends of fitness and tools to measure quality.

The original aim of this thesis prior to the Covid-19 pandemic was to run several fitness fun days across the borough of Swansea with the Active Young Peoples team. During these fun days the fitness assessments would take place alongside the collection of movement quality data via MEMs devices during these assessments. A secondary data collection would take place during school playtime, MEMs devices would have collected data on the quality of movement during free play. We aimed to understand whether quality of movement was similar during indoor fitness assessments to outdoor playtime and whether this quality affected their fitness result.

In light of this the Covid-19 restrictions took place prior to any data being collected, which in turn meant a restructure of the thesis. Due to the vast amount of data collected from fitness fun days in previous years it was decided to look at how the fitness levels changed over the years as it became apparent that there were schools who had participated over multiple years. To encapsulate the aspect of quality after scoping current research it was decided that a scoping review would be beneficial to aim to create clarity in this area of research. While it was disappointing to not be able to run my own Fitness Fundays days and collect my own data, this whole process has taught me how to work flexibly and change direction in my research while adapting and overcoming any challenges across the process.

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