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Measuring and Defining Children's Fundamental Movement Skills

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Abstract

Introduction: Fundamental movement skill (FMS) competence is associated with positive, health-related outcomes and can promote physical activity (PA) in adulthood. The revision of the Test of Gross Motor Development, Second Edition (TGMD-2) incorporated practitioner feedback reflecting societal changes, thus developing the Test of Gross Motor Development, Third Edition (TGMD-3). This study compared FMS proficiency according to TGMD-2 and TGMD-3. It further investigated the use of TGMD-3 in measuring FMS competence in older children.

Methods: Two hundred and twelve children (n =112 boys; 52.8%; 12.5 ± 2.4 years) were recruited in South Wales. FMS skills were assessed using the TGMD-2 locomotor and object control and TGMD-3 locomotor and ball skills subscales. Inter- and intra-rater agreement was 92.7% and 90.3%, respectively. Mastery, near mastery (mastery/near mastery combined) and sex differences were subsequently investigated. To predict FMS performance against TGMD-2 total and subscale scores, regression analysis was undertaken using both these scores. Confirmatory factor analysis (CFA) was used to verify the factor structure of TGMD-3 and goodness-of-fit statistics were generated to understand how well the TGMD-3 assessment measures FMS ability in older children.

Results: No child achieved mastery in either TGMD-2 or TGMD-3, while the proportion of children achieving mastery/near mastery (M/NM) decreased from TGMD-2 to TMGD-3 (skills measured in both assessments), reflecting notable differences in skill component criteria. Similar sex differences were observed in total assessment and subscale scores between the TGMD versions. There was a significant relationship between TGMD-2 and TGMD-3 total scores ($\rho=0.945$; $p<0.01$) and subsequent subscales: locomotor skills ($\rho=0.922$; $p<0.01$) and object control/ball skills ($\rho=0.915$; $p<0.01$). Overall TGMD-3 performance can be predicted from performance in both TGMD-2 subscales, with object control (TGMD-2) performance predicting ball skills proficiency (TGMD-3) and locomotor skill performance in TGMD-2 predicting TGMD-3 locomotor skill proficiency. A two-factor model was supported, however, the measure of best fit does not encompass all skills associated with TGMD-3 for older children.

Conclusions: The findings support the removal of the underhand roll and demonstrates sex differences in TGMD-2 and TGMD-3 total mastery and object control/ball skills subscales. Skill component criteria changes suggest a higher degree of difficulty to achieve mastery in

TGMD-3. The ability to predict TGMD-3 from TGMD-2 has important future implications, increasing inter-study comparability and thereby enabling significant advances in our understanding of FMS in youth. Identifying overall levels, trends and inequalities among children and young people is imperative to inform and deliver effective programmes and initiatives aimed at increasing PA, health-related fitness and physical competence levels.

Scientific Outputs

Presentations

Murray, M., McNarry, M.A., Hill, P., Stratton, G. & Mackintosh, K.A. *Measuring and Defining Children's Fundamental Movement Skills.* United Kingdom & Ireland Motor Competence Network Meeting, Liverpool, United Kingdom. January 2020. Oral Presentation

Murray, M., Hill, P. McNarry, M.A., Mackintosh, K.A. & Stratton, G. *Evaluating FMS During Late Childhood and Adolescence*. United Kingdom & Ireland Motor Competence Network Meeting, Cork, Republic of Ireland. January 2019. Oral Presentation

Murray., M., McNarry, M.A., Stratton, G. & Mackintosh, K.A. *Developing objective assessment methods of Fundamental Movement Skills through visualisation.* Applied Sport Technology Exercise and Medicine Research Centre (A-STEM) Postgraduate Conference, Swansea, Wales, UK. November 2017. Oral Presentation.

Declarations and Statements

1. I, Maeve Áine Mairéad Murray, hereby declares that the work presented in this thesis has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

2. I, Maeve Áine Mairéad Murray, hereby declares that the thesis is the result of my own investigations, except where otherwise stated and that other sources are acknowledged by footnotes giving explicit references and that a bibliography is appended.

3. I, Maeve Áine Mairéad Murray, hereby gives consent for the thesis, if accepted, to be available for photocopying and for inter-library loan, and for the title and summary to be made available to outside organisations.

Signed: [redacted] (candidate)

Date: 26/03/2021

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"Optimum Semper Facere"

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This thesis is dedicated to a gentleman,

Ar dheis Dé go raibh a anam

Contents Page

List of Tables

List of Figures

Abbreviations

A-STEM	Applied Sport Technology Exercise and Medicine
A	Alpha
BMI	Body mass index; weight (kg) divided by height (m^2)
BOT	Bruninks-Oseretsky Test of Motor Proficiency
C1*	FMS behavioural component criteria
CFA	Confirmatory factor analysis
CFI	Comparative fit index
Df	Degrees of Freedom
FMS	Fundamental Movement Skills
GFI	Goodness of fit index
GSGA	Get Skilled Get Active
ICC	Intraclass correlation coefficients
IPLA	International Physical Literacy Association
Kg	Kilogram
LTAD	Long Term Athlete Development
MET	Metabolic Equivalent of Task
M/NM	Mastery/Near Mastery combined score
MVPA	Moderate to vigorous intensity physical activity
n/ N	Number
p/ P	Level of significance
PA	Physical Activity
PASS	Physical Activity and Skills Study
R	Coefficient of correlation r^2 Coefficient of determination; statistical measure that represents the proportion of the variance for a dependent variable that is explained by an independent variable
RMSEA	Root Mean Square Error of Approximation
SD	Standard deviation
SE	Standard error
SRMR	Standardised Root Mean Square Residual

T	t-Test statistic
TGMD	Test of Gross Motor Development
TGMD-2	Test of Gross Motor Development, Second Edition
TGMD-3	Test of Gross Motor Development, Third Edition
TLI	Tucker-Lewis index
UK	United Kingdom

1.0 Introduction

1.1 Rationale and Background

Fundamental movement skills (FMS) are the building blocks for movement (Gallahue & Ozmun, 2006) and, as such, are a prerequisite for more complex motor skills and movement patterns. Indeed, FMS are the foundation for many specialist sports skills (J. E. Clark, 2007; Gallahue, Ozmun, & Goodway, 2012; O'Keeffe, Harrison, & Smyth, 2007) and are essential to successfully participate in sport and physical activity (PA; Gallahue & Ozmun, 2006). FMS are broadly grouped as locomotor skills (e.g., running, jumping, hopping) and object-control skills (e.g., catching, throwing, kicking; Haywood & Getchell, 2009), with most children developmentally capable of mastering all of the FMS in childhood. Indeed, basic motor patterns for fostering FMS are best developed between 1 to 7 years old (J. E. Clark, 2007; Gallahue et al., 2012), with competence in FMS achieved before 10 years of age (Haywood & Getchell, 2009) through childhood exposure to developmentally appropriate activities and equipment, instruction and feedback created by a positive learning environment (Gallahue & Ozmun, 2006). Failure to master FMS by this age may create a proficiency barrier (J. E. Clark, 2007; Seefeldt, 1980) which could prove detrimental to PA levels in adulthood (L. M. Barnett, Stodden, et al., 2016).

Motor development during childhood is considered a facilitator for lifelong physically active lifestyles (LeGear et al., 2012). Positive links have been established between movement skill and health (Robinson et al., 2015; Logan et al., 2018; Cattuzzo et al., 2016), with recent systematic reviews indicating a strong positive link between PA, health and well-being in children (Granger et al., 2017; Marker, Steele, & Noser, 2018) which underpins the importance of learning to move and its essential role in developing PA (Stodden et al., 2008). Children with better developed movement skills typically finding it easier to be active and engage in more PA than those with less developed movement skills, resulting in a better health trajectory (Stodden et al., 2008). Indeed, improved childhood movement skill proficiency supports general health, quality of life in later life and reduces the risk of all-cause mortality (Hulteen, Morgan, Barnett, Stodden, & Lubans, 2018; Paterson & Warburton, 2010; Sigmundsson, Lorås, & Haga, 2016). Thus, enhanced physical competence in children and young people is foundational for PA promotion and associated health benefits, with transferable value throughout the life course.

1.2 Fundamental Movement Skills Research Trends

Despite this important role of FMS competency, global findings indicate that many children are reaching secondary school age without assured coordination and control of FMS (Pill & Harvey, 2019). Reasons suggested for this lack of proficiency are multifaceted and include the influence of socioeconomic status (Edwardson, Gorely, Musson, Duncombe, & Sandford, 2014)(Edwardson et al., 2014; Foulkes et al., 2015; McPhillips & Jordan-Black, 2007; Yao & Rhodes, 2015), cultural/ethnicity-related factors (L. M. Barnett, Hinkley, Okely, & Salmon, 2013; Hardy, Reinten-Reynolds, Espinel, Zask, & Okely, 2012; Ratzon, Greenbaum, Dulitzky, & Ornoy, 2000; Roeber, Tober, Bolt, & Pollak, 2012; Tsapakidou, Anastasiadis, & Zikopoulou, 2014), environmental factors (L. M. Barnett et al., 2013; Chow & Chan, 2011; Lester et al., 2017; Okely & Booth, 2004; Parvez et al., 2011) and other sociological factors (L. M. Barnett, Lai, et al., 2016).

In addition to these societal and environmental level factors, there is growing evidence that there may also be biological related factors (Butterfield, Angell, & Mason, 2012; Lester et al., 2017), with sex differences in the rate of progress to FMS proficiency and/or overall mastery level (Cliff, Okely, Smith, & McKeen, 2009). Specifically, boys achieve higher levels of motor competence than girls (i.e., L. M. Barnett, Lai, et al., 2016; Behan, Belton, Peers, O'Connor, & Issartel, 2019; V. P. Lopes, Stodden, Bianchi, Maia, & Rodrigues, 2012; Spessato, Gabbard, Valentini, & Rudisill, 2013; see Appendix 1). Findings also indicate that sex differences exist more specifically within the subsets of FMS as boys are better in certain object control skills (e.g. throwing; Bryant, Duncan, & Birch, 2014; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006), as well as total object control subscale skills (i.e., Bardid et al., 2016; Cliff et al., 2012; Cohen, Morgan, Plotnikoff, Callister, & Lubans, 2014; Hardy, King, Farrell, Macniven, & Howlett, 2010; O'Brien, Belton, & Issartel, 2016a; see Appendix 1). In contrast, girls have been shown to display higher proficiency in locomotor skills (Behan et al., 2019; L. E. Bolger et al., 2018; Cliff et al., 2012; Cohen et al., 2014; Erwin & Castelli, 2008; Hardy, King, Farrell, et al., 2010; Kelly, O'Connor, Harrison, & Ní Chéilleachair, 2019). A varying range of results, as demonstrated in Appendix I, could be due to previous studies measuring a specific group of skills and not a broad range of FMS (Eather et al., 2018; Ehl, Roberton, & Langendorfer, 2005; Hardy, Barnett, Espinel, & Okely, 2013; McKenzie, Alcaraz, & Sallis, 1998; Milanese, Bortolami, Bertucco, Verlato, & Zancanaro, 2010). It could, therefore, be argued that further investigation of children's FMS is required to analyse movement proficiency and sex differences across a broader array of skills.

1.3 Fundamental Movement Skills Future Research

In accord with the optimal time for FMS development during childhood, most research has focused on analysing motor competence in children aged 4 to 10 years old (i.e., Bardid et al., 2016; Freitas et al., 2015; V. P. Lopes et al., 2012; Wrotniak et al., 2006; see Appendix 1). Consequently, there has been little focus on the FMS of early adolescent youth, despite the importance of the adolescent period for the progression of children's motor competence into the specialist skill phase of motor development (J. E. Clark, 2007; Gallahue et al., 2012). Further work is required to elucidate the progression of FMS competency during adolescence and the influence of age on the sex differences already apparent during childhood.

1.4 Research gaps

Despite the widespread recognition of the importance of FMS for health and wellbeing and implications for researchers, teachers and practitioners to have a thorough understanding of motor skill development when working with youth, there remains no gold-standard method of assessing FMS. Indeed, the development of numerous motor skill assessment tools has meant that no single movement skill assessment has been accepted as the gold standard (Ward, Thornton, Lay, & Rosenberg, 2017). This has further confounded the ability to draw inter-study comparisons. The Test of Gross Motor Development, Second Edition (TGMD-2), is perhaps the most common measurement instrument for FMS assessment (Logan et al., 2018; Pill & Harvey, 2019), as it is composed of both criterion-referenced and norm-referenced components (Burton & Miller, 1998; Cools et al., 2008; D. A. Ulrich, 2000). Indeed, performance results from the TGMD-2 allows practitioners, teachers and researchers to record more detailed FMS information. This is because skill competency levels based on the TGMD-2 behavioural skill breakdown criteria can be analysed through the TGMD-2 assessment construct, which will also provide substantial information on skill mastery levels.

The TGMD-2 was recently revised to develop the Test of Gross Motor Development, Third Edition (TGMD-3; D. A. Ulrich & Webster, 2015). The revisions of the TGMD-2 led to the newly named ball skills sub-test on the TGMD-3, instead of the object control sub-test. Individual skills were also revised, with the TGMD-3 including three new skills but the removal of the skip. Therefore, the revised TGMD-3 consists of 13 FMS, compared to 12 FMS represented in the TGMD-2. Furthermore, several FMS skill component performance criteria were revised to standardise scoring. The TGMD-3 is considered the most up to date and relevant FMS measure, as it incorporates practitioner feedback regarding TGMD-2 and reflects the changes in the study population, ensuring that it is in accord with changes in society

(Webster and Ulrich 2017). Whilst some initial validation studies have been conducted (Estevan et al., 2017; Temple & Foley, 2017; Valentini, Zanella, & Webster, 2017; Wagner, Webster, & Ulrich, 2017), use of the TGMD-3 have mostly centred on specific populations (disadvantaged children: Burns, Brusseau, & Hannon, 2017; children with visual impairments: Brian et al., 2018; intellectual disability: Simons & Eyitayo, 2016) or different countries (Estevan et al., 2017; Mohammadi, Bahram, Khalaji, Ulrich, & Ghadiri, 2019; Wagner et al., 2017) and are therefore limited in their generalisability. Furthermore, it is important to ascertain the comparability of the outcomes within and between children with regard to TGMD-2 and TGMD-3 to ensure that previous studies can continue to be utilised in the future. Moreover, extending the use of the TGMD-3 to link up the phases of childhood and adolescence, as reflected in the fundamental and specialised movement phase of skill learning (Gallahue, Ozmun, and Goodway 2012), would develop practitioner understanding of childhood FMS development and it's transition into adolescence.

1.5 Thesis Aims

The aims of this thesis were therefore to perform FMS assessment using the most recent motor skill measurement instrument (TGMD-3) and extend its use to older children. Additionally, a comparison of FMS proficiency for children as assessed by both TGMD-2 and TGMD-3 was undertaken to enable a cross comparison of motor competence according to each assessment strategy and provide recommendations for the interpretation of future research. The final aim of this thesis was to consider the influence of sex on FMS competency and whether this is dependent of the assessment tool used.

2.0 <u>Literature Review</u>

2.1 Physical Activity and Health

Physical activity (PA) is a multi-factorial behaviour influenced by psychological, social, environmental and demographic variables (Charlton et al., 2014). Regular PA is widely acknowledged as a significant foundation to a good quality of life (Gülsah, Can, & Gözaydin, 2011; Marker et al., 2018). PA has immediate and long term health benefits and it is universally accepted as an effective preventative measure for a variety of health risks and non-communicable diseases (Blair, Cheng, Holder, Barlow, & Kampert, 2001; Department of Health, 2011; Lee et al., 2012). Indeed, regular PA is critical to the reduction in disease and mortality (Fox & Hillsdon, 2007), since it has been said to have a direct response on an individual's health (Bauman, 2003; Ramirez et al., 2018; Reiner, Niermann, Jekauc, & Woll, 2013). It is estimated that physical inactivity causes 6% of the burden of disease from coronary heart disease, 7% of type 2 diabetes, 10% of breast cancer, and 10% of colon cancer (Lee et al., 2012). PA is also associated with positive mental health outcomes (Bertheussen et al., 2011; Biddle & Asare, 2011).

Despite this importance, low PA levels have been reported in children in United Kingdom (UK; Edwards, Tyler, Blain, Bryant, Canham, Carter-davies, et al., 2018; Harrington et al., 2016; Hughes, Johnstone, Bardid, & Reilly, 2018; Standage et al., 2018; Woods et al., 2018). Children and young people should engage in moderate to vigorous physical activity (MVPA) for an average of at least 60 minutes per day across the week (Department of Health and Social Care, 2019; Janssen & LeBlanc, 2010). MVPA is PA that is performed at a moderate to vigorous intensity, which is over an estimated 60% of maximum heart rate. Globally, a minority of young people meet the current worldwide recommendation of 60 minutes per day of MVPA (Hallal et al., 2012; Kalman et al., 2015). Emerging evidence has seen daily MVPA decrease with age among boys and girls (World Health Organization, 2009), with a significant decrease between ages 11 and 15 years observed in 33 and 35 countries and regions in boys and girls, respectively (World Health Organization, 2016). Furthermore, girls are less physically active in most countries and regions and the sex gap has not changed over time, suggesting that girls should be targeted with sex-specific approaches and interventions (Kalman et al., 2015).

Recent reports also suggest concomitant increases in sedentary behaviour, defined as any waking behaviour in a sitting or reclining posture, with an energy expenditure of no more than 1.5 METs (Tremblay et al., 2017). As sedentary behaviour can be viewed as an independent risk factor for health (Saunders, Chaput, & Tremblay, 2014), with a meta-analysis by Tremblay et al. (2011) revealing an inverse relationship between sedentary behaviour and health outcomes, the high levels of sedentary activity in children observed in the United Kingdom (Gorely, Marshall, Biddle, & Cameron, 2007) are concerning.

2.2 Consequences of Poor Movement

Learning to move is a necessary skill underpinning PA (Stodden et al., 2008); children with better developed movement skills may find it easier to be active and engage in more PA than those with less developed movement skills. Indeed, children with poorer movement skills were found to be less physically active than those with better movement competence (Williams et al., 2008). Proficiency in basic movement is understood to relate to individual beliefs regarding movement competency (Stodden et al., 2008; Weiss & Amorose, 2005). Therefore, a more proficient mover will be more likely to enjoy and sustain interest in PA compared to a less skilled individual. Stodden and colleagues (2008) proposed a conceptual model based on a reciprocal and developmentally dynamic relationship between motor skill competence and PA which suggests that the relationship between the two areas changes over time. The developmental mechanisms influencing PA trajectories of children (see Figure 1) explain the interaction between the development of motor skills, PA and weight management. This model suggests that motor skill competence is the underlying mechanism that will influence PA as impacted by age, perceived motor competence, health related fitness and the risk of obesity (Stodden et al., 2008).

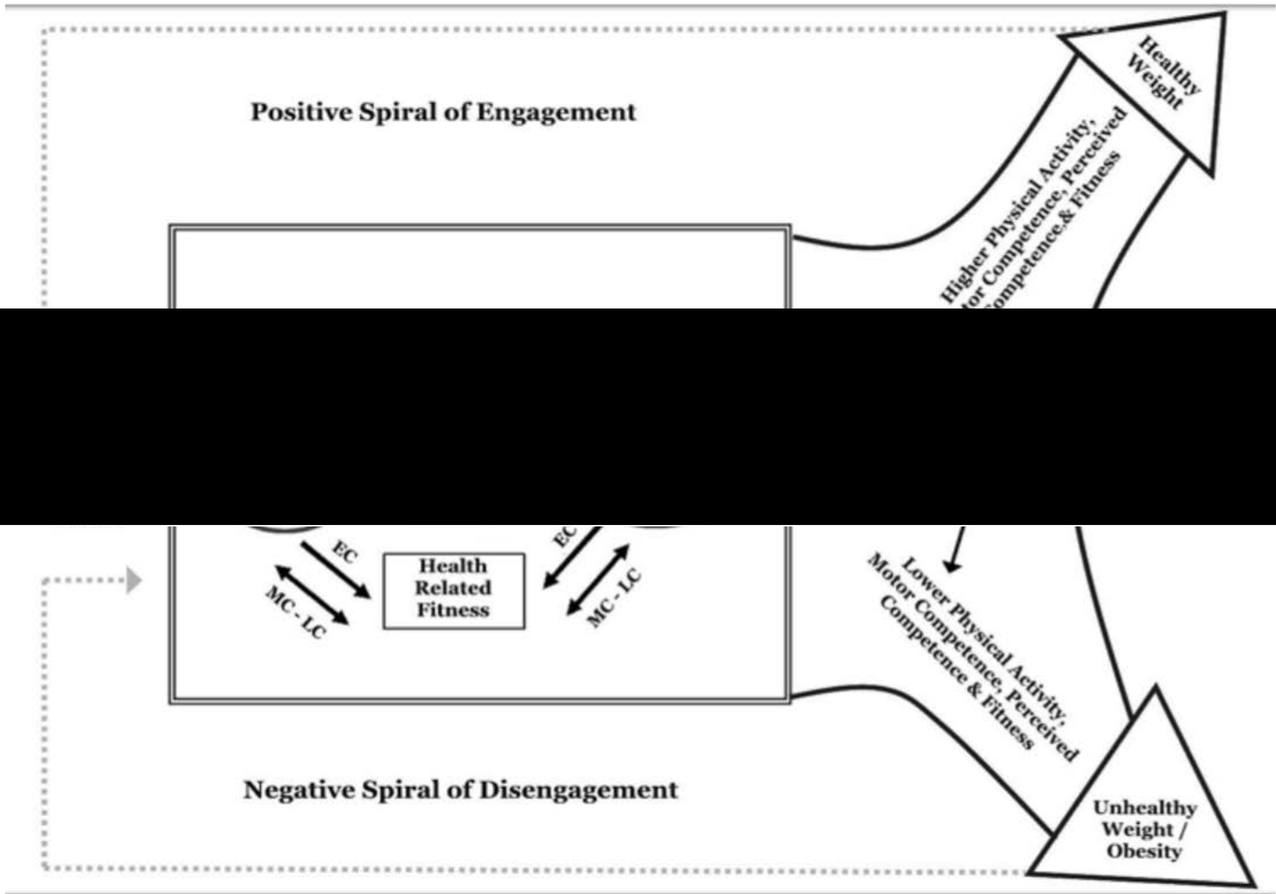


Figure 1. Theoretical model of developmental mechanisms influencing physical activity pathways of children (Stodden et al., 2008)

Research has reported negative effects of reduced movement proficiency on health-related fitness in children (Okely, Booth, & Chey, 2004; Okely, Booth, & Patterson, 2001b, 2001a). Conversely, developed motor skills in young children are considered to be linked with various positive health outcomes in adiposity (Okely et al., 2004), lower body fat (Duncan, Bryant, & Stodden, 2017), obesity (Stodden et al., 2008; Aalizadeh, Mohamadzadeh, and Hosseini 2014; Rodrigues, Stodden, and Lopes 2016) and cardiorespiratory fitness Okely, Booth, and Patterson 2001a; Vlahov, Baghurst, and Mwavita 2014). Movement skill competency has also been reported to correlate positively with self-esteem (B. D. Ulrich, 1987), cognition (van der Fels et al., 2015) and behavioural outcomes such as academic achievement (Jaakkola, Hillman, Kalaja, & Liukkonena, 2015; L. Lopes, Santos, Pereira, & Lopes, 2013).

2.2.1 Current Trends in Movement Skill – What's the Problem?

Low levels of childhood movement proficiency have been reported worldwide (see Appendix I: Worldwide FMS Trends). Worryingly, these findings indicate that many children reach secondary school age without assured coordination and control of the "fundamental" movement skills (FMS: Pill & Harvey, 2019). It is also pertinent to note that girls and boys do not typically progress to proficiency or mastery level at the same rate (Cliff et al., 2009), therefore, researchers, teachers and practitioners require a thorough understanding of motor skill development when working with youth. Research projects, (Foweather, 2010; L. Lopes et al., 2013; Okely & Booth, 2004; Pang & Fong, 2009; Spessato et al., 2013) as presented in Appendix I, suggest differences in movement proficiency between sex in children of the same age. Indeed, both age and sex have been found to influence basic skill levels among children (Bardid et al., 2016; Bryant, Duncan, et al., 2014; Freitas et al., 2015; Spessato et al., 2013), with higher levels of motor skill proficiency (or total scores) typically reported for boys (Behan et al., 2019; Erwin & Castelli, 2008; Hume et al., 2008; Laukkanen, Pesola, Havu, Sääkslahti, & Finni, 2014; V. P. Lopes et al., 2012; McKenzie et al., 1998; Spessato et al., 2013). Sex differences are also consistently reported within the sub-components of motor skill proficiency, with most indicating boys perform better in object control skills (e.g. throwing) and girls display a higher proficiency in locomotor (e.g. run) and stability skills (e.g. balance). Where sex differences within sub-components of FMS were observed (L. M. Barnett, van Beurden, Morgan, Brooks, & Beard, 2009; Behan et al., 2019; Slotte, Sääkslahti, Metsämuuronen, & Rintala, 2015), boys were found to perform better overall. This may imply that, overall, and in a practical sense, girls may have less advantage than boys in locomotion and stability. Age was found to have a positive relationship with motor skill coordination (Bardid et al., 2016; Wicks, Telford, Cunningham, Semple, & Telford, 2015). Research on basic skill proficiency in adolescents, nonetheless, suggests that older children are not mastering FMS (Lester et al., 2017; McGrane, Belton, Powell, & Issartel, 2017; O'Brien et al., 2016a).

Motor skill proficiency and PA were generally found to be positively associated (Cliff et al., 2009; Slykerman, Ridgers, Stevenson, & Barnett, 2016; Wrotniak et al., 2006). Specifically, children with greater motor skill competence show higher engagement in spontaneous PA participation on a regular basis and those with motor difficulties may choose not to participate in PA as a coping strategy (Bouffard, Watkinson, Thompson, Dunn, & Romanowski, 1996). Motor development during childhood is considered a facilitator for lifelong physically active lifestyles (LeGear et al., 2012), whilst it has also been suggested that promoting PA in early childhood may also help develop motor skills (Timmons, Naylor, & Pfeiffer, 2007). Therefore, a reciprocal relationship between PA and motor skill could be assumed. Poor motor coordination can lead to decreased childhood PA levels and, consequently, further decreased motor co-ordination levels compared to children with acceptable levels of motor development (Fong et al., 2011; Pesce, Crova, Cereatti, Casella, & Bellucci, 2009). Decreased PA levels in childhood have a knock on effect on motor skill development levels (Seefeldt, 1980; Stodden, True, Langendorfer, & Gao, 2013).

Children and adolescents who participate in sport and achieve greater levels of motor skill competence will continue to actively participate in PA as adults (Malina, 1996). A longitudinal study exploring the effects of early motor skill proficiency during adulthood found a strong positive association between FMS development at age 6 years and time spent in leisure time PA at age 26 years (Lloyd, Saunders, Bremer, & Tremblay, 2014). Further, studies have also shown that enhanced motor competence during childhood tracks across the lifespan by leading to higher levels of PA and health-related fitness during adolescence (L. M. Barnett, van Beurden, Morgan, Brooks, & Beard, 2008; L. M. Barnett, van Beurden, Morgan, Brooks, et al., 2009; V. P. Lopes, Rodrigues, Maia, & Malina, 2011; Robinson et al., 2015). Indeed, cross-sectional study findings have shown that motor competence is associated with participation in PA (Fisher et al., 2005; Lubans, Morgan, Cliff, Barnett, & Okely, 2010; Williams et al., 2008; Wrotniak et al., 2006) and skill specific activity (Raudsepp & Päll, 2006) and also organised sport and play experiences (Okely et al., 2001b). It is therefore significant that literature associates a higher level of adult PA with youth sport participation (Tammelin, Näyhä, Hills, & Järvelin, 2003; Telama, Yang, Hirvensalo, & Raitakari, 2006; Trudeau, Laurencelle, & Shephard, 2004; Van Mechelen, Twisk, Post, Snel, & Kemper, 2000). Improved childhood movement skill therefore supports general health, quality of life in later life and reduces the risk of all-cause mortality (Hulteen et al., 2018; Paterson & Warburton, 2010; Sigmundsson et al., 2016). Learning to move proficiently in childhood is essential as it provides the necessary foundation and confidence for lifelong PA. Thus, enhanced physical competence in children and young people is foundational for PA promotion and associated health benefits, with transferable value throughout the life course.

2.3 Physical Competence and Physical Literacy

Physical competence is a multidimensional concept (Tyler, Foweather, Mackintosh, & Stratton, 2018) and plays an important role in the growth and development of children (J. E. Clark & Metcalfe, 2002; Gallahue et al., 2012; Stodden et al., 2008). It is, therefore, proposed by Whitehead (2010) that physical competence is the sufficiency in movement vocabulary, movement capacities and developed movement patterns performed by an individual that also demonstrates such abilities in a range of movement forms. Viewed as an independent psychomotor factor, physical competence is related to PA (Guinhouya, 2012). The relationship of physical competence to PA includes not only the acquisition of health- and skill-related components of fitness, but also movement skills which all play an important role in youth growth and development (J. E. Clark & Metcalfe, 2002; Gallahue et al., 2012; Hulteen et al., 2018; Robinson et al., 2015). Sedentary behaviour was observed to influence health outcomes which were independent of PA level, while physical competence was related to PA and sedentary behaviours (Fong et al., 2011; Pesce et al., 2009). Difficulties attaining physical competence in childhood perpetuate decreased PA engagement and consequently further decrease improvements in competent movement, when compared to children with an achieved level of physical competence (Fong et al., 2011; Pesce et al., 2009). Thus, physical competence appears to be an important determinant of PA engagement.

Emerging evidence identifies physical competence as an important component of physical literacy (Tyler, Foweather, Mackintosh, & Stratton, 2018). Indeed, Whitehead (2010) explains physical competence as the catalogue of one's movements, movement capabilities and developed movement patterns which can be deployed in a range of movement forms. Physical literacy, therefore, is important for the physical development of skills. The International Physical Literacy Association (IPLA, 2017) and Whitehead (2007) describe physical literacy as the motivation, confidence, physical competence, understanding and knowledge to maintain PA at an individually appropriate level throughout life. Indeed, physical literacy is understood to be a lifelong concept with a 'cradle to grave' consideration (Stratton, Foweather, & Hughes, 2017). The establishment of physical literacy as one of the core principles of movement development is well accepted (Whitehead, 2007; 2010). The holistic embodiment of learning is also readily acknowledged (Wainwright, Goodway, John, et al., 2019) as it provides a conceptual basis for the intentional action to develop the human-embodied capability where human potential can be nurtured and maximized (Durden-Myers, Whitehead, & Pot, 2018).

The Welsh Government have taken a proactive position on the physical development of youth by placing physical literacy as a high priority in education, sport and health policy (Stratton et al., 2017). Moreover, this development is focused on the key foundation skills in movement, which are central to the Physical Education framework and curriculum. However, it is through the implementation of the Foundation Phase of education (3 to 7 years old) in Wales that physical literacy is seen to have an impact. Indeed, the Foundation Phase of education reflects a worldwide trend within education systems of clustering subject matter into learning areas that extend beyond subjects (MacDonald, 2003). Specifically, embodied learning resonates with the play-based approach of the Foundation Phase in Wales for children (Wainwright, Goodway, John, et al., 2019). SKIP-Cyrmu is a physical literacy programme used to develop children's motor skills in the Foundation Phase. This programme found children were more involved in tasks and had higher levels of well-being when tasks were perceived as play, with physical literacy developments at this age improving childhood motor competence (Wainwright, Goodway, John, et al., 2019; Wainwright, Goodway, Whitehead, Williams, & Kirk, 2019).

Physical literacy, as the combination of kinaesthetic intelligence and ability for skilful actions (Arnold, 1979), is the development of and the motor competence in fundamental movement skills (e.g. walk, run, jump, throw) and fundamental sport skills (e.g. catch, hop, gallop) that permit a child (or adult) to move confidently in a wide range of PA, rhythmic, and sport situations (Higgs et al., 2008). Indeed, physical literacy is a critical precursor for positive health trajectories, particularly PA and health-related fitness, across the lifespan (L. M. Barnett, Lai, et al., 2016; Hulteen et al., 2018; Robinson et al., 2015; Stodden et al., 2008; Whitehead, 2010). Physical literacy therefore has the potential to underpin the healthy development of the whole person (Edwards, Bryant, Keegan, Morgan, & Jones, 2017; International Council of Sport Science and Physical Education (ICSSPE), 2013). The key message behind the development of physical literacy in the early years is the special emphasis on the importance of movement competency, especially in the basic (or fundamental) movement patterns which are the foundation for more specific movement skills. It is these more specific movement skills that are the foundation of activity and performance. Research has suggested that this type of motor skill development is not a natural process and will need to be taught and practiced by children to gain mastery of these skills (J. E. Clark, 2007). To understand this process of development, it is essential to understand the physical/ physiological development of children.

2.4 Motor Development, Motor Skill and Motor Competence

Motor development is essential for children to master basic skills. Indeed it is the development of motor competence which reflects the degree of proficiency in performing a wide array of basic/fundamental motor skills, as well as the underlying processes such as coordination, control and quality of movement (Bardid, Vannozzi, Logan, Hardy, & Barnett, 2019; Gabbard, 2008). Motor competence is also the degree to which an individual can perform a goal directed movement (Robinson et al., 2015). Appropriate acquisition of motor competence is essential to children's physical, cognitive and social development (Payne & Isaacs, 1998). Motor development is the study of lifespan changes in motor behaviour (Roberton, 1989) and therefore children will often be seen to function at different development phases depending on their experiential background and genetic make-up (Gallahue, 1989). Motor development, defined as the process by which an individual progresses from simple movements to complex motor skills (Haywood & Getchell, 2009), is established in childhood. In view of this, Ulrich (2000) purports that the common agreement among motor developmentalists is that a child's gross motor behaviour changes dramatically over the first 8 years of life when growth is most rapid (J. E. Clark, 1994; Payne & Isaacs, 1998). Affective growth is learning that increases the ability of children to act, interact and react effectively to their environment (Gallahue 1996). Consequently, motor development is central to the overall development of children and adolescents (Sigmundsson, Trana, Polman, & Haga, 2017). Branta, Haubenstricker, and Seefeldt (1984) indicate that basic movement skills are developed consecutively. Thus, a progressive child development programme should include time dedicated to the mastery of motor competence and physical literacy. It can be, therefore, understood that as motor skills do not just develop on their own, knowledge of motor skill development is required, along with knowledge of the interactive process of individual biological constraints and the environment.

Research focusing on the development of motor skill and motor competence is extensive. A common trend in skill development models is the inclusion of an early years multi skills, fundamental skills or sampling stage as seen in the review of Bailey, Collins, Ford, Macnamara, et al. (2010). A natural process for motor development is viewed to support the Long Term Athlete Development model (LTAD: Balyi, 2001; Ford et al., 2011) for the development of physical literacy. The study of fundamental skills has its roots in motor development research and as such it can also be seen in the FUNdamental stage of Balyi's LTAD model, aimed at children aged 6-9 years old. Similarly, Vandaele et al. (2011) suggest that fundamental skills should be learned, developed and mastered between the ages of 4 to 6 years old. The emphasis in this stage of motor development is on the overall advancement of the athlete's physical capacities, FMS and the ABC's or basics of athleticism (Balyi, 2001; Stafford, 2005). It is, therefore, understood that motor development in early childhood is crucial. Basic motor skill patterns develop from this foundation age and appear to be the most critical to later skill attainment (J. E. Clark, 2007).

Fundamental movements involve a series of developmental stages, with each stage possessing a different degree of complexity (Flinchum 1975; Gabbard 1992; McClenaghan and Gallahue 1978; Roberton 1989). Children need to acquire mature fundamental movement patterns to improve their performance (McClenaghan & Gallahue, 1978). Acquiring mature patterns requires improvements in speed, balance, control, strength, and coordination to be able to pass through the different development stages (Ford et al., 2011). These developmental stages have been incorporated into various theoretical frameworks that begin with reflexive movements and finish with specialized and skilled movements (Burton & Miller, 1998; Salehi, Sheikh, & Talebrokni, 2017). Ulrich (2000) suggests a common development stage overview which contains four stages representing multiple sequential periods where qualitative differences are observed in a child’s motor behaviour. However, this overview lacks detail with regards to age descriptors for the later stages when compared to the models proposed by Clark (2007) and Gallahue, Ozmun, and Goodway (2012) that represent a more accepted general understanding (O’Brien, Belton, and Issartel 2016b).

Clark (2007) explained motor skill development as a lifelong journey of sequential stages and illustrates this as a framework or the “Mountain of Motor Development” (Figure 2). Similarly, Gallahue, Ozmun, and Goodway (2012) present a conceptual model of motor development that provides general guidelines for describing and explaining motor behaviour (Figure 3). Fundamental motor patterns are required to be developed between 1 to 7 years old, with the acquisition of basic co-ordinated patterns of movement forming the basis of later emerging sport skills (J. E. Clark, 2007). During a similar age range, Gallahue, Ozmun, and Goodway (2012) establish a rudimentary movement phase (birth to 2 years old) and a fundamental movement phase (2 to 7 years old). After this period, Gallahue suggests that there is a specialized movement phase (7 to 14 years old), consisting of three subsections of transitional, application and lifelong utilization stages. Likewise, a context specific motor skills period is identified by Clark as between 7 to 11 years old, inevitably supporting the mountain top phase of skilfulness beginning at 11 years old. Development of fundamental skills of movement is therefore theorised to start at birth and continue until 11 to 12 years of age, depending on the complexity of the skill (Gabbard, 2008).

Significantly, Stodden et al. (2008) identify middle childhood as between 7 to 10 years old and explained that at this age children’s cognitive ability has developed to a stage where they can compare themselves to their peers. As children mature, self-concept changes as does perceptions of their own motor competence; older children become more aware of their ability which has implications for their feelings and motivation (Harter, 1988). During early school years, a child's gross motor performance plays a significant role in influencing how peers view the child and so a child who is less skilled is less likely to participate in group games which has negative impact on a child's physical self-concept and motivation to be active (D. A. Ulrich, 2000). Interestingly, Chamley (2005) describes the development of fine motor skills and hand eye coordination to coincide with two major growth spurts that occur within the brain during middle childhood. These changes between the ages of 6 and 8 years old and 10 and 12 years old match the key times for development of physical competence and improved motor coordination and ability in children (Gabbard, 2008). Markedly, Ford et al. (2011) discuss these same periods in childhood as the ''windows of opportunity'' associated with the LTAD model (Balyi & Hamilton, 2004; Higgs et al., 2008). There has also been suggested to be a 'proficiency barrier' indicating a critical threshold of motor competence development should basic skills not be targeted for development during this period in childhood (Seefeldt, 1980; Stodden et al., 2013). Indeed, a barrier would see individuals with underdeveloped or poor motor competency as PA drop outs or as individuals with a limited variety of activities as low skilled performers (Stodden et al., 2013). Regardless of the specific approach taken to define the developmental sequences, researchers agree that the age at which a specific motor skill emerges, the rate of passage through the identified developmental sequence and the amount of time required to mature, are highly variable among individuals (Branta et al., 1984; D. A. Ulrich, 2000).

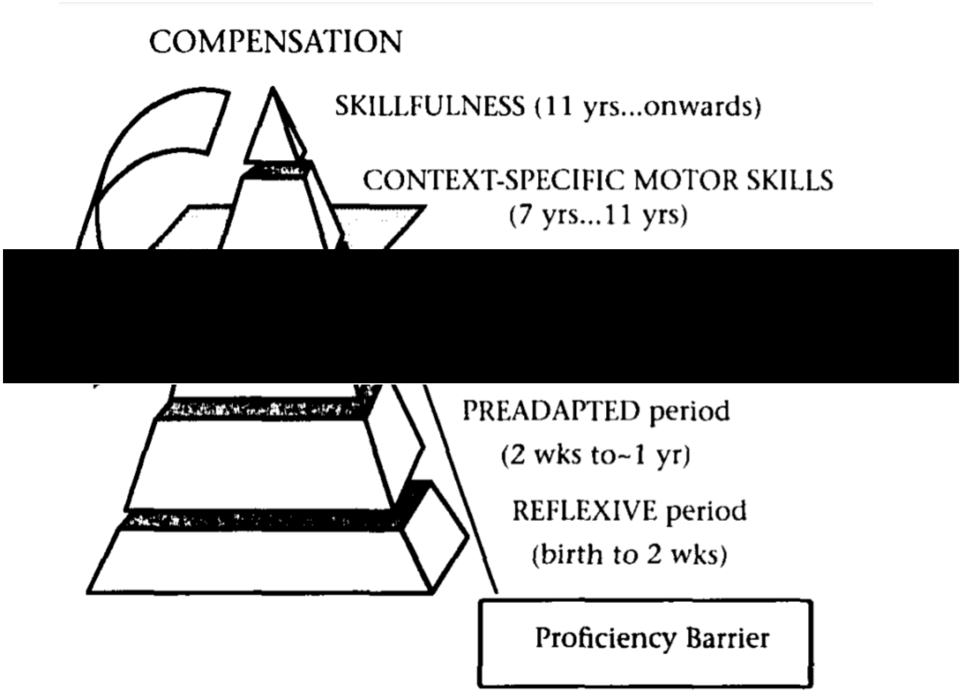


Figure 2. The Mountain of Motor Development (A schematic of the mountain broken down into phases (J. E. Clark, 1994, 2007; J. E. Clark & Metcalfe, 2002).

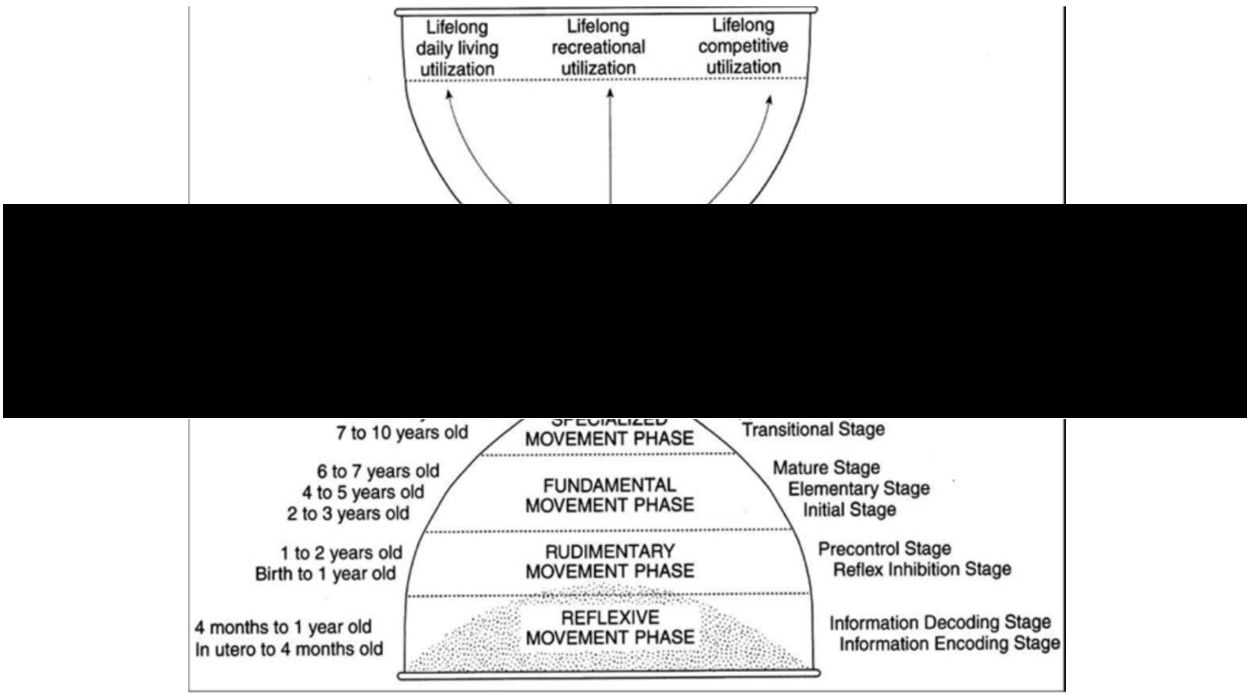


Figure 3. The Hourglass: Lifespan Model of Motor Development (Gallahue et al., 2012).

2.5 Fundamental Movement Skills (FMS)

Fundamental or basic skills are seen as the "building blocks" of more advanced, complex movements required to participate in sports, games, or other context specific PA (Gallahue et al., 2012). Similarly, fundamental movements and sport skills are viewed as the basic building blocks of physical literacy (CS4L, 2011). These types of basic and fundamental skills are more readily identified as FMS (L. M. Barnett, Stodden, et al., 2016). Results from a recent systematic review of motor competence terminology conducted by Logan et al. (2018) found the term fundamental movement skill, and not fundamental motor skill, to be more readily used by researchers worldwide. It is, therefore, suggested by Logan and colleagues (2018) that the terms fundamental movement and fundamental motor are used interchangeably, unless a research team provide a specific rationale for choosing one over the other. FMS subsequently includes object control/ ball/ manipulative skills such as throwing, catching, dribbling, kicking, strike, rolling and locomotor skills which involve moving the body through space such as walking, running, jumping, hopping, leaping, galloping, sliding and skipping (Gallahue et al., 2012; Haywood & Getchell, 2009). Balance/ stability skills, as discussed by Logan et al. (2018) and shown in literature (Burton & Rodgerson, 2001; Fleishman & Quaintance, 1984), are traditionally categorized as underlying abilities for locomotor skills as opposed to stand-alone FMS. Indeed, it is important to acknowledge that not all components are solely isolated. For example, the ability to stabilize the body can also be required in ball skills (e.g. kicking requires the planting of the foot to perform a stable action for the opposite foot to strike the ball).

All children develop a rudimentary fundamental movement pattern over time, however, mature patterns of FMS do not develop "naturally" (J. E. Clark, 2007). Childhood play and exploration is not enough for the development of these skills, therefore teachers and coaches need to have the necessary understanding of motor development to identify the appropriate task and environmental conditions to support the development of children's motor competence (Gallahue et al., 2012; Maude, 2010). Research suggests it takes between 240 and 600 minutes to master FMS (Hardy, King, Espinel, et al. 2010), which means it takes approximately 10 hours instruction for most children to master one fundamental movement skill. Progression to the mature stage of a fundamental movement pattern depends on a variety of factors. The child requires appropriate instruction in the skill to learn and the learning environment must be conducive to the child's maturation level and the conditions within the task (Gallahue & Ozmun, 2006; Pickup & Price, 2007). High quality instruction, which is developmentally appropriate, has been established to provide an effective FMS intervention in preschool aged children (Robinson & Goodway, 2009; Valentini & Rudisill, 2004), an age which has previously been determined as essential for FMS development (J. E. Clark, 2007; Gallahue et al., 2012). Robinson and Goodway (2009) found a learning environment that developed low autonomy and a mastery motivational climate assisted object control FMS development for pre-school children. FMS, therefore, should be taught, learnt and reinforced (Goodway & Branta, 2003; Valentini & Rudisill, 2004) in an environment that provides adequate time for childhood practice of these skills.

2.5.1 FMS Behaviour Criteria Components

Literature suggests that 10 years of quality practice, or 10 thousand hours of deliberate practice, is required to achieve expert levels of skill performance and become a skilled master in sport (Ericsson, Krampe, & Tesch-Römer, 1993; Simon & Chase, 1973). Therefore, a monotonic (straight-line) relationship exists between deliberate practice and expertise (Ericsson et al., 1993). However, skill learning initially must be broken down into stages. A development continuum (see Figure 4) was proposed by Branta and colleagues (1984), to illustrate how movement skill practitioners view proponents of total body configuration as having sufficient cohesion among certain characteristics of a pattern to define stages of development. Progression from one stage to another does not imply an abrupt change but a continuum of skill development among characteristics around a point on the continuum (Branta et al., 1984). Figure 4 therefore depicts the concept of progressive change in a developmental sequence with specific identifiable points on the gird that are predictable (Branta et al., 1984).

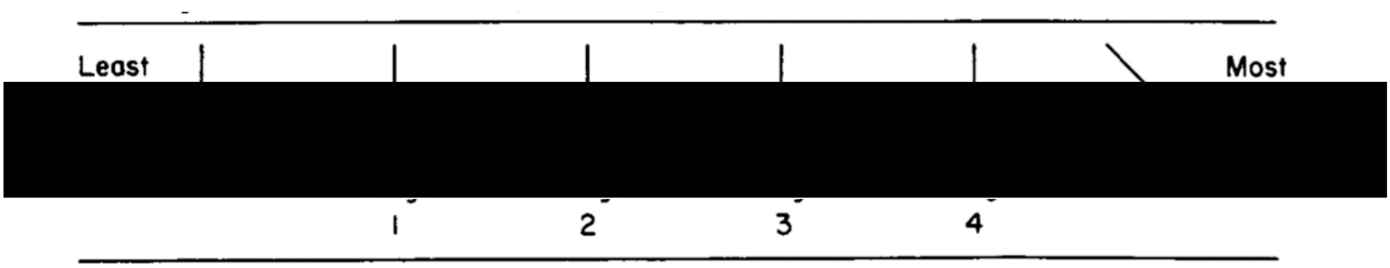


Figure 4. Development continuum of skill sequences as proposed by Branta, Haubenstricker, and Seefeldt (1984)

The developmental make-up of the movement pattern of FMS has been said to have specific characteristics and behavioural components (Seefeldt & Haubenstricker, 1982; Wickstrom, 1983). These behavioural components are performance criteria and in general represent a mature pattern of the FMS (D. A. Ulrich, 2000). As FMS are common motor activities, they have specific movement patterns associated with each skill (Gabbard, 1992); for example, catch as described by Ulrich (2000) consists of three behavioural components: component 1 (C1), component 2 (C2) and component 3 (C3) as its specific movement pattern. These behavioural components represent a process-measure of the overall skill performance for the child. Van Beurden, Zask, Barnett and Dietrich (2002) describes the value of dissecting each FMS and assessing in terms of a small number of skill components. Accomplishing skill components are considered essential to mastery of that skill (Booth et al., 1999). This breakdown of skills into components affords their measurement a level of objectivity beyond that of a single overall score and provides a good foundation for measuring change over time (van Beurden et al., 2002). Furthermore, Hardy, King, Farrell, et al. (2010) detail how competency in performance criteria is consistent with the developmental progress and the continuum of skill acquisition in children. The different performance skill component competencies indicate the value of teaching each skill component individually and providing children with opportunities to repeat the action on multiple occasions in order to develop FMS mastery (Hardy, King, Farrell, et al., 2010). Repetitive practise of FMS skill components can develop FMS competence which will be reflected in an individual’s judgements about their ability to perform locomotor and object control skills (Weiss, 2000).

Cliff et al. (2012) analysed FMS skill components as separate development points reflecting overall mastery. Further analysis illustrated how this approach allowed the researchers to examine and identify the skill components with the lowest prevalence of mastery among overweight and obese children (Cliff et al., 2012). Grouping the skill components thematically, Cliff and colleagues were able to report patterns of movement, suggesting plausible biomechanical origins specifically for overweight children, such as potential flat-footed ground contact during the run and a difficulty in bending knees to perform an underhand roll. Similarly, Foulkes et al. (2015) were able to use FMS skill component breakdown to analyse sex differences in preschool children in Northwest England. In this study, girls were found to be more proficient at components requiring correct leg movement/feet placement, whilst boys were more proficient at components requiring coordination of the legs and correct trunk movement/ body position (Foulkes et al., 2015). These findings provide a more in-depth insight into skill competency levels of boys and girls and could provide more understanding regarding sex differences in FMS performance. However, very little research exists into the breakdown of FMS skill competency in this way in older children and adolescents. Analysing FMS in this way could provide further insight into skill competency levels for this age group and afford more understanding on skill. As O'Brien, Belton and Issartel (2016a) identifies, there are numerous data available in relation to overall skill mastery but there is limited data documenting the skill proficiency at a component level of performance. Many of these components are often interrelated across the range of FMS, which, if analysed, may allow researchers to identify emergent trends of similar motor skill deficiency. Hence, skill analysis at the behavioural component level may assist movement practitioners in improving FMS proficiency through targeted intervention programmes.

2.5.2 Sex differences in FMS

Similarly to Foulkes et al. (2015), Kokstejn, Musalek, and Tufano (2017) and Hardy, King, Farrell, et al. (2010) found that boys and girls perform differently and excel in different skills. Ziviani, Poulsen and Hansen (2009), Bolger et al. (2018) and Vandaele et al. (2011) reported sex differences in FMS performance in a primary school aged children (J. E. Clark, 2007; Gallahue et al., 2012). Unfortunately, a similar trend in sex difference follows into adolescence, as boys perform more proficiently in total FMS scoring assessments than girls (McGrane, Belton, Powell, Issartel, et al., 2017). However, it is object control/ball skill mastery that displays a significant sex gap (L. M. Barnett, Stodden, et al., 2016; L. M. Barnett, van Beurden, Morgan, Brooks, & Beard, 2010; Butterfield et al., 2012; Duncan, Jones, O'Brien, Barnett, & Eyre, 2018; Jiménez Díaz, Salazar Rojas, & Morera, 2015; Lester et al., 2017; McGrane, Belton, Powell, & Issartel, 2017; O'Brien et al., 2016a).

Adolescence is a transitional period of life marked by many biological, environmental, social and psychological transformations which in turn can affect the level of FMS competency (Garcia, 1994). The onset of puberty during this timeframe could also suggest that depending on age, there may be sex differences in FMS (McGrane, Belton, Powell, Issartel, et al., 2017). However, environmental factors which impact on FMS competence could be seen as more influential (L. M. Barnett, Lai, et al., 2016; Raudsepp & Paasuke, 1995) for adolescent FMS mastery.

In Wales, recent research has found that girls' physical competency in the national physical literacy measure, the Dragon Challenge, was generally lower than boys (Stratton et al., 2017).

Specifically, girls' manipulative skills were found by Stratton and colleagues (2017) to be 30% lower than boys and therefore it would seem schoolchildren in Wales follow the global trend of a FMS sex gap (Ehl, Roberton, and Langendorfer 2005; Raudsepp and Paasuke 1995; Runion, Rpberton, and Langendorfer 2003; van Beurden et al. 2002). Overhand throw is the only FMS included in the Dragon Challenge which is solely recognised as a manipulative skill (see Figure 5) whereas other object control skills such as basketball dribble, catch and wobble spot are linked to one other FMS subscale (Tyler et al., 2018). Indeed, research practitioners have indicated that girls performance in throwing and object/ manipulative/ ball skills in general could be reflective of a sex bias (L. M. Barnett et al., 2010; Hardy et al., 2013) as boys more commonly play sport and games involving ball skills. Specific established research has indicated throwing as a specific FMS where a sex gap exists (Thomas & French, 1985) with overhand throwing identified as the largest sex difference among the 46 meta-analyses reported by Hyde (2005). Indeed, as Stratton et al. (2017) have illustrated that there is a sex bias in Wales, it would be advantageous to analyse this further in standalone FMS and especially in overhand throwing.

Girls and young women have typically shown less skilled throwing performances and less advanced kinematic patterns than boys and men (Yan, Payne, & Thomas 2000a; Yan et al., 2000b; Thomas, Gallagher, & Thomas 2001). Indeed, girls throwing characteristics were observed to be at lower developmental levels (component rating) for overhand throwing patterns in a kinematic constraints based throwing study in children (Stodden et al., 2006a; Stodden et al., 2006b). Hardy et al. (2013) found overhand throwing competency decreased from primary school to high school for girls in their study of thirteen-year trends in FMS. Specifically, not only was girls' overhand throw mastery low in primary school but as time progressed and girls transitioned into high school, and through puberty, their mastery in this skill further decreased (Hardy et al., 2013). Considering overhand throwing is an important FMS linking the development of other FMS, such as catching (Dirksen, De Lussanet, Zentgraf, Slupinski, & Wagner, 2016) and sports specific skills like javelin throwing and badminton smash (O'Keeffe, Harrison, & Smyth 2007; Thomas, 1997; Wickstrom, 1983), a lack of proficiency in this skill could have negative implications for girls future PA and sports participation (L. M. Barnett et al., 2010). However, research into adolescent FMS mastery is limited in specific skill analysis, especially among particular skills where a sex difference has been observed. Opportunities to identify trends in skill component achievement and sex differences would be valuable for Physical Education teachers working with single sex classes.

Task	Stability / Body Management	Locomotion	Manipulative
1. Balance bench	●	o	
2. Core agility	●		
[redacted]			
6. Catch		o	●
7. T-agility	●	●	
8. Jumping patterns	●	●	
9. Accelerate to sprint		●	

• = primary skill category involved in task; o = secondary skill category involved in task

Figure 5. Types of Skills utilised in the Dragon Challenge assessment task (Stratton et al., 2017)

2.5.3 FMS Mastery

Traditionally, the established method of reporting FMS assessment results was to present a measure for the sample who have mastered all components of the skill (Walkley, Holland, Treloar, & Probyn-Smith, 1993) with little investigation into lower levels of mastery. Van Beurden, Zask, Barnett and Dietrich (2002) defined the level of "mastery" through a calculation of the number of behavioural skill components achieved. The proportion of children exhibiting total mastery (M) was defined as those exhibiting all skill components during both trials (attempts at performance) of each FMS (Cliff et al., 2012). However, this method does not provide any insight into those who are close to mastering all the components but may have missed out on achieving one element of the skill (Booth et al., 1999; Okely & Booth 2004). This missed skill component could theoretically be a one off miss or a skill element (e.g. preparation position of arms to catch) that could be identified, practised and achieved through an intervention. Consequently, Booth and colleagues (1999) established the "near mastery"

(NM) category for those who had mastered all but one of the components of each skill. Booth and colleagues (1999) found this an appropriate method to make comparisons in FMS mastery between urban and rural schoolchildren and across tertiles of socioeconomic status in Australia. This was subsequently further developed by van Beurden et al. (2002) to establish a third mastery category coded as ‘poor’. This term covered scores which did not fall into the mastery or near mastery categories and therefore poor mastery was termed as any score that was more than one component missed of a skill. Combining mastery and near mastery (M/NM) as a proportional measure (L. M. Barnett et al., 2010) provides researchers with a further classification for children, identifying a group as possessing Advanced Skills (Booth et al., 1999; Okely & Booth 2004) or “advanced skill proficiency” (Booth, Denney-Wilson, Okely, & Hardy, 2005). It could also be suggested that practitioners who report M/NM levels for their cohort could theoretically also infer the level(s) of poor mastery observed.

Reporting on mastery has allowed researchers to illustrate differences in FMS for specific populations. Worldwide FMS levels has been displayed in different countries for similar age ranges. In Asia, 6 to 9 year old school children displayed similar results for basic skills such as the gallop (>78% mastery) but comparison of other skills shows a large difference (52%) in leap (Mukherjee, Ting Jamie, & Fong, 2017; Pang & Fong, 2009). In the southern hemisphere, object control and ball skill comparisons between 5 to 11 year olds (Valentini, Spessato, & Rudisill, 2007) and 5 to 13 year olds (Mitchell et al., 2013) show similar mastery in kicking skills (>5%) but a larger difference in striking skills (38%). However there were greater mastery differences in locomotor skills, such as the run (47%) and slide (50%) which can be seen (Mitchell et al., 2013; Valentini et al., 2007). Reporting on mastery in this way allows comparisons (Bardid, Rudd, Lenoir, Polman, & Anderson, 2015; L. E. Bolger et al., 2018; Pang & Fong, 2009), but the use of several different motor assessment tools for motor competence impairs a more global understanding of motor competence development.

Analysis of FMS proficiency in older children can highlight lows levels of FMS competency that persist after the best age for FMS acquisition (J. E. Clark, 2007; Gallahue et al., 2012). Indeed, results of M/NM and advanced skill proficiency has been used effectively to discuss FMS levels and sex differences in this age group (L. M. Barnett et al., 2010; Booth et al., 1999; O’Brien et al., 2016b). Detailed analysis can therefore provide practitioners working with this age group more insight on how particular skills can be enhanced to achieve mastery (Booth et al., 1999). Specifically, M/NM or M and NM can effectively indicate where FMS intervention can be focused to develop mastery levels for adolescents.

2.6 FMS Assessments

The human motor system includes a larger number of mutually independent skills. Therefore, assessment protocols should include a substantial number of movement skills (Netelenbos, 2003). Usually, research in the area of motor skill development focusses on motor impairment and motor deficits (Cools et al., 2008) but growing literature is establishing national trends in FMS proficiency for typically developing children (Edwards, Tyler, Blain, Bryant, Canham, Carter-Davies, et al., 2018; Harrington et al., 2016; Hughes et al., 2018; Standage et al., 2018). FMS performance can be examined by several assessment tools that are aimed at a specific target group and hence have specific content (Cools et al., 2008). No single movement skill assessment has been accepted as a gold standard, however, many valid instruments for the assessment of movement skills exist (Ward et al., 2017). FMS assessment tools can consist of specific content or have a similar purpose but also differ in their constructs/assessment techniques (A. Barnett & Peters, 2004; Cools et al., 2008; Piek, Hands, & Licari, 2012). FMS, therefore, link to locomotor skill, object control/ manipulative/ ball skill and/ or balance/ stability skill subscales. Logan et al. (2018), however, found that FMS assessments are more commonly based on only locomotor and manipulative/ ball skills. They can therefore be norm-referenced, by comparing the child's performance to that of a normative group which quantifies the child's FMS proficiency or a criterion referenced FMS assessment tool, comparing the child's performance to pre-determined criterion which considers the qualitative aspects of the movements required to perform the movement skill item (Cools et al., 2008).

In addition to the variation in the specific skills included, there has typically been considerable heterogeneity in the assessment of performance. Foulkes et al. (2015) and Kelly et al. (2019) demonstrated two assessors working together, as a typical example to ensure rigorous FMS data collection. Moreover, there is a general consensus that video recording motor competency assessments, with at least one camera, allows all aspects/components of the FMS performance to be assessed coherently (L. M. Barnett, van Beurden, Morgan, Lincoln, et al., 2009; Eather et al., 2018; Foulkes et al., 2015; Foweather, 2010; Kelly et al., 2019; O'Brien et al., 2016a; Pang & Fong, 2009; Tyler, Foweather, Mackintosh, & Stratton, 2018). However, in some instances, it is not always possible or practical to video individuals due to ethical considerations or particular resource requirements (L. M. Barnett, Minto, Lander, & Hardy, 2014; L. M. Barnett et al., 2010). Training assessors prior to testing is also pertinent (Foulkes et al., 2015; Foweather, 2010), and has been shown to result in high (≥0.74 and above) inter-rater reliability (L. M. Barnett, van Beurden, Morgan, Lincoln, et al., 2009; Foulkes et al., 2015; Kelly et al., 2019; Okely & Booth, 2004). FMS competence can be evaluated by considering the process-orientated measures of movement or the product/outcome based characteristics of movement (Burton & Miller, 1998; Hands, 2002). Outcome-based assessments are typically the end product of the FMS performance e.g., distance jumped, time to run, speed of action (Burton & Miller, 1998; Logan, Robinson, & Getchell, 2012). Product-orientated measures include tools such as the Assessment of Perceptual and Fundamental Motor Skills (APM) Inventory (Numminen, 1995); Fundamental Movement Skill (FMS) Polygon (Zuvela, Bozanic, & Miletic, 2011) and McCarron Assessment of Neuromuscular (MAND: McCarron, 1997). The outcome-based assessment tools are quick and easy to administer, providing an objective assessment measure (Hands, 2002; Logan et al., 2018; Cools et al., 2008). However, as assessors require very little understanding of human movement to perform these types of assessments, they provide little information about movement patterns or processes that would help practitioners when forming interventions targeting deficits in FMS proficiency (Hands, 2002).

Process-oriented movement assessments e.g. Motor Skill Checklist (Department of Education Victoria, 1996) and Bruninks-Oseretsky Test of Motor Proficiency (BOT: Bruininks & Bruininks, 2005), are preferred to product-orientated assessments because they identify more accurately specific topographical aspects of movement (D. A. Ulrich, 2000). Specifically, FMS with their composition of observable behavioural skill components (checklist) can be assessed together as a process, constituting a mature performance of the skill. (Burton & Miller, 1998; Cools et al., 2009; Hands, 2002). Checklists or a list of FMS skill components are based on theoretical approaches to motor development (Hands, 2002) and can vary in number between assessment tools for the same skill e.g. catch consists of 3 component criteria if assessed by TGMD-2 (D. A. Ulrich, 2000) but consists of 6 component criteria if assessed by Get Skills Get Active (GSGA: NSW Department of Education and Training, 2000). The high variability between assessment tools for basic FMS suggests that there is a wide range of movement patterns that can define proficient performance (D. A. Ulrich, 2000). The utilization of both process- and product-oriented approaches allows for ample information on movement behaviours to be derived from the assessment (Webster & Ulrich, 2017). One such assessment, the Test of Gross Motor Development (TGMD), is composed of both criterion-referenced and norm-referenced components (Burton & Miller, 1998; Cools et al., 2008; D. A. Ulrich, 2000) and, as such, may allow practitioners, teachers and researchers to garner more information (Webster & Ulrich, 2017).

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

The most widely used FMS assessment tool is the Test of Gross Motor Development, Second Edition or TGMD-2 (Logan et al., 2018; Pill & Harvey, 2019). The TGMD-2 is a standardised and norm-referenced tool that assesses the fundamental gross motor skills of children in two subscales (locomotor skills and object control skills) from 3 to 10 years of age (D. A. Ulrich, 2000). Its normative sample was based on 1,208 children residing in 10 states in the United States (D. A. Ulrich, 2000). The acceptability of TGMD-2 is due to its easy application and composite structure that allow a multidimensional interpretation of motor development (V. P. Lopes, Saraiva, & Rodrigues, 2018). The TGMD-2 manual (D. A. Ulrich, 2000) provides empirical evidence of its validity and reliability, reporting good internal consistency for each sub-test (α=0.76–0.92) and for the gross motor quotient (GMQ: α=0.87–0.94), as well as acceptable test–retest reliability (r=0.86–0.96, depending on the age group). Ulrich (2000) reports that the TGMD-2 construct validity was established by the confirmatory factor analysis (CFA: chi square/ df=5.29 and Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index, and Tucker–Lewis Index (TFI) ranged from 0.90 to 0.96).

Each child performs the FMS and assessors award scores for each respective criterion based on whether the criterion was fulfilled (score awarded = 1) or not (score awarded = 0) according to Ulrich (2000). The total score for each item is established by the summation of all individual performance criteria scores for both trials and the total TGMD-2 score determined from the summation of each of these item scores (D. A. Ulrich, 2000; D. A. Ulrich & Webster, 2015). Each subscale contains six FMS skills, with individual FMS comprising of at least three behavioural skill components. The FMS are categorised into object control skills (underhand roll, overhand throw, kick, dribble and striking a stationary ball) or locomotor skills (run, gallop horizontal jump, slide, leap and hop). Subscale scores are reflective of the skill component criteria of each FMS as object control skills have a maximum total of 48 and locomotor skills also have a maximum score of 48. The rationale behind this assessment tool is similar to the earlier edition, the Test of Gross Motor Development (TGMD) developed by Ulrich in 1985 (D. A. Ulrich, 2017), which identifies children who are significantly behind their peers in gross motor skill development. The aims of the TGMD-2 assessment are to plan an instructional programme in gross motor skill development, assess individual progress in gross motor skill development, evaluate the success of the gross motor programme and to provide a measurement instrument for research involving gross motor development (V. P. Lopes et al., 2018; D. A. Ulrich, 2000). Validity of TGMD-2 in different groups of individuals (males, females, European Americans, African-Americans, and Hispanic Americans, as well as children with Down syndrome) was also demonstrated (V. P. Lopes et al., 2018). Consequently, it is the cross-cultural support for TGMD-2 that is encouraging for researchers and practitioners working with youth.

2.6.2 Test of Gross Motor Development, Third Edition (TGMD-3)

Recently, a revision of TGMD lead to the Test of Gross Motor Development, Third edition or TGMD-3 (D. A. Ulrich, 2013). The object control sub-test was renamed ball skills sub-test because many new users from public health and other professions outside of kinesiology did not automatically understand the phrase “object control skills” (D. A. Ulrich, 2017). In the locomotor skill sub-test, skip was reinstated from the original TGMD and leap was deleted. Many adapted Physical Education teachers suggested that the skip was a much better skill for helping to identify children with Autism Spectrum Disorders who had motor deficits and the omission from the TGMD-2 limited its usefulness for this population (D. A. Ulrich, 2017). The removal of leap, however, means a measurement for the co-ordinated footwork action for jumping from one foot to land on the other is no longer assessed. In the ball skills sub-test, underhand roll was removed, and underhand throw was added as it is a more common skill among sports. Ulrich’s (2017) rationale for also removing underhand roll was due to assessor feedback who found preschool children would typically drop to their knees to perform this skill, eliminating the possibility of demonstrating all performance criteria. One handed strike was also added to the ball skills sub-test as it was recognised as a more common skill used around the world, especially in Asian countries.

Changes also occurred in several FMS skill component performance criteria with an aim to clarify scoring for assessors so that movement patterns can be observed with more accuracy. Several performance criteria had word changes to decrease assessor confusion when scoring. All performance criteria requiring a certain number of repetitions were changed to a standard four successive repetitions in TGMD-3 in order to maximise the consistency across all skills. For certain individual FMS, the number of behavioural skill components changed between the TGMD assessments. The increase in the number of FMS and therefore skill components on the ball skills subscales was in response to public health research (L. M. Barnett, Morgan, Van Beurden, Ball, & Lubans, 2011; L. M. Barnett, van Beurden, Morgan, Brooks, et al., 2009; Cohen et al., 2014; Vlahov et al., 2014) which suggests that a child’s ball skill competency relates to their future level of PA (D. A. Ulrich, 2017).

Recently, Mohammadi et al. (2019) highlighted the importance of analysing the psychometric properties and validating the revisions of TGMD-3 in order to evaluate the accuracy and significance of the obtained test scores. Confirmatory Factor Analysis (CFA) has been used to evaluate the construct validity for a two-factor model (ball skills and locomotor skills subscales) for TGMD-3 (Brian et al., 2018; Estevan et al., 2017; Mohammadi et al., 2019; Valentini et al., 2017; Wagner et al., 2017). Published normative data reports the average coefficient alpha as .88 for the locomotor skills sub-test, .89 for the ball skills sub-test and .93 for total skills (locomotor and ball skills: D. A. Ulrich, 2019). Indeed, Webster and Ulrich (2017) found a two-factor CFA model produced a slightly better fit compared to a one-factor CFA and reported fit measures of $\chi2$ (64) = 273.72, $p<0.001$, Comparative Fit Index (CFI) = 0.96, Tucker Lewis Index (TLI) = 0.95, Root Mean Square Error of Approximation (RMSEA) = 0.09, Standardised Root Mean Square Residual (SRMR) = 0.03. Results of the psychometric properties of this assessment are promising (Wagner, Webster and Ulrich 2017). However, validation of the TMGD-3 is ongoing (D. A. Ulrich, 2017) as more specific data is required to provide information on the reliability and validity of this form of assessment (Webster and Ulrich, 2017) and to evaluate the usability of the TGMD-3 in different settings (Wagner, Webster and Ulrich 2017). Some validation studies have taken place (see Appendix II) but are mainly representative of specific study populations.

It can be argued that the generalisation of certain assessment scores are limited to the society for which the instrument has been validated (Vallerand, 1989). The psychometric properties of the TGMD-3 should be evaluated before its application in different countries and settings. Given that most motor competence assessment tools do not extend into adolescence, it is difficult to link up the phases of childhood and adolescence or fundamental and specialised movement phases (Gallahue et al., 2012) of skill learning to better understand childhood FMS development and its transition into adolescence. Issartel et al. (2017) validated the TGMD-2 for an adolescent population and therefore extended its use as an assessment tool for researchers, teachers and practitioners. Validating the TGMD-3 assessment, as the most recent revised and evaluated measure of motor competence, for a similar adolescent population would be of benefit. TGMD-3 considers practitioner feedback and reflects the changes in the study population (Webster and Ulrich, 2017).

The aim of this thesis is therefore to validate the recently revised TGMD-3 and extend its use to an adolescent population. A secondary aim is to compare TGMD-2 and TGMD-3 assessment tools to identify any key differences that may influence future research and enable the generalisation of research findings regardless of the assessment tool used. Finally, this thesis aims to measure FMS proficiency in adolescents and to investigate the influence of sex on FMS

3.0 Methods

3.1 Participants and Settings

Participants consisted of 212 adolescents (n =112 boys; 52.8%) aged 11.1 – 15.4 years. Recruitment was targeted at schools and community groups involving young people aged 6 – 16 years old in South Wales. Specifically, eleven secondary schools and three youth groups were approached to participate, with subsequent study presentations made to four secondary schools and two youth groups (42.9%). The greatest barrier to participation for schools were school timetable restrictions, curriculum needs and staff shortages for substitute cover. One community youth group was re-locating their premises during the data collection timeframe and there was no individual participant uptake for testing from the remaining group. One mixed secondary comprehensive school was therefore recruited for testing (7.1%). Full ethical approval was granted according to the guidelines and policies of the College of Engineering Research Ethics and Governance Committee (approval number 2016-113, date of approval 27th September 2017; approval number PG2018-065, date of approval 5th July 2018).

3.2 Instruments and Procedures

3.2.1 Anthropometric Measurements

Body mass (kg) and sitting height (cm) were measured prior to the Fundamental Movement Skills (FMS) assessments. Children wore light, athletic clothing or their Physical Education kit, emptied their pockets and were barefoot. Each child's body mass was measured to the nearest 0.1kg using portable weighing scales [Seca 876, Hamburg, Germany]. Stature was measured as the child stood upright against a stadiometer [Seca 213 portable stadiometer, Hamburg, Germany] and looked straight ahead. The vertical distance between the floor and top of the skull was measured to the nearest 0.1cm and recorded. All anthropometric measurements were taken once by the same trained researcher using standard techniques (Lohamm, Roche, & Martorell, 1988). Body Mass Index (BMI) was calculated as BMI = body mass (kg)/stature^2 (m).

3.2.2 Fundamental Movement Skill Assessments

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

The Test of Gross Motor Development, Second Edition (TGMD-2) is a validated, process-oriented assessment designed to qualitatively evaluate gross motor skill performance of children between the ages of three and ten years (Ulrich, 2000) and has also been used (Lester et al., 2017; McGrane, Belton, Fairclough, Powell, & Issartel, 2018; McGrane, Belton, Powell, Issartel, et al., 2017; O'Brien et al., 2016a) and validated in adolescents (Issartel et al., 2017). The TGMD-2 assessment examines the performance of 12 FMS that are comprised within two subscales: object control and locomotor skills. Object control skills include: throwing, catching, striking, kicking, dribbling, and underhand rolling. Locomotor skills include: running, sliding, galloping, jumping, hopping, and leaping. Each skill is evaluated based on three to five performance criteria, as illustrated in Table 1.

Table 1. Structure and Items on the TGMD-2

Subset	*Skill*	*Number of Performance Criteria*	*Maximum Score*
Locomotor	Hop	5	10
	Slide	4	8
	Gallop	4	8
	Horizontal Jump	4	8
	Leap	3	6
	Run	4	8
Object Control	Dribble	4	8
	Kick	4	8
	Two Handed Catch	3	6
	Overhand Throw	4	8
	Underhand Roll	4	8
	Two Handed Strike	5	10

Test of Gross Motor Development, Third Edition (TGMD-3)

The Test of Gross Motor Development, Third Edition (TGMD-3) is a revised version of the TGMD-2 and, as such, is also a process-orientated assessment that is designed to assess the gross motor performance of children (D. A. Ulrich & Webster, 2015). The assessment includes a selection of locomotor and ball skills (formerly object control skills) that represent fundamental motor skills that are commonly taught in Physical Education curriculums on an international scale (Allen, Bredero, Damme, Ulrich, & Simons, 2017). The locomotor skills include: run, skip, gallop, slide, horizontal jump and hop. The ball skills include: dribble, underhand throw, overhand throw, two-handed catch, kick, one-handed strike and two-handed strike. The key changes, resulting from feedback from specialists working with children from different specialist populations, is the inclusion of skip and removal of leap from the TGMD-2 to TGMD-3 and changing the underhand roll to an underhand throw, which is more commonly used in games and sports. Moreover, the one-handed strike was also added as a locomotor skill sub-test as this skill is used worldwide in racquet sports (D. A. Ulrich, 2017). This means that TGMD-3 has a total of six locomotor skills and seven ball skills (Table 2), compared to six skills on each subscale of the TGMD-2. An increase in the number of ball skills, as well as the relative weighting, may potentially impact sex differences. Reliability studies have shown good intra- and inter-rater reliability of the TGMD-3 of 0.99 and 0.97, respectively (Ju Maeng, Webster, & Ulrich, 2016).

Table 2. Structure and Items on the TGMD-3

Subset	*Skill*	*Number of Performance Criteria*	*Maximum Score*
Locomotor	Hop	4	8
	Slide	4	8
	Gallop	4	8
	Horizontal Jump	4	8
	Run	4	8
	Skip	3	6

	Dribble	3	6
	Kick	4	8
	Two Handed Catch	3	6
Ball Skills	Overhand Throw	4	8
	Underhand Throw	4	8
	Two Handed Strike	5	10
	One Handed Strike	4	8

3.3 Study Protocol

3.3.1 Fundamental Movement Skill Measures

FMS were assessed following the TGMD-2 (D. A. Ulrich, 2000) and TGMD-3 (D. A. Ulrich & Webster, 2015) protocols. A protocol assessment plan/pack (Appendix III) was created to standardise the order of assessment and combination of skills of TGMD-2 and TGMD-3 (see page 151 - 155). The protocol covered all skills included in TGMD-2 and TGMD-3 and was designed to be time-efficient and fatigue-resistant as skills were not performed to exhaustion. The potential effects of fatigue were further mitigated by ensuring short rest periods were implemented between each of the short bouts of FMS. Children were assessed in an appropriate space with a sports-based floor planned, prepared and organised as seen in Figure 6. Specifically, where there was overlap of skills for TGMD-2 and TGMD-3, which can be seen in Table 1 and Table 2, skills with the same criterion in both assessments were combined (Table 3). Several skills were affected by a change in performance criterion number or wording and a combined scoring script were made (Appendix III, page 135 - 140). Examples include TGMD-2 hop which contains five skill criteria, whereas TGMD-3 hop lists four criteria. Furthermore, the criteria one (C1) for the TGMD-2 gallop requires arms to be bent and lifted to waist level at take-off, whereas for the TGMD-3 gallop C1 requires arms to be flexed and swinging forward. Specifically, gallop, slide, two-handed strike and overhand throw had different criterion wording, with dribble and hop described by a different number of criteria. No skills were therefore performed more than advised by the assessment manuals (D. A. Ulrich, 2000, 2013). This resulted in 15 fundamental movement skills being performed and assessed.

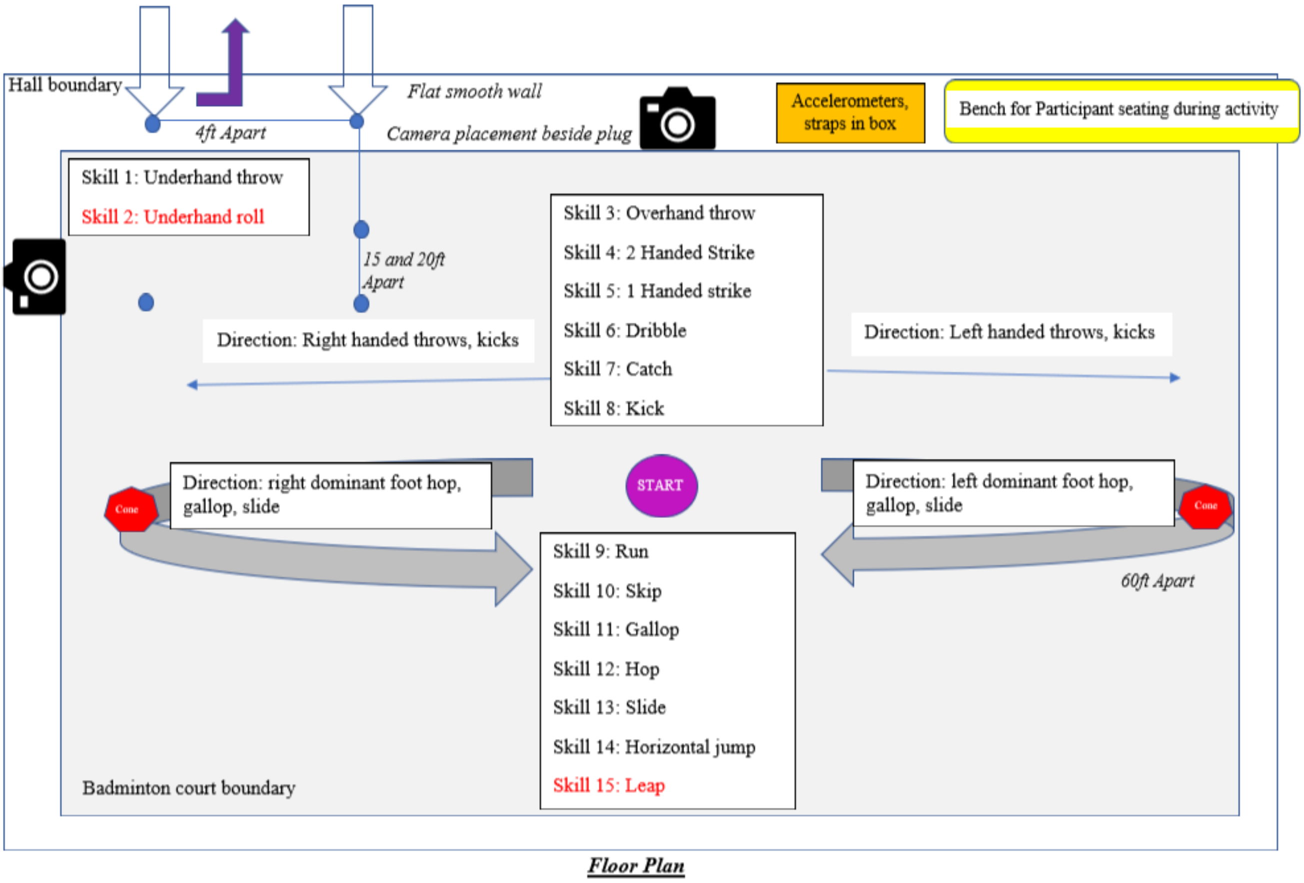


Figure 6. Floor plan demonstrating protocol, measurements and camera angle placement

Table 3. FMS detail for each assessment method

Subscale	*TGMD-2 Skill*	*TGMD-3 Skill*	*Identified as*
Locomotor Skills	Run	Run	Run
	Gallop	Gallop	Gallop
	Horizontal Jump	Horizontal Jump	Horizontal Jump
	Slide	Slide	Slide
	Hop	Hop	Hop
	Leap	*N/A*	Leap
	N/a	Skip	Skip
Object Control *TGMD-2*	Striking a stationary ball	Two hand strike of a stationary ball	Two Handed Strike
	Stationary dribble	One hand stationary dribble	Dribble

	Catch	Two-hand catch	Catch
Ball Skills	Kick	Kick a stationary ball	Kick
TGMD-3	Overhand Throw	Overhand Throw	Overhand Throw
	Underhand Roll	*N/A*	Underhand Roll
	N/a	Underhand Throw	Underhand Throw
	N/a	One handed strike of self-bounced ball	One Handed Strike

3.3.2 Testing Format

The children were familiarised with the testing environment and procedures prior to the commencement of their individual assessment. Two researchers facilitated the testing with one researcher providing a demonstration and instructions (see Appendix III: page 141-142) for each FMS to be completed. Each child performed 15 FMS skills, in two test trials one after the other. Each performance was video recorded from two angles: a saggital plane view (hand-held iPad) and a frontal plane view (tripod-fixed iPad) to ensure complete body movement during FMS skill performance was captured. The distance and camera angles were always consistent, as exemplified in Figure 5. If a participant did not understand the task correctly, for example they performed an underhand throw instead of an overhand, they were given a further verbal description of the skill and asked to repeat the trial.

3.3.3 Scoring

Children's gross motor performances were observed and evaluated based on performance criteria that describe each fundamental movement skill. Scores were awarded for each respective criterion based on whether the criterion was fulfilled (score awarded = 1) or not (score awarded = 0; (D. A. Ulrich, 2000; D. A. Ulrich & Webster, 2015). The total score for each item was established by the summation of all individual performance criteria scores for both trials and the total TGMD-2/3 score determined from the summation of each of these item scores (D. A. Ulrich, 2000; D. A. Ulrich & Webster, 2015). The maximum score (see Table 1) a participant can obtain on the TGMD-2 is 96 (48 from each subset), whilst the maximum score a participant can obtain on the TGMD-3 is 46, 54 and 100 for the locomotor, object control skills and overall gross motor performance, respectively (see Table 2).

3.3.4 Assessment

In the present thesis, skill analysis was simultaneously completed by the lead researcher and a second researcher who formed the assessor team. Specifically, each assessor separately viewed the password-encrypted video sequences at normal speed, or in slow motion when contending with motion blur. Performances were analysed in line with the TGMD-2 and TGMD-3 criteria and graded accordingly. If the assessor was unsure whether a child had met a performance criterion, then the footage was viewed by both assessors, with final scoring agreed upon. This meant a final agreement of 100% was established by the team. Intra- and inter-rater reliability was established prior to scoring using the Percent Agreement Method [number of agreements/ (number of agreements + disagreements) × 100], similar to methods used by Ré et al. (2018). This was based on videos of 14 participants during a pilot who completed the same protocol and formed a subsample. Inter-observer agreement was 92.7% (range 87.2–98.3%), while the intra-rater agreement was 90.3% (range 86.1–97.5%).

3.3.5 Total Assessment Mastery, Skills Competency and Skill Specific FMS Mastery

Each child's assessment scores were totalled and recorded for TGMD-2 and the corresponding subscales of object control skills and locomotor skills, as well as TGMD-3 and the corresponding subscales of ball skills and locomotor skills. Total performance mastery was recognised at any child who achieved full scores on TGMD-2/ TGMD-3. Skill competency levels were analysed through TGMD-2 and TGMD-3 assessment constructs, which consist of behavioural skill components that make up each FMS e.g. four skill component criteria make up the run for both assessments. Similarly, Foulkes et al. (2015) analysed skill competency in children in this way. Previous research in FMS skill assessment defined the levels of mastery of FMS skills (L. M. Barnett et al., 2010; Booth et al., 1999; van Beurden et al., 2002) as total mastery (M), near mastery (NM) and mastery/near mastery (M/NM). This understanding of FMS ability was supported in recent research conducted in similar adolescent populations by Belton et al. (2014) and O'Brien et al. (2013). Study results were therefore classified into categories of mastery, near mastery, and mastery/near mastery (see Table 4). Subsequently, as mastery and near mastery values were combined (M/NM; L. M. Barnett et al., 2010), children were further classified as possessing Advanced Skills (Booth et al., 1999; Okely and Booth, 2004) or "advanced skill proficiency" (Booth et al., 2005). Reporting on M/NM levels also inferred the level(s) of poor mastery which is also identified in Table 4 (Belton et al., 2014; Kelly, O'Connor, Harrison, & Ní Chéilleachair, 2019).

Table 4. Mastery Outcomes for each FMS

Label	*Criteria per skill*	*Score Example*
Total Mastery (M)	Correct performance of all components of a skill	e.g., run = 8/8
Near Mastery (NM)	Correct performance of all components but one	e.g., catch =5/6 or
Poor Mastery (PM)	More than one performance component missed	e.g., kick = 2/4; 1/4 or 0/4
Mastery/Near Mastery (M/NM)	Combined score of mastery and near mastery	e.g. horizontal jump = 8/8 and 7/8

3.4 Data Analysis

Results were analysed and presented using mean and standard deviation (mean ± SD) for decimal age, BMI score, and TGMD-2 and TGMD-3 total scores and their respective subscale scores. Statistical analysis was completed using SPSS version 25 (IBM SPSS Statistics Inc., Chicago, IL, USA), with a significance level of 0.05. A Shapiro-Wilk test was conducted to determine if the TGMD-2 and TGMD-3 scores were significantly different from a normal distribution. As the data was not normally distributed, Spearman's rank correlation coefficients were created for the TGMD-2 and TGMD-3 Gross Motor Quotient total scores, locomotor subscale scores, object control and ball skill subscale scores. An Independent Samples T-test was used to investigate sex differences. A paired samples t-test was performed to determine statistically significant differences between total and subscale scores on each test. To explore the relationship between performance on TGMD2 and TGMD3, and identify the key predictors of performance, hierarchical stepwise linear regression was used, with TGMD3 performance as the outcome variable.

Confirmatory Factor Analysis (CFA) was undertaken using AMOS 25.0 (Arbuckle, 2014). Goodness-of-fit statistics were generated, including root-mean-square-error of approximation (RMSEA), standardized root mean square residual (SRMR), comparative fit index (CFI) and Tucker-Lewis Index (TLI). Whilst Chi square (χ^2) and its associated degrees of freedom (Df) are commonly reported for fit indices, research has shown problems with sensitivity to sample size (Brian et al., 2018; Marsh, Balla, & McDonald, 1988; Perry, Nicholls, & Clough, 2015). More emphasis was therefore placed in the current thesis on other fit indices (Byrne, 2001). Values for both the TLI and CFI were considered as marginal fit for values >0.85, acceptable fit for values >0.90 and superior fit for values >0.95 (Hu & Bentler, 1999). The RMSEA, considered to be among the most robust fit indices, was also used (Hooper, Coughlan, & Mullen, 2008; Hu & Bentler, 1999). Values of <0.05 were considered good fit, values >0.05 and <0.08 were considered acceptable fit, and values >0.08 and <0.10 were considered marginal fit. It is typically accepted that an excellent fit between the hypothesized model and the data are indicated by values for SRMR of 0.08 and 0.06 or less, respectively (Byrne, 2001). The adequacy of the model to the data was therefore evaluated, as in previous research (Brian et al., 2018; Issartel et al., 2017; Wong & Cheung, 2010). In addition, standardised factor loadings, standardised residuals, and modification indices were analysed to screen for model misspecification (Perry et al., 2015). Items with standardised factor loadings below 0.25 were considered for potential removal from the model. It was accepted that best fit between the hypothesized model and the data is indicated by the highest values for CFI and lowest values for RMSEA and SRMR (Hu & Bentler, 1999).

4.0 Results

4.1 Participant information

Overall, 212 adolescents (52.8% boys), aged 12.4 years ± 2.4 years, currently engaged in secondary level education took part in this study. Boys, on average, were significantly taller and heavier than the girls (*p*<0.05), which contributed to a mean difference in BMI of 0.45 $kg{\cdot}m^{-2}$ (Table 5).

Table 5. Descriptive information for girls and boys

		Girls (n = 100)	Boys (n = 112)
Age (years)	Mean	12.9	13.3
	SD	1.6	1.5
Height (cm)	Mean	155.7	160.5
	SD	8.1	12.7
Mass (kg)	Mean	50.9	55.8
	SD	10.5	15.0
BMI	Mean	20.8	21.3
	SD	4.1	4.2

Notes: Standard deviation (SD), Centimetres (cm), Kilograms (kg), Body Mass Index (BMI)

4.2 Fundamental Movement Skills (FMS)

The mean assessment scores for each skill from both subscales within the TGMD-2 (Table 6) and TGMD-3 (Table 7) are summarised. Boys average FMS scores for both object control and ball skill subscales were significantly higher than the girls (*p*<0.01). Boys also scored higher in each skill of the locomotor subscales, except for the leap (TGMD-2) and skip (TGMD-3). Both catch and run were observed to have the highest average score and lowest standard deviation.

Table 6. Descriptive statistics (mean ± SD) for TGMD-2

Skill	Maximum Score	Total (n =212)	Boy (n =112)	Girl (n =100)
Object Control				
Underhand Roll	8	4.5 ± 2.4	5.4 ± 2.2	3.5 ± 2.3
Overhand Throw	8	4.2 ± 2.8	5.7 ± 2.1	2.3 ± 2.2
Strike	10	8.1 ± 2.0	8.9 ± 1.5	7.3 ± 2.1
Stationary Dribble	8	6.2 ± 2.4	7.1 ± 1.7	5.2 ± 2.6
Catch	6	5.6 ± 0.8	5.7 ± 0.7	5.6 ± 0.9
Kick	8	6.1 ± 2.2	7.2 ± 1.3	4.9 ± 2.3
Locomotor				
Run	8	7.7 ± 0.8	7.9 ± 0.5	7.6 ± 1.0
Gallop	8	6.0 ± 2.0	6.1 ± 2.1	5.9 ± 1.9
Hop	10	7.5 ± 1.8	7.9 ± 1.5	7.1 ± 2.0
Slide	8	7.6 ± 1.1	7.6 ± 1.0	7.5 ± 1.1
Horizontal Jump	8	6.0 ± 1.9	6.1 ± 1.8	5.8 ± 1.9
Leap	6	4.6 ± 1.2	4.3 ± 1.3	4.9 ± 1.1

Notes. Maximum score is sum of both trials

Table 7. Descriptive statistics (mean ± SD) for TGMD-3

Skill	Maximum Score	Total (n =212)	Boy (n =112)	Girl (n =100)
Ball Skills				
Underhand Throw	8	6.9 ± 1.3	7.2 ± 1.2	6.6 ± 1.3
Overhand Throw	8	4.0 ± 2.7	5.6 ± 2.2	2.2 ± 2.1
Two Hand Strike	10	7.5 ± 1.8	8.2 ± 1.5	6.8 ± 1.9
One Hand Strike	8	6.2 ± 1.7	6.8 ± 1.3	5.6 ± 1.9
One Handed Dribble	6	4.7 ± 1.8	5.4 ± 1.3	3.9 ± 2.1
Two Hand Catch	6	5.7 ± 0.8	5.7 ± 0.7	5.6 ± 0.9
Kick	8	6.1 ± 2.2	7.2 ± 1.3	4.9 ± 2.3

Locomotor				
Run	8	7.7 ± 0.8	7.9 ± 0.5	7.6 ± 1.0
Skip	6	4.7 ± 1.6	4.6 ± 1.7	4.9 ± 1.4
Gallop	8	5.8 ± 1.9	5.8 ± 2.0	5.7 ± 1.8
Hop	8	5.5 ± 1.7	5.9 ± 1.5	5.2 ± 1.8
Slide	8	7.6 ± 1.1	7.7 ± 1.0	7.5 ± 1.1
Horizontal Jump	8	6.0 ± 1.9	6.1 ± 1.8	5.8 ± 1.9

Notes. Maximum score is sum of both trials

4.3.1 TGMD-2 Skill Competency

The proportion (%) of boys and girls who successfully achieved each criterion of TGMD-2 (Table 8 and 9) demonstrates that all youth, irrespective of sex, scored the maximum for all criteria of the catch, run and slide, with >88.5% competency. The highest scoring skill components were the second criteria of leap and run, with children achieving 96% and 100%, respectively. In contrast, the lowest scoring skill component was the overhand throw criteria component one (C1) at 34.9%, which requires a downward movement of the hand/arm. It was noted within the leap, that the total competency scores for the sub-components C1 and criteria component two (C2) were nearly double the score achieved for criteria component three (C3), which required a forward reach with the arm opposite the lead foot (45.5%). Participants scored >50% in 20 of the 24 skill criteria for object control and 21 of the 24 skill criteria of locomotor skills. Significant sex differences were observed for 19 of the 24 object control skills. Specifically, boys achieved higher scores than girls in every object control skill criterion, except for the catch C3. The largest difference between sexes was for overhand throw criteria component four (C4), with boys scoring 60.8% higher than girls. Overhand throw C4 requires the child to follow through beyond ball release, diagonally toward the non-preferred side.

Girls scored higher than boys in seven individual skill criteria components of locomotor skills including gallop (C3 and C4), slide C2, horizontal jump C4 and leap (C1, C2, C3). Indeed, leap was the only skill where girls scored higher than their male counterparts in all criteria components. However, a statistically significant difference was only observed for leap C1. Girls scored the maximum 100% in slide C2, which required a co-ordinated sideways step with the lead foot followed by a slide of the trailing foot to a point next to the lead foot. The lowest achieved skill criteria component for boys was leap C3 at 38.4% and for girls was overhand throw C1 at 14.0%.

4.3.2 TGMD-3 Skill Competency

All skill criteria components of catch, slide and run, as assessed by TGMD-3, were highly achieved by both boys and girls (≥89.0%) as illustrated in Table 8 and 9. For individual performance criteria, boys and girls demonstrated high levels of competence (≥90.0%) in underhand throw (C1 and C4), two handed strike C1, skip C1, gallop (C3 and C4), hop C4 and horizontal jump C3. The lowest criteria component achieved for the group (31.6%) was for the gallop C1, which requires arms to be flexed and swinging forward. The second lowest scoring criteria component (35.1%) requires a wind-up as initiated with a downward movement of hand and arm for overhand throw C1.

Run C2 was the highest scoring criteria component, with 100% of all participants achieving this skill component. Boys scored higher than girls in all criteria of ball skills, except for the catch C2 where arms are required to extend reaching for the ball as it arrives. Whilst not statistically significant (p>0.05), girls scored more than boys in three locomotor skill criteria: skip (C2 and C3), gallop (C3 and C4) and slide C2. The largest differences (≤30.3%) in competence between boys and girls were for the ball skills of kick (p<0.0001) for C2 (34.7%) and C4 (43.7%), dribble (p<0.0001) for C2 (34.7%), and the overhand throw (p<0.0001) for C1 (40%) and C2 (43.1%). The largest significant sex difference (56.7%) was observed in the overhand throw C4 (p<0.0001), which involves follow through of the child's throwing hand after the ball release, across the body toward the hip of the non-throwing side.

Significant sex differences were observed for 20 of the 23 ball skills criteria. There were three significant sex differences observed for the 27 locomotor skill criteria components of run C1 and hop C1 (p<0.0001,) as well as slide C1 (p<0.05). Boys demonstrated higher competence for each performance criterion in throwing skills (except for underhand throw, C3), with significant differences observed in both the underhand C2 (p<0.0001) and C4 (p<0.05), and overhand throw (p<0.0001) for all four sub-components (C1, C2, C3 and C4). There were significant differences (p<0.0001) for boys and girls striking skills, specifically two-handed strike (C2, C3, C4) as well as criteria 5 (C5) and one-handed strike (C1, C2, C3 and C4). There were also significant differences (p<0.0001) in all criteria of dribble and kick where co-ordinated arm, or leg movements were required. The lowest proportion (%) of boys achieved criteria component one of gallop (34.4%), requiring arms to flex and swing forward.

Table 8. Proportion (%) of Boys and Girls Demonstrating Competency f Skill using result of Locomotor Skills

		TGMD-2 Locomotor Skills						***TGMD-3 Locomotor Skills***			
TGMD-2 Skill		Performance Criteria	Total	Boys	Girls	*TGMD-3 Skill*		Performance Criteria	Total	Boys	Girls
Run	C1	Arms move in opposition to legs, elbows bent	97.2**	100.0	94.0	Run	C1	Arms move in opposition to legs with elbows bent	97.2**	100.0	94.0
	C2	Brief period where both feet are off the ground	100.0	100.0	100.0		C2	Brief period where both feet are off the surface	+	100.0	100.0
	C3	Narrow foot placement landing on heel or toe (i.e., not flat-footed).	95.3	96.9	93.5		C3	Narrow foot placement landing on heel or toes (not flat-footed).	95.3	96.9	93.5
	C4	Nonsupport leg bent approximately 90 degrees (i.e., close to buttocks)	94.1	96.4	91.5		C4	Non-support leg bent about 90 degrees so foot is close to buttocks.	94.1	96.4	91.5
Gallop	C1	Arms bent and lifted to waist level at takeoff	45.8	49.6	41.5	Gallop	C1	Arms flexed and swinging forward	31.6	34.4	28.5
	C2	A step forward with the lead foot followed by a step with the trailing foot to a position adjacent to or behind the lead foot	76.4	79.9	72.5		C2	A step forward with lead foot followed with the trailing foot landing beside or a little behind the lead foot (not in front of the lead foot)	76.4	79.9	72.5
	C3	Brief period when both feet are off the floor	94.6	93.8	95.5		C3	Brief period where both feet come off the surface	94.6	93.8	95.5
	C4	Maintains a rhythmic patter for four consecutive gallops	84.9	83.5	86.5		C4	Maintains a rhythmic pattern for four consecutive gallops	84.9	83.5	86.5
Hop	C1	Nonsupport leg swings forward in pendular fashion to produce force	70.3**	79.0	60.5	Hop	C1	Non-hopping leg swings forward in pendular fashion to produce force	70.3**	79.0	60.5
	C2	Foot of nonsupport leg remains behind body	45.8	47.8	43.5		C2	Foot of non-hopping leg remains behind hopping leg (does not cross in front of)	45.8	47.8	43.5
	C3	Arms flexed and swing forward to produce force	65.8	70.1	61.0		C3	Arms flex and swing forward to produce force	65.8	70.1	61.0
	C4	Takes off and lands three consecutive times on preferred food	96.5	96.9	96.0		C4	Hops four consecutive times on the preferred foot before stopping	95.3	96.4	94.0

	C5	Takes off and lands three consecutive times on nonpreferred foot	96.5	98.7	94.0		N/A				
N/A						Skip	C1	A step forward followed by a hop on the same foot	93.4	91.1	96.0
							C2	Arms are flexed and move in opposition to legs to produce force	51.4	50.9	52.0
							C3	Completes four continuous rhythmical alternating skips	90.3	86.6	94.5
Horizontal jump	C1	Preparatory movement includes flexion of both knees with arms extended behind body	83.5	88.4	78.0	Horizontal Jump	C1	Prior to take off both knees are flexed and arms are extended behind the back	83.5	88.4	78.0
	C2	Arms extend forcefully forward and upward reaching full extension above head	50.2	52.2	48.0		C2	Arms extend forcefully forward and upward reaching above the head	50.2	52.2	48.0
	C3	Take off and land on both feet simultaneously	93.4	95.5	91.0		C3	Both feet come off the floor together and land together	93.4	95.5	91.0
	C4	Arms are thrust downward during landing	72.4	70.5	74.5		C4	Both arms are forced downward during landing	72.4	70.5	74.5
Slide	C1	Body turned sideways so shoulders are aligned with the line on the floor	88.7	92.9	84.0	Slide	C1	Body is turned sideways so shoulders remain aligned with the line on the floor (score on preferred side only)	88.9*	93.3	84.0
	C2	A step sideways with lead foot followed by a slide of the trailing foot to a point next to the lead foot	98.6	97.3	100.0		C2	A step sideways with the lead foot followed by a slide with the trailing foot where both feet come off the surface briefly (score on preferred side only)	98.6	97.3	100.0
	C3	A minimum of four continuous step-slide cycles to the right	99.1	99.1	99.0		C3	Four continuous slides to the preferred side	99.1	99.1	99.0
	C4	A minimum of four continuous step-slide cycles to the left	92.2	92.9	91.5		C4	Four continuous slides to the non-preferred side	92.2	92.9	91.5

Leap	C1	Take off on one foot and land on the opposite foot	87.7*	82.1	94.0	N/A
	C2	A period where both feet are off the ground longer than running	96.9	96.4	97.5	
	C3	Forward reach with the arm opposite the lead foot	45.5	38.4	53.5	

Significant difference ** is p<0.0001; * is p<0.05

Table 9. Proportion (%) of Boys and Girls Demonstrating Competency of Skill using results of Object Control and Ball Skills

		TGMD-2 Object Control						***TGMD-3 Ball Skills***			
TGMD-2 Skill		Performance Criteria	Total	Boys	Girls	*TGMD-3 Skill*		Performance Criteria	Total	Boys	Girls
Striking a stationary ball	C1	Dominant hand grips bat above nondominant hand	94.1	94.6	93.5	Two Handed Strike	C1	Child's preferred hand grips bat above non-preferred hand.	94.1	94.6	93.5
	C2	Nonpreferred side of body faces the imaginary tosser with feet parallel	81.1**	89.7	71.5		C2	Child's non-preferred hip/shoulder faces straight ahead.	84.2**	93.3	74.0
	C3	Hip and shoulder rotation during swing	74.1**	89.3	57.0		C3	Hip and shoulder rotate and derotate during swing.	44.1**	53.6	33.5
	C4	Transfers body weight to front foot	76.2**	85.3	66.0		C4	Steps with non-preferred foot.	75.7**	85.3	65.0
	C5	Bat contacts ball	81.6	84.8	78.0		C5	Hits ball sending it straight ahead.	79.0	83.0	74.5
N/A						One-hand forehand strike of self-bounced ball	C1	Child takes a backswing with the paddle when the ball is bounced.	89.4**	96.4	81.5
							C2	Steps with non-preferred foot.	72.9*	80.8	64.0
							C3	Strikes the ball toward the wall.	87.0*	92.4	81.0
							C4	Paddle follows through toward non-preferred shoulder.	61.6**	71.0	51.0
Stationary Dribble	C1	Contacts ball with one hand at about belt level	83.5**	92.0	74.0	One-hand stationary dribble	C1	Contacts ball with one hand at about waist level	83.5**	92.0	74.0
	C2	Pushes ball with fingertips (not a slap)	73.4**	89.7	55.0		C2	Pushes the ball with fingertips (not slapping at ball)	73.3**	89.7	55.0
	C3	Ball contacts surface in front of or to the outside of foot on preferred side	75.0**	86.2	62.5			N/A			
	C4	Maintains control of ball for four consecutive bounces without having to move the feet to retrieve it	76.9**	86.2	66.5		C3	Maintains control of the ball for at least four bounces without moving their feet to retrieve the ball	76.9**	86.2	66.5

Catch	C1	Preparation phase where hands are in front of the body and elbows are flexed	96.5	96.9	96.0	Two-hand catch	C1	Child’s hands are positioned in front of the body with the elbows flexed	96.5	96.9	96.0
	C2	Arms extend while reaching for the ball as it arrives	96.9	95.5	98.5		C2	Arms extend reaching for the ball as it arrives	96.9	95.5	98.5
	C3	Ball is caught by hands only	89.2	92.9	85.0		C3	Ball is caught by hands only	89.2	92.9	85.0
Kick	C1	Rapid continuous approach to the ball	60.6**	71.9	48.0	Kick	C1	Rapid, continuous approach to the ball.	60.6**	71.9	48.0
	C2	An elongated stride or leap immediatlye prior to ball contact	83.5**	97.8	67.5		C2	Child takes an elongated stride or leap just prior to ball contact	83.5**	97.8	67.5
	C3	Nonkicking foot placed even with or slight in back of the ball	88.2**	96.9	78.5		C3	Non-kicking foot placed close to the ball	88.2**	96.9	78.5
	C4	Kicks ball with instep of preferred foot (shoe-laces) or toe	73.6**	94.2	50.5		C4	Kicks ball with instep or inside of preferred foot (not the toes)	73.6**	94.2	50.5
Overhand Throw	C1	Windup is initiated with downward movement of hand/ arm	34.9**	53.6	14.0	Overhand Throw	C1	Windup is initiated with a downward movement of hand and arm	35.1**	54.0	14.0
	C2	Rotates hip and shoulders to a point where the nonthrowing side faces the wall	41.3**	61.6	18.5		C2	Rotates hip and shoulder to a point where the non-throwing side faces the wall	41.3**	61.6	18.5
	C3	Weight is transferred by stepping with the foot opposite the throwing hand	71.7**	85.3	56.5		C3	Steps with the foot opposite the throwing hand toward the wall	71.9**	85.7	56.5
	C4	Follow-through beyond ball release diagonally toward the nonpreferred side	56.1**	84.8	24.0		C4	Throwing hand follows through after the ball release, across the body toward the hip of the non-throwing side	50.9**	77.7	21.0
						Underhand Throw	C1	Preferred hand swings down and back reaching behind the trunk.	97.6	98.7	96.5
							C2	Steps forward with the foot opposite the throwing hand.	63.4**	74.1	51.5

N/A							C3	Ball is tossed forward hitting the wall without a bounce.	88.9	87.5	90.5
							C4	Hand follows through after ball release to at least chest level.	94.8*	97.3	92.0
Underhand Roll	C1	Preferred hand swings down and back, reaching behind the trunk while chest faces cones	72.2**	85.7	57.0	N/A					
	C2	Strides forward with foot opposite the preferred hand toward the cones	56.4**	71.0	40.0						
	C3	Bends knees to lower body	49.3**	58.0	39.5						
	C4	Releases ball close to the floor so ball does not bounce more than 4 inches high	45.8**	54.0	36.5						

Significant difference ** is $p<0.0001$; * is $p<0.05$

4.4.1 Mastery, Separately Measured by TGMD-2 and TGMD-3

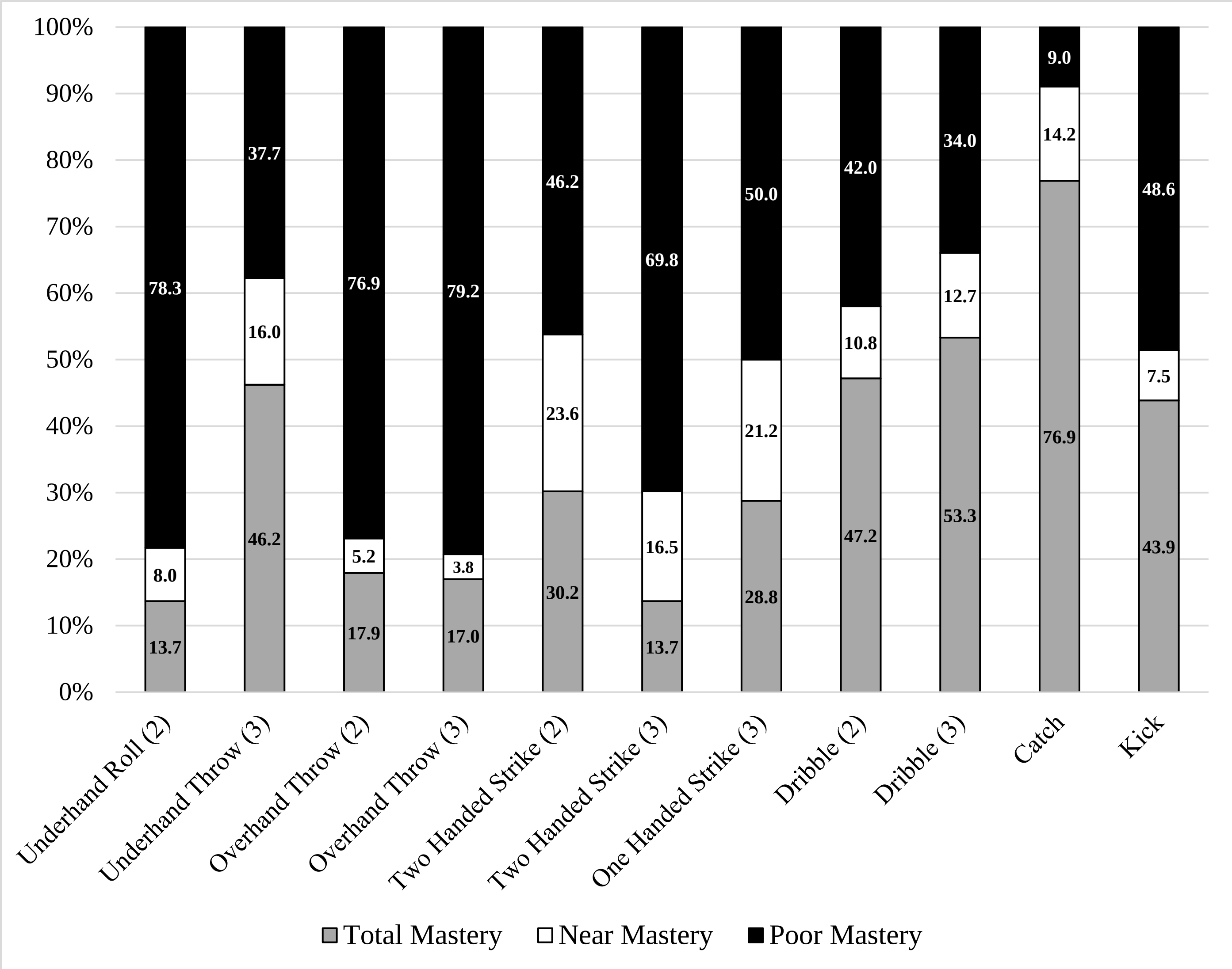
Two boys achieved the maximum score of 48 (total mastery) for object control (0.9%), as assessed by TGMD-2, whilst no girls achieved total mastery in this subscale (0%). No children, irrespective of sex, achieved total performance mastery for locomotor skills (score of 48) and, consequently, no individuals were observed to have total mastery in FMS, as assessed by TGMD-2. Two boys and one girl achieved total performance mastery (1.4%) in ball skills (score = 54), as assessed by the TGMD-3. Total performance mastery on the locomotor subscale was achieved by two boys (0.9%). Therefore, in accord with TGMD-2, total performance mastery for TGMD-3 assessment was also not achieved (maximum score of 100).

4.4.2 Mastery Skill Breakdown Combining TGMD Assessment FMS

Mastery, near mastery and poor mastery levels were observed for every skill performed by this cohort. Mastery/Near Mastery (M/NM) was recorded as the combination of mastery and near mastery scores. Poor mastery in the combined assessment ball skills/object control subscales ranged from 9.0% for the catch to 79.2% for the overhand throw (TGMD-3; Figure 7). Specifically, more than 50% of children had poor mastery in underhand roll (TGMD-2), overhand throw (TGMD-2), overhand throw (TGMD-3), two-handed strike (TGMD-3) and one-handed strike (TGMD-3). The highest proportion of M/NM found was for the catch, with a M/NM score of 91.1%. Mastery levels for the remaining ball skills ranged from 53.3% for dribble (TGMD-3) to 13.7% for underhand roll (TGMD-2) and two-handed strike (TGMD-3).

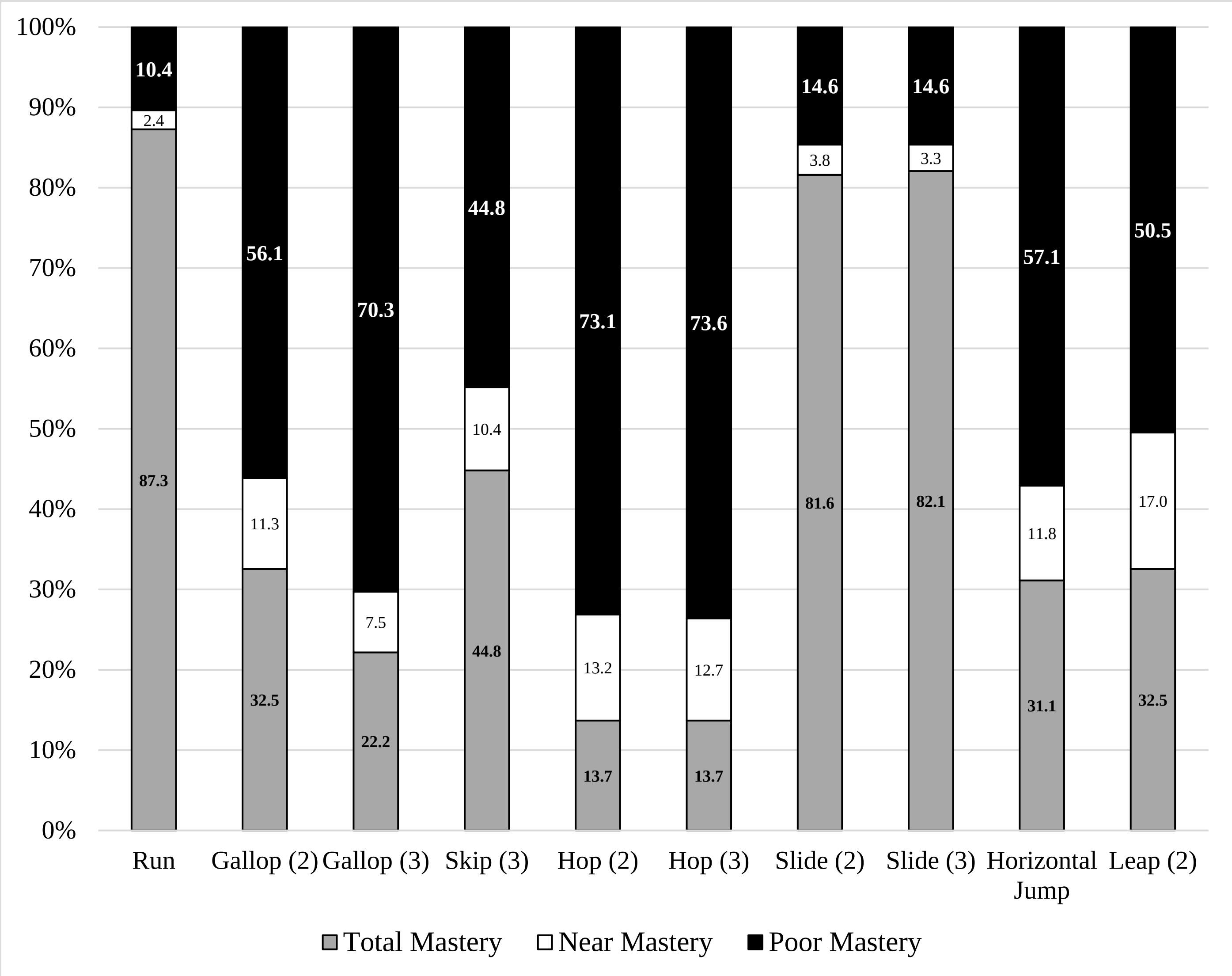
The highest proportion of children achieving M/NM for locomotor skills was for the run (89.7%; Figure 8). The slide, irrespective of whether assessed using the TGMD-2 or TGMD-3, also had high levels of mastery, with 82.1% and 81.6%, respectively. Hopping was the least mastered skill, with the lowest proportion of children achieving mastery (13.7% for both TGMD-2 and TGMD-3), and the highest proportion for poor mastery at 73.1% and 73.6% for TGMD-2 and TGMD-3, respectively. Significant sex differences were found for mastery, near mastery and poor mastery of all skills ($p<0.001$).

The proportion of children achieving M/NM decreased from the TGMD-2 to TMGD-3 assessments for overhand throw, two-handed strike, hop and gallop by 2.3%, 23.6%, 0.5% and 14.1%, respectively, and subsequently increased the proportion of those classified as poor mastery. Mastery/near mastery scores increased from TGMD-2 to TGMD-3 for dribble (8.0%). Whilst the same poor mastery score was observed for the slide (14.6%).



Notes: Skills identified as (2) for TGMD-2 assessment criteria, (3) for TGMD-3 assessment criteria.

Figure 7. Proportion (%) of children (n = 212) achieving Total Mastery, Near Mastery and Poor Mastery in combined Object Control (TGMD-2) and Ball Skills (TGMD-3)



Notes: Skills identified as (2) for TGMD-2 assessment criteria, (3) for TGMD-3 assessment criteria.

Figure 8. Proportion (%) of children (n = 212) achieving Total Mastery, Near Mastery and Poor Mastery in combined Locomotor Skills

4.5 Sex Differences in FMS

There were significant sex differences ($p<0.001$) for total TGMD-2 and TGMD-3 assessment scores (Table 8). Significantly higher average scores were observed for boys for each FMS subscale and total TGMD-2 and TGMD-3 ($p<0.001$). There were no significant sex differences for locomotor skills for the TGMD-2 ($p = 0.09$) and TGMD-3 ($p = 0.06$).

Table 10. Average Score for each skill (mean ± SD) for TGMD-2 and TGMD-3

	Maximum Score	Total (n =212)		Boys (n =112)	Girls (n =100)
TGMD-2					
Object Control	48	34.6 ± 6.7	***	40.0 ± 5.4	28.7 ± 7.8
Locomotor	48	39.4 ± 4.9	$p = 0.09$	40.0 ± 4.9	38.8 ± 4.9
Total	96	74.1 ± 11.5	***	79.9 ± 8.4	67.5 ± 11.0
TGMD-3					
Ball Skills	54	41.1 ± 8.2	***	46.0 ± 5.3	35.6 ± 7.4
Locomotor	46	37.3 ± 5.1	$p = 0.06$	37.9 ± 5.0	36.6 ± 5.1
Total	100	78.4 ± 11.3	***	83.9 ± 8.3	72.2 ± 11.1

***Significant difference ($p<0.001$)

4.6. Predicting TGMD-3 from TGMD-2

Spearman’s rank correlation highlighted a statistically significant relationship between Gross Motor Quotient (GMQ) scores for TGMD-2 and TGMD-3 (0.945; $p<0.01$). There was a strong positive correlation of 0.922 ($p<0.01$) between object control scores for TGMD-2 and ball skills scores and of 0.915 ($p<0.01$) between locomotor scores for TGMD-2 and TGMD-3. Key parameters to include in the multiple regression (Table 9) were identified from univariate regression analyses.

Table 11. Linear Regression Analysis

Variable	Coefficient	*p*-value
TGMD-2 GMQ	0.937	0.01
Age	2.780	0.01
Sex	11.787	0.01
Height	0.309	0.01
TGMD-2 Object Control Score	1.137	0.01
TGMD-2 Locomotor Score	1.600	0.01

A simple linear regression was performed with TGMD-3 total score as the dependant variable and TGMD-2 outcome score as the covariate/explanatory variable. This was repeated for TGMD-2 subscale scores, age, height and mass with TGMD-2 subscale totals, age and height found to be statistically significant ($p<0.001$). Further results were found with TGMD-2 GMQ ($\beta = 9.011$; $r^2 = 0.904$; $p<0.05$), age ($\beta = 41.991$; $r^2 = 0.147$; $p<0.05$), height ($\beta = 29.380$; $r^2 = 0.088$; $p<0.05$) and sex ($\beta = 72.150$; $r^2 = 0.271$; $p<0.05$). TMGD-2 object control skills' subscale ($\beta = 39.011$; r2 = .759; $p<0.05$) and TGMD-2 locomotor skills' subscale ($\beta = 15.283$; $r^2 = .476$; $p<0.05$) were identified as potential predictors but stepwise linear regression revealed that only TGMD-2 and age were significant predictors: TGMD-3 = 12.062 + (0.957 x TGMD-2) - (0.348 x Age). TGMD-3 total performance can also be predicted from TGMD-2 subscale performances as object control and locomotor skill were found separately to predict overall (total proficiency) in the TGMD-3 assessment: TGMD-3 total score = 1.137 x (TGMD-2 object control + 39.011); TGMD-3 total score = 1.600 x (TGMD-2 locomotor skill + 15.283). Each subscale in TGMD-2 was also found to have predictive qualities for their corresponding subscale in TGMD-3. Object control (TGMD-2) performance was observed to predict ball skills proficiency in TGMD-2: TGMD-3 ball skills = 0.891 x (TGMD-2 object control + 10.212). Finally, locomotor skill performance in TGMD-2 was found to have predictive ability for TGMD-3 locomotor skill proficiency: TGMD-3 locomotor skills = 0.965 x (TGMD-2 locomotor skills - 0.753).

4.7. Validation of TGMD-3 for Adolescent Population

Data illustrating the FMS proficiency level of this group as presented in Table 7 were analysed to determine model fit measures. In total, three models were tested using Confirmatory Factor Analysis (CFA). Table 10 presents the goodness of fit measures for each of the models tested. The first Model tested (Model 1; Table 10) corresponds to the original two-factor model (locomotor skills and ball skills) of the TGMD-3 (Webster & Ulrich, 2017). Previous research using TGMD-2 (Issartel et al., 2017) and TGMD-3 (Brian et al., 2018; Estevan et al., 2017; Wagner & Ulrich, 2017) assessment data support the choice of a two-factor solution for CFA. In this study the two factors of ball skills and locomotor skills were found to be moderately correlated (r =0.70 p<0.001).

The values for Model 1, however, showed poor Tucker Lewis Index (TLI) and Comparative Fit Index (CFI) but a good fit for Root Mean Squared Error of Approximation (RMSEA; Marsh, Balla, & McDonald, 1988). Subsequently, a second analysis was performed, as Model 1 was deemed to be only satisfactory because several values provided a low contribution to the overall model (Table 10). At this stage, several individual skills presented low standardised regression weights and did not contribute to the overall model, reducing the goodness of fit. Therefore, the lowest loading skill was removed resulting in a better fit and a new model presented as Model 2. Subsequent, removal of the next lowest loading skill produced a final model of best fit. In Model 3, the reduction in the number of skills (13 to 11 skills) contributed to higher TLI and CFI and, for the value suggested by Byrne (2001), improved RMSEA values, which are usually penalised by overly complex models (Hooper, Coughlan, & Mullen, 2008). The latent correlation between the two factors was r =0.72. The proposed two-factor model adequately fitted the data, $\chi2$ (43) = 87.1544, p<0.001, RMSEA = 0.070, SRMR = 0.0585, CFI = 0.892, confirming the validity of this factorial model and is represented as Figure 9. The items' factor loadings ranged from 0.29 to 0.67 and were all statistically significant (p<0.001). Each FMS was found to positively load with their subsequent subscale factor (see Figure 9).

Table 12. Descriptive values for each of the 3 Models

Model	Description	χ^2	Df	Prob	CFI	TLI	RMSEA	(S)RMR
Model 1	Full model two correlated factors	148.123	64	0.000	0.821	0.782	0.079	0.0699
Model 2	Reduced model two factors: Catch removed	123.109	53	0.000	0.843	0.805	0.079	0.0685
Model 3	Reduced two factor Model: Catch and Skip removed	87.154	43	0.000	0.892	0.862	0.070	0.0585

Notes: Degrees of frequency (Df); Chi squared (χ^2); Tucker Lewis Index (TLI); Comparative Fit Index (CFI); Root Mean Squared Error of Approximation (RMSEA); Standardised Root Square Mean Residual ((S)RMR)

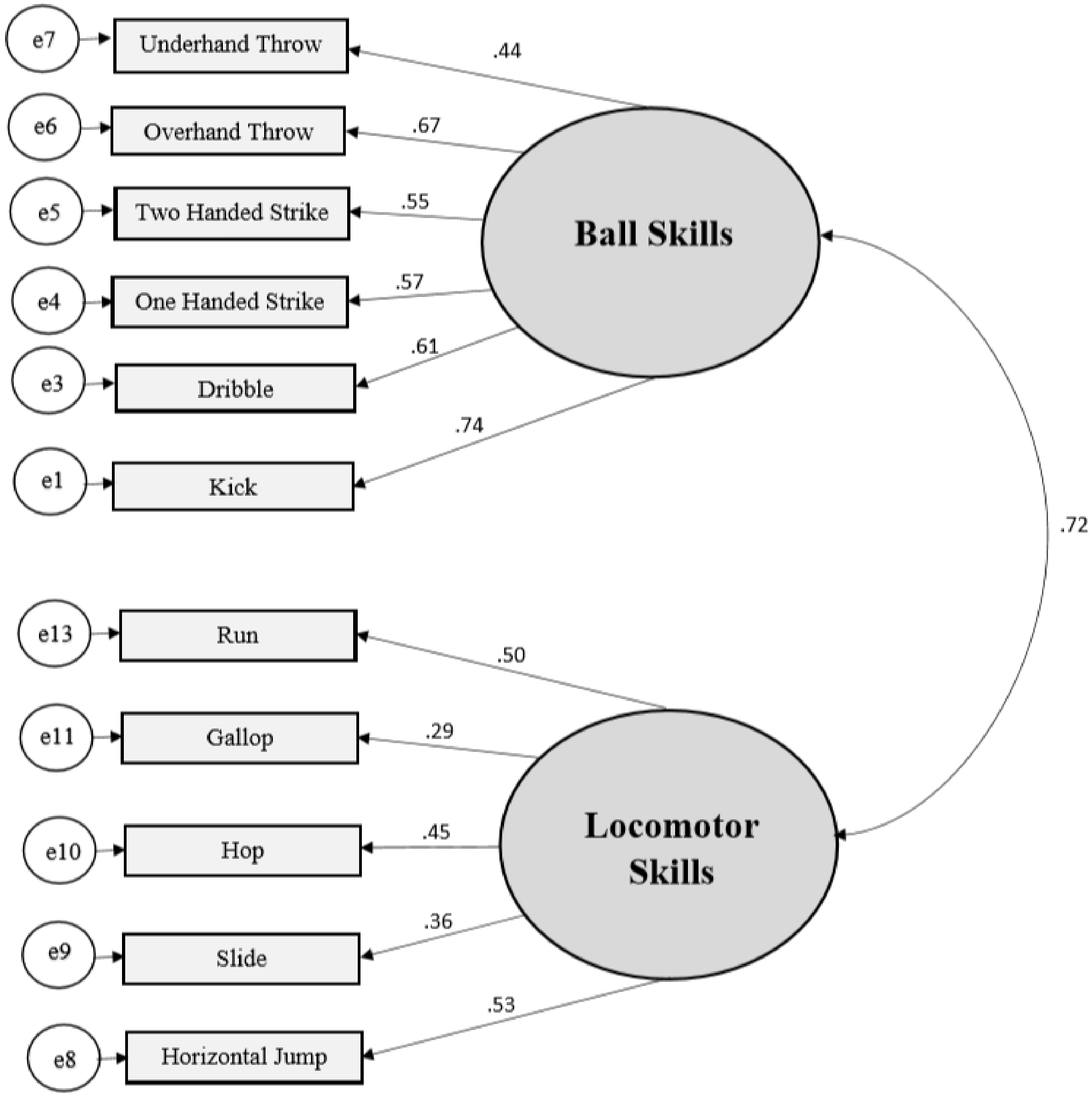


Figure 9. The two-factor model of the TGMD-3 for an adolescent population with catch and skip removed.

5.0 Discussion

The main aim of the present thesis was to measure and compare fundamental movement skill (FMS) competency and mastery according to the well-established Test of Gross Motor Development, Second Edition (TGMD-2) and newly developed Test of Gross Motor Development, Third Edition (TGMD-3) in an adolescent population. Furthermore, the current thesis sought to investigate the influence of sex and to ascertain whether the TGMD-3 two-factor model (ball skills and locomotor skills) is appropriate for an adolescent population. Overall, irrespective of the FMS assessment used, no adolescents achieved FMS Total Mastery. Nonetheless, there were differences in mastery levels of individual skills, when comparing Test of Gross Motor Development (TGMD) assessments, which may impact future interpretation of Total Mastery. Moreover, sex differences were observed, with boys achieving higher FMS scores, irrespective of the TGMD edition. Similar significant sex differences were also found for the object control skills subscale of TGMD-2 and ball skills subscale of TGMD-3 assessments. No significant sex differences were observed for the locomotor skills subscales for either TGMD edition.

5.1 Comparison of TGMD-2 and TGMD-3

This thesis found that utilising a different version of the TGMD assessment, resulted in significant differences in FMS. Specifically, the removal of the leap and underhand roll, as well as the inclusion of the underhand throw and one-handed strike, significantly change the overall interpretation. These changes in skill inclusion within the testing battery impacted on the apparent competency of the current cohort, with an increase of 32.5% in total mastery (M). This is most likely due to the amount the underhand throw is used in games and sports (Ulrich, 2017) and its relevance for an older age group.

A further change to TGMD-3 was the introduction of the one-handed strike, which was suggested to more closely reflect key skills involved in globally popular racket sports (D. A. Ulrich, 2017), thereby seeking to diminish cultural effects on the assessment of FMS (L. M. Barnett et al., 2019). This thesis found that the introduction of the one-handed strike resulted in similar sex variances, with significant differences observed ($p<0.05$) in the preparation components of criteria one (C1), three (C3) and four (C4) when compared to two-handed strike (measured by both TGMD-2 and TGMD-3) preparation criteria components (C1, criteria two (C2), C3 and C4). However, the execution phase of hitting the ball, C3, in the one-handed strike showed a significant sex difference (*$p<0.05$*), which was not evident during the two-handed strike criteria five (C5). Brian et al. (2018) proposed that the one-handed strike is one of the most challenging skills within the ball skills subscale of the TGMD-3 as it is a reception and propulsion skill that requires a sophisticated ability for perception in controlling motor processes to move objects. Indeed, bouncing a tennis ball, as required for the first phase of this skill, relies upon figure-ground perception, ball tracking, relative timing, multi-limb coordination, dynamic balance and humeral-forearm lag from the trunk (Gallahue, Ozmun, & Goodway, 2012). Proficiency in the one-handed strike could therefore be argued to be more aligned with older children (McKenzie et al., 1998) and could have an age effect (Birch, Cummings, Oxford, & Duncan, 2016). In accord with this, the one-handed strike was associated with 50.0% of Mastery/Near Mastery (M/NM) and 50.0% poor mastery in the current sample, in comparison to Kelly, O'Connor, Harrison and Ní Chéilleachair (2019) who reported 34.6% for M/NM and a correspondingly higher (75.5%) poor mastery in younger children (9.0 ± 1.1 years).

The reintroduction of the skip in TGMD-3 resulted in over half of this cohort achieving M/NM for this skill. In agreement with the present findings, girls have been reported to score higher in the skip (Kelly et al., 2019) due to their experience in similar actions (Haywood & Getchell, 2009) such as in dance and gymnastics (Blatchford, Baines, & Pellegrini, 2003; Garcia, 1994; Thomas & French, 1985). Indeed, contrary to boys, Sport Wales (2018) identified that there is a high participation rate in dance, gymnastics and trampolining for girls in South Wales. In contrast to McGrane, Belton, Powell and Issartel (2017) who reported a significant sex difference in total skip performance ($p \leq 0.05$) for adolescents, the present thesis found no significant sex difference for skip performance criteria component one to three (C1, C2 and C3). However, sex differences were observed in the leap, a similar locomotor skill to the skip. Indeed, in the present thesis, the leap was the only skill where girls scored significantly higher than boys. Specifically, both C1 and C2 of the leap illustrate <90% success rate for girls, however only C1 resulted in a sex difference. Similarly to Foulkes et al. (2015) who assessed fundamental movement skills in pre-school children in North West England, this suggests that although girls are more proficient in leaping, behavioural component criteria has not shown a significant dominance over boys,

Although five locomotor and five object control skills were common to both TGMD-2 and TGMD-3, the skill component criteria differed notably for some of these skills, which subsequently influenced the percentage classified as achieving mastery. Specifically, there were three locomotor skills where changes to individual criteria requirements, or the actual number of skill component criteria, resulted in changes between TGMD-2 and TGMD-3 locomotor skill scores. Changes to the behavioural component criteria were proposed by Ulrich and Webster (2015) to clarify scoring and improve the accuracy of assessment of movement patterns (Mohammadi et al., 2019). Furthermore, the intention was to standardise the performance criteria for skills that required repetitions by stating that four repetitions should be performed to maximise consistency across all skills. Perhaps the most notable changes were in the dribble and hop, for which the number of component criteria was decreased and/or the product requirement was modified. Despite these changes, however, it is interesting to note that the overall competency assessment did not differ significantly between the TGMD-2 and TGMD-3. For example, for hop, C4 and C5, produced relatively similar outcomes (>95% for skill competency) and total mastery was not affected (13.7%). This could be observed to have positive implications for universal assessment of FMS. The data presented in this thesis could be used to justify and cross compare hop measurements in children. Simply, FMS assessments which include different behavioural criteria as skill components of the hop could be cross compared. Theoretically, process-oriented assessments, such as the TGMD-2 (Logan, Barnett, Goodway, & Stodden, 2017), and now possibly TGMD-3, could be used to compare qualitative movement patterns for hop as measured by Get Skilled; Get Active (GSGA; New South Wales Department of Education and Training, 2000) and developmental sequences (Roberton & Halverson, 1988).

Logan and colleagues (2017) observed moderate-to-strong correlations across process- and product-oriented assessments of the hop. It could, therefore, be suggested that the hop provides an effective basic skill for cross study comparison. Conversely, Barnett, van Beurden, Morgan, Brooks and Beard (2010) found the hop to be one of the poorest performed skills, irrespective of sex, and suggested that the lack of clarity in assessment criteria could relate to a reduced ability to describe the associated proficiency adequately. However, Logan and colleagues (2017) found similarities between the TGMD-2 and Get Skilled Get Active (GSGA) C3 for the hop, where co-ordinated arm action is required. The results demonstrated that the removal of one assessment component for the dribble in TGMD-3, compared to TGMD-2, resulted in an increase in Total Mastery to over 50% and a reduction in poor mastery (>35%). As such, children were more likely to achieve mastery in dribbling when assessed by the TGMD-3. Furthermore, these changes in mastery according to the assessment criteria highlight potential issues in drawing conclusions from inter-study comparisons, potentially limiting comparisons to only those that have utilised the same generation of the TGMD and thus the generalisability of study findings.

FMS affected by wording changes in their assessment criteria were also found to be important. Specifically, following the changes, skill competency was found to differ between TGMD-2 and TGMD-3 for gallop C1, slide C2, two-handed strike C2, C3, C4 and C5 and overhand throw C4. Notably, the slide C1 demonstrated an increase in boy's performance from TGMD-2 to TGMD-3, where a subsequent significant sex difference was observed, thereby altering potential conclusions. Similarly, interpretation of competency in the two-handed strike performance was test-dependent, with the requirement for the child to specifically un-rotate their swing for the two-handed strike in TGMD-3 resulting in a 30% drop in competency level compared to the TGMD-2. This was a key factor in the 16.5% decline in two-handed strike mastery achievement in TGMD-3. Therefore, researchers and practitioners should ensure they adopt an informed approach when analysing two-handed Strike performances measured against TGMD-3 and TGMD-2 skill component criteria.

5.1.1 Predicting FMS Performance

The overall results in this thesis differed for FMS mastery when subscales were considered. Specifically, two boys, but no girls, achieved total performance mastery (0.9%) in the object control subscale for TGMD-2, compared to two boys and one girl achieving total performance mastery in ball skills (1.4%) as assessed by TGMD-3. On the locomotor skills subscales, two boys achieved Total Mastery (0.9%) during TGMD-3, in contrast to none when utilising the TGMD-2. It is interesting to note, however, there were no differences in TGMD-2 and TGMD-3 subscale scores, which both indicated that no children achieved Total Mastery of both subscales. Those children observed to have mastered locomotor competence did not have the same proficiency on the ball skills subscale. These results therefore suggest that researchers and practitioners require clear and confident validation of TGMD-3 so that it does not disadvantage populations.

An additional complication with the comparison of overall mastery between these assessments are the changes outlined regarding the edition of TGMD sub-components. In terms of scoring, the TGMD-3 requires a higher skill competency total score (maximum score of 100) for individuals to achieve compared to a lesser total of 96 for TGMD-2. Total score differences between TGMD-2 and TGMD-3 are represented in the difference of subscale totals. The increase in ball skills, and therefore ball skills' skill components, was established by Ulrich

(2017) to be reflective of public health research advocating children's ball skill competency as a positive relationship to future physical activity (PA) levels (Lubans et al., 2010). These changes, coupled with the increase in the number of total component criteria to be assessed (from 96 to 100), would suggest that it is harder for children to achieve mastery when assessed by the TGMD-3. Indeed, as Hardy et al. (2013) established, FMS assessment assumes each component has equal value, and skills with fewer components are mathematically easier to master.

5.2 Prediction of TGMD-3

Differences between the TGMD-2 and TGMD-3 have highlighted noteworthy considerations for researchers and especially for inter-study comparisons. However, the current findings nonetheless suggest that TGMD-3 performance could be predicted from TGMD-2 outcomes, potentially enabling more appropriate inter-study comparisons to be made. Specifically, age and TGMD-2 gross motor quotient scores (GMQ) were identified as the key predictors of TGMD-3 performance, explaining 90.5% of the variance in TGMD-3 performance. Given that the TGMD-2 is the most highly used tool to assess FMS by researchers and practitioners (Basman, 2019; Pill & Harvey, 2019), the current findings are central to the long-term translation of this original evidence base.

It is pertinent to note that some researchers may only use specific subscales or certain groups of skills from the TGMD-2 (Butterfield et al., 2012; McGrane et al., 2018; McGrane, Belton, Powell, Issartel, et al., 2017). The current regression results indicate that both subscales of TGMD-2 have predictive abilities for their counterparts in TGMD-3. The object control skills subscale for TGMD-2 demonstrated strong prediction for ball skill performance in TGMD-3. Equally, total locomotor skill performance in TGMD-2 was also found to determine competency for TGMD-3 locomotor skills. Notably, both TGMD-2 subscales were also observed to predict total TGMD-3 performance. This has important implications for future studies, theoretically highlighting that a subset of the overall assessment battery can be used with no loss of predictive ability. This therefore potentially decreases participant burden and increases the feasibility of repeated assessments over time, thereby significantly advancing our understanding of FMS in youth.

5.3 Confirmatory Factor Analysis

A two-factor model for the validation of TGMD-3 (adolescent population) based on the separately identified subscales was hypothesised. The model proposal was reflective of previous research using the TGMD (Evaggelinou, Nikolaos, & Papa, 2002), TGMD-2 (Issartel et al., 2016; Lopes, Saraiva, & Rodrigues, 2018; Wong & Cheung, 2010) and TGMD-3 (Brian et al., 2018; Mohammadi et al., 2019; Valentini et al., 2017; see Appendix II). Accordingly, the current results revealed that the latent constructs for ball skills and locomotor skills subscales have a significant relationship (0.72). Initially models 1 and 2 did not demonstrate appropriate goodness of fit index (GFI), comparative fit index (CFI), root mean square error approximation (RMSEA) and standardised root mean residual (SRMR) values. The proposed final model (Model 3) in this thesis provided high GFI and CFI values and small RMSEA. Factor loadings were all positive and, as such, provided support for the use of a two-factor model for the TGMD-3 in adolescent populations. Furthermore, three skills (skip, one-handed strike and underhand throw) included in the TGMD-3 were correlated with their respective subscales of locomotor skills (skip) and ball skills (one-handed strike and underhand throw) initially, with subsequent issues revealed in model fit proceedings for skip. Initial analysis found that, whilst significant, some of the loading coefficients were not high (e.g. catch – 0.24, skip – 0.31 and gallop – 0.35). However, the removal of catch (Model 1) and catch and skip (Model 2) suggests that these skills were less useful for determining the factor (FMS subscale) for children in South Wales. All correlations were positive and significant, providing further support for the proposed TGMD-3 two-factor model for adolescents.

The present confirmatory factory analysis (CFA) revealed similar findings to those reported by Issartel et al. (2017) in adolescents. However, in the current analyses, it was evident that the measure of best fit does not encompass all skills associated with TGMD-3, as illustrated in Model 3. Specifically, catch and skip were removed from the model as they had the lowest loading. In older children, catching proficiency has been found to be age-dependent and a covariate to age (Okely & Booth, 2004; Okely et al., 2001b). Furthermore, in accord with Okely and Booth (2004), the prevalence of M/NM in catch suggests minimal effort is required to change overall classification. It could also be argued that the catch, as assessed by both TGMD assessments, only consists of three skill component criteria that the child must meet to achieve mastery, making it considerably easier to achieve the M/NM criteria in this skill compared to the two-handed strike, which has five skill components. In accordance, this thesis found the catch to be associated with the highest performance, with 91.1% of the sample achieving M/NM. Deceptively, the catch was less helpful for determining the ball skills subscale for this cohort of children, as they are more competent at catching a ball by two hands. As children age, catching has been shown to be more readily mastered (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010; Hardy, Barnett, Espinel, & Okely, 2013), therefore catching with one hand instead of two could provide more of an insight into development of the FMS in adolescence.

Removal of the skip from Model 3 provided better fit measures and therefore supports the argument by Brian and colleagues (2017) that skipping is one of the most challenging skills in any TGMD-3 battery. This is due to the requirement for children to possess co-ordination, dynamic balance, strength and a strong sense of timing to perform the skip competently (Gallahue et al., 2012) and therefore the subsequent variation in performance of the skip in this thesis was not observed to correlate as well with other skills. It also could highlight the limited relevance of skipping in the everyday life of older children. This suggestion is further supported by the low factor loading associated with gallop, indicating that playground skills, such as galloping and skipping, which are more readily performed in early years, are not as relevant for older children (Brian et al., 2018). Indeed, assessor reflections in the study by Issartel and colleagues (2017) and anecdotally observed in the present thesis suggest that adolescent motivation and willingness to engage in the performance of both the gallop and skip was low, potentially influencing the apparent competency (Issartel et al., 2017). Notably, Wagner, Webster and Ulrich (2016) highlight the issues associated with the assessment of the gallop, calling for further refinement of the performance criteria to clarify that quality of movement is more important than overall speed of movement. Catch and skip FMS are notably the only TGMD-3 skills that consist of three skill behaviour components, which could be related to a lower sensitivity in these measures because of the smaller range of assessment criteria. Therefore, it could be suggested that the catch and skip were therefore not very discriminatory.

5.4 Sex Differences in FMS

A key consideration in the assessment of FMS and the subsequent identification of appropriate targets for future intervention is the potential presence of sex differences, both within and between subscales. The current results add to the growing body of FMS competency literature which has reported on boys superiority in FMS performance (L. E. Bolger et al., 2018; Breslin, Murphy, McKee, Delaney, & Dempster, 2012; Düger, Bumin, Uyanik, Aki, & Kayihan, 1999; Thomas & French, 1985), highlighting divergent results according to sex. Specifically, and consistent with previous studies, boys were observed to achieve higher total scores when compared to age-matched girls (Abas, Shanker Tedla, & Krishnan, 2011; Foulkes et al., 2015; Hume et al., 2008; Kelly et al., 2019). Indeed, significant sex differences were observed for 19 of 24 object control behavioural skill component criteria in TGMD-2, and 20 of the 27 ball skills in TGMD-3. Further analyses revealed significant differences for FMS subscales, similar to published research (Jiménez Díaz et al., 2015; Okely & Booth, 2004; Vandaele et al., 2011; Wicks et al., 2015). In this thesis, a significant difference was found in object control/ball skills subscale performance only. Whilst there remains controversy with regards to the influence of sex, not least due to considerable inter-study differences in the age and maturity level of the sample populations, the current findings concur with others that have found no sex difference in locomotor skills (Foulkes et al., 2015; Goodway, Robinson, & Crowe, 2010).

In a recent systematic review of children's movement competence, Pill and Harvey (2019) found that boys were more likely to possess better movement competency in object control skills. This outcome is consistent with the current results in which boys demonstrated significantly better performances in both object control skills (TGMD-2; $p<0.001$) and ball skills (TGMD-3; $p<0.001$). Subsequently, the present thesis supports the growing body of research showing adolescent boys dominance in these types of manipulative and ball skills motor competence of adolescent populations (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010; Jiménez Díaz et al., 2015; McGrane, Belton, Powell, Issartel, et al., 2017; O'Brien, Belton, & Issartel, 2016a; O'Brien, Duncan, Farmer, & Lester, 2018) for boys dominance in these types of manipulative and ball skills. Explanations for the poorer movement competence in girls currently centre on socio-cultural and environmental factors (Eather et al., 2018), with suggestions that boys are more likely to engage in ball games and utilise space around them (Blatchford, Baines, & Pellegrini, 2003; Okely, Booth, & Patterson, 2001) and that object control skills are more common to sports typically undertaken by boys (Hardy, Barnett, Espinel, & Okely, 2013). Stereotypical cultural practices can be viewed to favour specific play practices; boys have more readily available opportunities to develop skills such as throwing and kicking (Hardy, King, Espinel, Cosgrove, & Bauman, 2010) and therefore have a chance to establish competency in such skills compared to girls. Sex differences in ball skills therefore may reflect the various activities which children typically participate in during their younger years (Foweather, 2010).

In a recent meta-analysis, Hyde (2005) provided support for a Gender Similarities Hypothesis, which suggests boys and girls are alike on most psychological variables (e.g. self-esteem, body esteem, depression symptoms, happiness and coping) irrespective of age, thus implying any differences in motor abilities are influenced by the learning environment. However, in a similar adolescent-aged cohort, Okely et al. (2001) highlighted a growing social trend where girls participation in organised PA and team sports is considered socially unacceptable (Petersen &

Taylor, 1980; Scully & Clarke, 1997). Girls who are more highly skilled movers continue to participate during adolescence (Sale, 1991), leaving their less physically competent counterparts behind. It could be argued that the outcomes of this thesis contribute to the discussion that girls are able to continue their development of locomotor skills into adolescence but are continuing to lag behind their male peers in manipulative and ball skills (Barnett, van Beurden, Morgan, Brooks, & Beard, 2010). Further research into PA and sports participation and FMS for girls from childhood into adolescence is therefore warranted.

The sex differences found in this thesis is contrary to those found in previous adolescent populations (Hands, Larkin, Parker, Straker, & Perry, 2009; O'Brien et al., 2016a). Hands and colleagues (2009) found no sex differences in motor competence, whereas O'Brien et al. (2016b) found the execution of boys and girls in object control skills to be similar. Sample size differences and varied inclusion of basic motor competence skills and FMS assessment methods used could explain these discrepant findings. Moreover, Hands et al. (2009) used the McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997), which included some fine motor skills. Whilst O'Brien and colleagues (O'Brien et al., 2016a) used a mix of three different assessment tools that focus on assessment of gross motor skills. Resounding evidence, however, indicates low skill competency levels (Eather et al., 2018) for girls and highlights a gap when compared to boys in the overhand throw (Barnett et al., 2010). Consequentially, overhand throwing has been shown to dominate the literature in FMS analysis and evaluation of the sex gap when assessing TGMD-2 (Cliff et al., 2012; Cohen et al., 2014; Slykerman et al., 2016) and TGMD-3 (Kelly et al., 2019).

5.5 Overhand Throw Sex Differences

Raw score averages illustrate an underperformance of girls compared to boys in each object control/ball skills, with overhand throw highlighted on both TGMD-2 (95%) and TGMD-3 (96%) as the highest score of poor mastery. It has been recognised that sex differences in object control skills that included throwing are more pronounced than in other motor skills (Thomas & French, 1985). The current findings are consistent with process-oriented object control and manipulation patterns in overhand throw measured from childhood to adolescence (L.M. Barnett et al., 2010; Spessato, Gabbard, Valentini, & Rudisill, 2013; Hardy et al., 2013; Wicks et al., 2015). Consistent with this thesis, adolescent girls were also found to have a lower overhand throw proficiency by O'Brien et al., (2018) and Hardy, Barnett, Espinel and Okely (2013).

Thomas and French (1985) proposed boys' increased arm circumference as a determinant of overhand throw performance. Given this potential sex-dependent, anthropometric determinant, it is important to note the breakdown in the assessment of overhand throwing skill technique. Specifically, the rotational aspect of the overhand throw is based on C2, in which girls typically scored poorly on both assessments. This supports the understanding that less advanced throwers do not possess trunk rotational or linear velocities that lead to a critical instance that induces lag effect (Stodden, Langendorfer, Fleisig, & Andrews, 2006), which is the propulsion of the ball leaving the hand at peak velocity. This low lag effect, an observed outcome for girls, is similarly reported by Stodden et al. (2006b) and could consequently explain the poor level of mastery for girls and the significant sex differences ($p<0.01$) observed in overhand throw C1 and C2.

Fundamentally, overhand throwing, as assessed by each edition of TGMD criteria, can be viewed as specific to certain sports skills, such as pitching in baseball, and may not be a technical coaching point for a learned skill in other sports requiring a larger ball (Hardy et al., 2013). For example, basketball, netball or handball, require game situations where there is very little time for placing the right stepping position or managing a large backswing (Gromeier, Koester, & Schack, 2017). It could be suggested that the overhand throwing performance for these sports does not match the expected skill component criteria in the TGMD assessments. As Hardy and colleagues (2013) suggested, low prevalence of competency among girls in overhand throw may be reflected in the actual skills assessed. Netball in this instance is the most participated extracurricular sporting activity for girls in Wales and is a top five played sport by girls in their local community setting/environment (Sport Wales, 2018). Therefore, overhand throwing a tennis ball may not resonate with girls (Hardy et al., 2013), whereas a shoulder pass in netball would. It could therefore be suggested that girls are making the transition into adolescence without acquiring basic proficiency in overhand throwing first. It could also be argued that as girls continue developing sports-specific throwing skills, the advancement of technique and skill competency is not transferable to other sports. Poor competence in overhand throw has the potential to result in limited skill progression and competence in specific sports skills, such as an overhead badminton clear and javelin throw (O'Keeffe et al., 2007). Mastery of the basic overhand throw leads to mastery of the serve in volleyball and tennis, the overhead clear in badminton, the smash in tennis and badminton, the shoulder pass in netball and basketball, and the baseball pitch and the javelin throw (J. R. Thomas, 1997; Wickstrom, 1983). This understanding certainly provides support for the argument that young children should be first taught throwing in ways that are not sport-specific (Gillgren, 1991).

The differences in M/NM between sexes for the overhand throw at 41.3% and 31.8%, for TGMD-2 and TGMD-3, respectively, is concerning. Butterfield and colleagues (2003) rationalised the catch-up effect in converging growth trajectories for the sexes, with parallel growth trajectories indicating a resistance to change and a likelihood of a biological influence on development. Parallel growth trajectories for boys and girls were found by Butterfield, Angell and Mason (2012) and Thomas and Marzke (1992) whose studies established that there was no catch-up effect for girls (Nelson, Thomas, & Nelson, 1991). More recently, although there were improvements in girls overhand throw through childhood and adolescence, Barnett and colleagues (2010) found that girls' lower throwing skill levels did not catch up to boys. It could, therefore, be suggested that a ball skills intervention programme, including a strong overhand throwing component, could be particularly important for younger girls. Systematic reviews conducted by Barnett et al. (2016) and Riethmuller, Jones and Okely (2009) found statistically significant improvements in FMS competency for interventions targeted at young children, which were maintained at follow-up, thereby encouraging for girls as they transition into adolescence.

5.6 Mastery

It is important for youth to demonstrate mastery as it ensures complete control and an enhanced skill level from learning. Developing children have the capacity to master all FMS by the age of 10 years, if provided with appropriate activities and equipment, specific feedback and enough practice time in an environment of active instruction and encouragement (Gallahue & Ozmun, 2006; Gallahue et al., 2012). Despite this, the current findings reveal low FMS mastery in both TGMD-2 (77.2%; 74.1 ± 11.5 out of possible 96) and TGMD-3 (78.4%; 78.4 ± 11.3 out of possible 100). These findings mirror trends in low levels of FMS mastery in the rest of the United Kingdom (Bryant, Duncan, & Birch, 2014; Foulkes et al., 2015; Foweather, 2010) and Ireland (Behan, Belton, Peers, O'Connor, & Issartel, 2019; Belton, O'Brien, Meegan, Woods, & Issartel, 2014; L.A. Bolger et al., 2019; Lester et al., 2017; O'Brien, Belton, & Issartel, 2016b). Given the adolescent age range of this cohort, it could be suggested that children in South Wales are transitioning into adolescence prior to mastering the fundamental skills that are essential to the next skilfulness or specialised movement phase, thereby limiting future development in adulthood for lifelong utilisation skill phases for PA (Balyi, 2001; J. E. Clark, 2007; Gallahue et al., 2012; D. A. Ulrich, 2000). In light of these results, and considering literature supporting positive outcomes, these results provide further support for FMS interventions in childhood (Lai, Costigan, Stodden, Salmon, & Barnett, 2014; Logan, Robinson, Wilson, & Lucas, 2011; Morgan et al., 2013).

More than 50% of children in the current thesis were observed to have poor mastery in the underhand roll (TGMD-2), overhand throw (TGMD-2), overhand throw (TGMD-3), two-handed strike (TGMD-3) and one-handed strike (TGMD-3). Hopping was the least mastered skill, with the lowest proportion of children achieving mastery (13.7%) and the highest demonstrating poor mastery (73.1% TGMD-2; 73.6% TGMD-3). These findings are in stark contrast to those reported elsewhere; specifically, recent studies completed in Ireland reported 68.7% M/NM in hop for 5-12 year olds (Behan et al., 2019), while Bolger et al. (2018) found that 19.6% and 36.6% of 6 and 10 year olds, respectively, had mastered the hop. Comparison of this thesis to results of younger cohorts (Behan et al., 2019; L. E. Bolger et al., 2018) would highlight competency issues for the older age group assessed in this thesis, given the typical observation of an age-related increase in skill proficiency (Gallahue & Ozmun, 2006). In agreement, Barnett et al. (2010) reported an increase of 33.2% and 37.8% for adolescent boys and girls respective hop performance following a six-year longitudinal study in New South Wales, Australia. However, given that national measure of Physical Literacy in Wales, the Dragon Challenge (Stratton et al., 2017), does not consist of a hopping element, a comparative analysis of children's performance in the hop in South Wales is not possible but other anecdotal explanations may apply.

This is the first study to report specific outcomes on hop proficiency in an adolescent population in recent years, therefore demonstrating a potential area of further research older children. Bryant and colleagues (2014) consider the hop to be one of the harder FMS to master due to the decrease in base support as body mass is shifted from the support leg to non-support leg, requiring children to maintain their centre of gravity and balance (Burkett, 2010). Developmental sequences (Halverson & Williams, 1985) describing change in body configurations for hopping were discussed by Painter (1994), who questioned hopping accuracy when measured by TGMD-2 (as reported on by Ulrich (1988)). Conclusions by Painter (1994) indicated that additional investigation is required to ascertain how the sequencing technique (component or composite) influences the assessment of FMS. However, inter- and intra-rater agreement, testing observation and assessor feedback for this thesis suggests that most children had the technique and ability to complete each component of the hop but were over exerting their performance to produce a technique for single leg bounding.

Interesting, Getchell and Roberton (1989) discussed hopping competency using the pendulum/spring analogy, which would align with hop criteria C1 and C2. Specifically, Getchell and Roberton (1989) suggested that pendulum movement for hopping, given a constant leg stiffness but change in mass and/or leg length with age, would impact on overall hop performance. This explanation is supported by the low performance observed in the second skill component criteria for hop (C2) in this thesis. Whilst a mature development of hopping sequences was observed by assessors, results showed a decrease in skill competency for children when hopping required the foot of the non-hopping leg to remain behind the hopping leg. This could be explained by the actions of the child to produce more power in their performance and extend their body shape to cover a larger ground distance. This would require the generation of more force in the pendulum action of the non-support leg, resulting in the foot of the non-hopping leg generating a larger swing and therefore consequently passing in front of the hopping leg. Pang and Fong (2009) similarly measured the same skill component (hop, C2) and found 96% skill competency level among a group of 6 to 9 year olds. Comparing this thesis hopping proficiency results with a younger cohort (Pang & Fong, 2009) would suggest hopping as a particular FMS of low competency, however assessor observations can add further insight.

Given that the influence of a larger pendulum swing to hop by the cohort in this thesis was noted initially, reviews were taken, in accordance with testing protocol instructions (D. A. Ulrich, 2000; D. A. Ulrich & Webster, 2015), to perfect demonstration and instruction for the child to perform a hop. Both inter- (92.7%) and intra-rater (90.3%) results provide confidence in the data analyses. It could, however, be postulated that older children and those practising sports perform a more sports-specific hopping technique. Specifically, older children are possibly used to performing a hop as a plyometric movement, requiring forceful and explosive actions, learnt as part of a training session or warm-up in the sporting environment they practice this in. Indeed, as the recent School Sport Survey (Sport Wales, 2018) revealed, nearly half of Welsh school children participate in extracurricular or community sport three or more times per week, with Football, Rugby and Netball named as those most preferred. This conclusion is in agreement with Masci, Vannozzi, Getchell and Cappozzo (2012) who's findings suggest that the transition of the pendulum swing of the support leg to a mature stage is more influenced by an increased individual sport experience and practice than by a change in anthropometry. It could be debated that older children identify the hop as a product task involving explosive and forceful movements to cover larger distances, which, in turn, masks their naturally learned hopping ability. Indeed, physiological adaptions during/following the onset of maturation could also impact older children’s performance in this particularly complex locomotor skill. As Gaul and Issartel (2016) note, biological maturation has an influence during the transition from childhood to adolescence. The occurrence of puberty with different maturation patterns and intra- and inter-individual growth during this phase (V. P. Lopes et al., 2012) would certainly impact on performances requiring strength and power, such as the hop. This could add to the understanding that as the development of children's mass (part of the displacing force) changes, as well as their leg length (Getchell & Roberton, 1989; Masci et al., 2012) their performance in this basic FMS will change.

It could be reasoned that a different method of assessment for hopping for an adolescent sample could provide further insight in FMS performance for researchers, coaches, teachers and practitioners. Instrument measurement issues were highlighted by Barnett et al. (2010) as a contributing factor to their lowest inter-rater reliability of their Physical Activity and Skills Study (PASS) sample (L. M. Barnett, van Beurden, Morgan, Brooks, et al., 2009), indicating an argument for further development in assessment due to its problematic nature. More recently, Logan, Barnett, Goodway and Stodden (2017) measured hop distance as a percentage of children’s height using Dartfish (Dartfish Motion Analysis Corporation, Marietta, GA). Hop distance was calculated based on a child’s ability to hop at least three times in a row on each leg for at least one of the two trials on that foot. Average hop distance (i.e., distance from heel to heel) was calculated based on the average of a minimum of three hops for each foot. Emerging evidence in accelerometery-based measurements of FMS (C. C. Clark, Barnes, Holton, Summers, & Stratton, 2016) has indicated that, although overall motor activity may be the comparable such as in the hop, the characteristics and quality of a child’s movement may be noticeably different, even when completing the same activities. Encouragingly, inertial sensors were suitable in describing hopping performance and were shown to be sensitive to developmental changes by Masci et al. (2012). Such promising outcomes could be investigated if developmental assessment is paired with this type of technology and therefore beneficial for assessors working with adolescents.

5.7 Skill Competency

In accord with Gallahue et al. (2012), it is understood that a failure to develop competent FMS will have an effect on task-specific ability at the specialised movement phase and sport-specific skills for long-term athletic development (Balyi & Hamilton, 2004). Each gross motor skill, presenting as a mature pattern of skill, contains several behavioural components that are presented as performance criteria (Ulrich, 2000). As such, it is essential that the analysis of skill competence at the behavioural component level, similar to previous research (Eather et al., 2018; Foulkes et al., 2015; Hardy, King, Farrell, et al., 2010; Kelly et al., 2019; Lester et al., 2017; O'Brien et al., 2016a; Okely & Booth, 2004), is used to establish a more in-depth understanding of FMS skill mastery. The skill competency analysis conducted in this thesis has extended our knowledge and identified that few children demonstrated competency in several locomotor and object control/ball skill components.

Notably, one skill component, the second performance criteria for run (C2), assessed by both TGMD-2 and TGMD-3, resulted in maximum achievement in this cohort of children. This finding mirrors research by Pang and Fong (2009), Cliff et al. (2012), Foulkes et al. (2015), Lester et al. (2017) and O'Brien et al. (2016) who also found run C2 criteria to have a 100% achievement outcome. Indeed, given that run criteria C2 requires a brief period where both feet are off the ground, it could be theorised that this process outcome could be more successfully achieved by the performer as this is a rudimentary locomotor element of behavioural criteria (Hardy et al., 2010) and could be performed without much practise, learned ability or effort. As implied by Booth et al. (1999), mastery of these skills could be increased without great effort compared to the effort required to achieve mastery of the forehand strike (one-handed strike) and kick. In support of this theory, running skills were found to be mastered faster than other FMS (Catenassi et al., 2007).

Indeed, such rudimentary locomotor movements, such as those involved in running, are mastered prior to more complex manipulative actions, which require co-ordination and stability of trunk and limb movements (Hardy et al., 2010). It is noteworthy that this criterion for the run (C2 'brief period where both feet are off the floor/ surface') is also a performance component for the gallop (C3) in both TGMD-2 and TGMD-3 and is similar in wording to criteria two for the leap (assessed by TGMD-2 only). Gallop (C3) and leap (C2), however, were not associated with the same 100% success rate. In accord with Pang and Fong (2009), Hardy et al. (2010) and Foulkes et al. (2015), there was a slight decrease in achievement in gallop (C3 'Brief period of time where both feet are off the floor/ surface') and leap (C2 'A period where both feet are off the ground longer than running') when compared to the same component in the run (C2). This finding suggests that children are not performing the same skill behaviour in a different FMS context with the same level of confidence. This is important in the translation to other situations, not least more specialised sports skills. Interestingly, studies measuring run and gallop similarly to the assessment conducted in this cohort found that girls scored higher than boys for gallop criterion 3 (Foulkes et al., 2015; Hardy et al., 2010; Pang & Fong, 2009). However, Foulkes et al. (2015) and Pang and Fong (2009) found boys performed better than girls for leap C2, which may, at least in part, be due to the younger participants incorporated in this research. Furthermore, as previously discussed, these discrepancies may be related to sex differences in the commonality of the movements to those utilised in daily life (Blatchford et al., 2003; Garcia, 1994; Haywood & Getchell, 2009; Perry et al., 2015; Thomas & French, 1985).

Interestingly, similar adolescent skill trends in male ball skill proficiency were found in Irish school children (O'Brien et al., 2016b), though, controversially, girls had high scores associated with execution in striking and kicking (O'Brien et al., 2016b). Whilst such findings are contrary to the present thesis, the current results are consistent with Farmer, Belton and O'Brien, (2017). It is postulated that such differences may be explained, at least in part, by cultural factors in Ireland (L. M. Barnett et al., 2019). Specifically, Ladies Gaelic Football, which requires a strong kicking ability, is a favourite sport among female youth in Ireland (Farmer, Duffy, Cahill, Lester, & O'Brien, 2018). Conversely, study outcomes from Dos Santos, Pacheco, Basso and Tani (2016) found that the most popular sport does not lead to higher rates of children mastering skills linked to the most popular national pastimes. Further research to ascertain FMS proficiency amongst adolescent populations is therefore warranted. Moreover, future comparisons of FMS performance from children from different cultural backgrounds will provide valuable information on global trends (Bardid et al., 2015).

This thesis highlights the importance of considering the sub-components of FMS. Research involved in developmental analysis has provided a valuable resource for researchers and educators who strive to understand children's acquisition of motor skills (Branta et al., 1984). Analysing skill competence at the component level provides information on the specific component(s) of a skill that are lagging or deficient, which can subsequently be used to guide instructional practices (Foulkes et al., 2015). Younger children may therefore require more tailored instruction and practices in order to demonstrate control of more complex skill components where older children may require more specific feedback for their stage of development. The detailed analysis of skill competency in this thesis extends our understanding of adolescent skill proficiency. On the macro level, overall proficiency indicated no performance criteria in object control or ball skills' components, was achieved by 100% of this cohort, indicating ball skills and/or ball control performance as a possible target for future interventions for an adolescent age group. Therefore, future research focussing on interventions could be appropriately tailored to resolve the areas of insufficiency or incompetence and thereby improve the overall movement competency. Modifying interventions using knowledge on specific skill components listed in and across FMS (van Beurden et al., 2002) would provide teachers, coaches and sports practitioners with a distinct strategy and plan of action for the children they are working with.

McGrane et al. (2018) reported a significant intervention effect following a multi-component, school-based intervention in 12 to 13 year old children called the Y-PATH intervention. This intervention consisted of four components. The student component had a specific focus on health-related activity and FMS in Physical Education, whereas the second component focussed on educating parents/guardians about the health benefit of PA. The teacher component found that all school staff participated in workshops where the main objective was to promote PA among staff and students during school time. The fourth component consisted of online resource availability. McGrane et al. (2018) found significant positive intervention effects across time for all children, regardless of sex, weight status or PA level ($p = 0.03$ to <0.0001). Notably, intervention improvements included increases in total FMS score as well as object control and total locomotor subscale scores (McGrane et al., 2018). Kalaja and colleagues (2012) revealed that it is possible to develop junior high school students' FMS and possibly prevent adolescent PA decline, through Physical Education classes focused on simple balance, locomotor and manipulative skill. The intervention consisted of set tasks at the start of each Physical Education lesson with specific findings showing that more than the 25 minute time slot (33 sessions) is needed to develop ball and locomotor skills to create long-term benefits (Kalaja et al., 2012). More recently, Lander, Eather, Morgan, Salmon and Barnett (2017) successfully improved early adolescent girl's FMS, showing a large effect size finding for object control skills. These findings suggest that FMS can be improved during adolescence and therefore beyond the optimal learning period of childhood (Okely et al., 2001b). This provides support for FMS development for Physical Education teachers, sports practitioners and coaches working with these age groups. However, it would be more beneficial for children to develop these basic skills prior to puberty to enhance positive health outcomes (Robinson et al., 2015) in adulthood lifelong PA behaviours (Lloyd, Saunders, Bremer, & Tremblay, 2014).

5.8 Summary

This is a challenging time for physical educators, coaches, sports practitioners and researchers working with children and adolescents. Decreasing PA levels, poor FMS competency (Edwards, Tyler, Blain, Bryant, Canham, Carter-davies, et al., 2018; Harrington et al., 2016;

Hughes et al., 2018; Standage et al., 2018; Woods et al., 2018) and common trends of high levels of sedentary behaviour (Smith, Fisher, & Hamer, 2015) have negative impacts on child, and subsequently adult, health. Results of this thesis should be considered to support childhood FMS development to improve PA and overall positive health outcomes. Indeed, withdrawal from PA is at its highest among teenagers (F. De Meester, Van Lenthe, Spittaels, Lien, & De Bourdeaudhuij, 2009) in accord with the age range of this thesis. Indeed, the low levels of FMS mastery found in this thesis further supports the necessity for development of FMS in childhood. Of interest, the age range incorporated in this thesis concurs with the time for individuals to transition from the application to lifelong utilisation stages of motor development within the aforementioned specialised movement phase (Gallahue & Ozmun, 2006). Low levels of FMS mastery and the sex differences in this thesis are comparative with Carson, Sackett and Edwards (2019) findings for young adults (18 ± 1.5 years) which suggests poor mastery levels of FMS, and indeed sex differences in FMS competence, continue into adulthood. Indeed, research has identified that it is imperative for youth to obtain these skills during childhood given that FMS attainment in adulthood is more challenging, whilst achieving a high level of proficiency in any sport becomes increasingly difficult (Gallahue et al., 2012; Stodden et al., 2008) and therefore the goal of lifelong PA is inaccessible (L. M. Barnett, van Beurden, Morgan, Brooks, & Beard, 2008; L. M. Barnett et al., 2009; Robinson et al., 2015). Future research should seek to address FMS development delays before adolescence to provide the best possible movement proficiency outcomes for individuals.

5.9 Strengths

The contribution to validating the TGMD-3 and the expansion of its proposed use for FMS measurement in older children, in the current thesis is encouraging. The potential use of the TGMD-3 for assessment, combined with teacher/sports coaching strategies and research, may provide a highly accurate and effective way to identify children in need of FMS intervention. The Confirmatory Factor Analysis (CFA) further details that lower loading FMS, such as the skip and catch, may not be relevant FMS for older children. In particular, the removal of the catch for older children in the final CFA model suggests that a more challenging assessment of one-handed catching (not assessed in the TGMD) could provide a better insight into basic mastery of this skill. Indeed, such findings provide a sound basis to inform the development of a guide for practitioners seeking to develop motor skills and FMS in this specific age group. Moreover, these findings are particularly important for the refinement of school curriculums, coaching programmes and public health strategies. In accord with Issartel et al., (2017), who found two factors (ball skills and locomotor skills) to be valid for older children in the TGMD-2, this thesis has also shown through CFA that ball skills and locomotor skills are important throughout the maturation process from childhood to adolescence. As indicated in recent studies (Eather et al., 2018; Foulkes et al., 2015), component level analysis provides precise information that can assist with the design of instruction programmes and targeted activities for children that are developmentally appropriate with a focus on subscale components of FMS skills. The results from this thesis support the use of component analysis in this way. Specifically, this thesis found a significant sex difference in overhand throw component criteria, with girls achieving a lower level of mastery than boys. Hopping technique was also recognised in this thesis as a particular FMS where behavioural component criteria indicated poor mastery for both sexes but suggested further research may be required in adolescent specific assessment of FMS.

Analysing FMS behavioural component criteria in this way could therefore be of importance for those primarily facilitating FMS development for adolescent populations, such as secondary level Physical Education teachers and Physical Education assistants and coaches. Indeed, the overhand throw results illustrate how vital FMS skills are to provide a foundation for other sport-specific skills (O'Keeffe et al., 2007) which are practised sports in secondary school Physical Education. Considering the positive health outcomes associated with improved FMS mastery levels (Kalaja et al., 2012; Martin, Rudisill, & Hastie, 2009; Mitchell, McLennan, et al., 2013), prescriptive Physical Education programmes would be an opportune environment to intervene and develop FMS, particularly when this opportunity has not been taken in early childhood. Importantly, the results of this thesis infer a requirement for researchers and practitioners to use assessment measures with an informed understanding of skill competency changes between TGMD-2 and TGMD-3. However, it is the predictive strength of TGMD-2 subscales in determining competence in TGMD-3 total score and subscales that provides assessors with encouraging evidence in establishing competency and trends through comparison. Indeed, an overall indication of FMS mastery could be established using one subscale assessment of TGMD-2, allowing practitioners more time to focus on specific skill interventions should this be required. This could impact on future research interpretations whilst also debating the relevance of certain fundamental skills for older age groups. Confirmatory Factor Analysis results, however, provide support for the two-factor model of the subscales of ball skills and locomotor skills of TGMD-3 FMS. Therefore, FMS development may be important throughout maturation from childhood to adolescence (Issartel et al., 2017).

5.9 Limitations

Whilst there are numerous strengths associated with this thesis, there are certain limitations that need to be considered. Firstly, the convenience sampling used may reduce the generalisability of the findings, not least due to most participants being recruited from one school in South Wales. To gain more insight into FMS competency levels, future research should seek to recruit participants from wider sociodemographic, cultural and geographical locations. Moreover, the cross-sectional design of the present thesis also precludes the delineation of the potential contribution of other variables that may influence FMS, such as maturation, PA levels and overall sports participation. Indeed, it is pertinent to note the age range in the current study, which is likely to coincide with the pubertal period of many of the participants. Notably, the boys were significantly taller and heavier than girls, likely favouring adolescent boys in any motor task for which size and strength are an advantage.

5.10 Future Implications

Evidence suggests that teacher-directed activities lead to greater improvement in children's FMS proficiency (J. E. Clark, 2007; Deli, Bakle, & Zachopoulou, 2006; Derri, Tsapakidou, Zachopoulou, & Kiomourtzoglou, 2001; McGrane, Belton, Powell, & Issartel, 2017). However, as teacher competency in assessing and identifying FMS competency is questioned (Lander, Barnett, Brown, & Telford, 2014), there is a demand for an objective measurement of essential FMS to provide a clear indication of competency. Such objective assessment measures of specific skills could identify where, for example, developmental delays are occurring, enabling the individual tailoring of intervention strategies. Moreover, time-costly assessments, such as the TGMD-2 and TGMD-3, may not be viable in a Physical Education Department setting where class sizes can be substantial, and timetables are restricted. Objective assessment methods could, therefore, provide a quick, reliable and visual representation of FMS competency for participants and teachers that would, in turn, influence curriculum interventions and planning.

Ideally, assessment of FMS should be completed in youth to identify developmental delays and enable early intervention, especially for girls, to provide adequate time to master essential FMS and reduce the sex gap. Targeting mastery levels in childhood for FMS, particularly ball skills, is encouraging due to the implications of mastery of ball skills in childhood as predictors of adult PA (D. A. Ulrich, 2017). It is necessary to identify FMS delays, intervene and remedy poor mastery levels for children in their youth to develop a sound foundation of basic skills to develop further specialist sports skills in adolescence. Increased emphasis on FMS in schools, and the wider educational environment, will develop childhood FMS (Okely & Booth, 2004) and consequently patterns for heightened PA levels that will continue throughout life.

6.0 References

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7.0 Appendices

Appendix I: Worldwide FMS Trends

Country	Authors	Sample Size	Age	FMS Assessment Tool	Results	Physical Activity	Sex differences
				Oceania			
Australia	Okely & Booth, (2004)	18 Primary schools N = 12,880	Year 1, 2 3 primary schools		M/NM low		Boys performed better at run Girls performed better at skip Boys better at some object control skills
Australia	McIntyre, Parker, Chivers and Hands (2018)	N = 91 (36% boys)	Young adults 18-30 years 21.4 ±3.3 years	MAND BOT-2			Boys higher total FMS Boys significantly better than girls
Australia	Hume, Okely, Bagley, Telford, Booth, Crawford and Salmon (2008)	3 Primary schools N = 311	Grade 5	3 object control skills 4 locomotor skills			Boys higher total FMS Boys performed better in object control (M/NM scores higher); specifically kick, overhand throw and two-handed strike
Australia	Erwin & Castelli (2008)						Boys better at object control Girls better at locomotor skills Girls better at stability skill
Australia	Barnett, van Beurden, Morgan, Brooks and Beard (2009)	Secondary school N= 276 (52% girls)					Boys better at object control Girls better at locomotor skills Girls better at stability skill
Australia	Ziviani, Poulsen and Hansen (2009)	4 Primary schools N = 124		MABC		Significant (weak) association weekend PA and balance skills for girls	Boys better at ball skills Girls better at balance tasks

						Non-significant correlations PA and ball skills or manual dexterity	
Australia	Hardy, King, Farrell, Macniven, & Howlett (2010)	N = 425		TGMD-2			Boys better at object control Girls better at locomotor skills Girls better at stability skill
Austrialia	Cliff, Okely, Smith and McKeen (2009)	N = 46	3-5 years	TMGD-2		boys, object-control skills were associated with physical activity and explained 16.9% (p = .024) and 13.7% (p = .049) of the variance in percent of time in moderate-to-vigorous physical activity (MVPA	
Australia	Cliff, Okely, Morgan, Steele, Jones and Baur (2012)	N = 165	5.5-10 years	TGMD-2	GMQ scores showed children ranked in bottom <1%		Boys better at object control Girls better at locomotor skills
Australia	Hardy, Reinten-Reynolds, Espinel, Zask and Okely (2012)	High School N = 6917			Low motor skill	Low competency in object-control skills and PA for boys Low competency in locomotor skills and PA for girls	
Australia	Cohen, Morgan, Plonikoff, Callister and Lubans (2014)	16 Primary schools N = 460		TGMD-2		Object control skills positively associated with MVPA	Boys better at object control Girls better on average at locomotor skills
Australia	Barnett, Ridgers and Salmon (2015)	3 Primary schools N = 102	5-8 years	TGMD-2			Boys better at object control
Australia	Slykerman, Ridgers, Stevenson and Barnett (2016)	2 Primary Schools N = 136		TGMD-2		Locomotor skills significant predictor of girls MVPA	Boys better object control skills No significant differences in locomotor skills

Australia	Hardy, Barnett, Espinel and Okely (2013)	N = 13,752	9-15 years	Five FMS (sprint run, vertical jump, catch, kick, and overarm throw) Process orientated	FMS competency was low, with prevalence rarely above 50%. low especially in the kick and overarm throw in girls.		Boys perform better total FMS Boys better object control skills (14% catch better, 38% kick better and 34% throw)
Australia	Eather, Bull, Young, Barnes, Pollock and Morgan (2018)	N = 153 *Girls only	4-12 years (7.7 ± 1.8 years)	TGMD-2 TGMD-3 (object control only)	Low mastery level for 17 of 24 criteria components <5% M/NM in strike, dribble, overhand throw and kick		
Australia	Barnett, van Beurden, Morgan, Brooks and Beard (2010)	40 schools N = 929	Mean age 10.06 years (2000) Mean age 16.44 years (2010)	GSGA			Boys performed better in object control (M/NM) No significant difference in locomotor
Australia	van Beurden, Zask, Barnett and Dietrich (2002)	18 schools N = 1,045	Grade 3 and 4	Victorian Fundamental Motor Skills Manual	<50% mastery Poorest in jump and sprint		
New Zealand	Mitchell, McLennan, Latimer, Graham, Gilmore and Rush (2013)	11 schools N = 701	years 0—8 school	TGMD	Low levels of FMS (Baseline measurement)		At baseline less than half of the children exhibited proficiency in kicking (21%), throwing (31%) and striking (40%) while most children were able to run (84.6%) and slide (78.0%)

Europe

British Isles							
England	Bryant, Duncan and Birch (2014)	1 Primary School N = 281	6-11 years	POC (Move It Grove It)	6 of 8 FMS were not mastered Catch and balance NM		Boys significantly better at kick and throw (object control) Girls significantly better at balance
England	Foweather (2010)		10-11 years		Low levels of FMS		
England	Duncan, Jones, O'Brien, Barnett and Eyre (2018)	N = 258 (53.8% boys)	4-7 years	TGMD-2 10m sprint Standing long jump 1kg medicine ball throw			Boys significantly performed better in total FMS (product and process)
England	Birch, Cummings, Oxford and Duncan (2016)	N = 539 school (47.9% boys)	6-11 years (7.7 ± 1.7 years)	Sprint, side gallop, balance, jump, catch, and throw			Boys significantly higher sprint Boys higher catching Boys higher throwing
England	Foulkes, Knowles, Fairclough, Stratton, O'Dwyer, Ridgers and Foweather (2015)	N = 168	3-5 years	TGMD-2	Low levels of FMS *except run, slide and leap Locomotor skills higher than object control		Boys performed significantly better than girls in object control No significant difference in total or locomotor
Scotland	Junaid and Fellowes (2006)	N = 103 (58% boys)		MABC			Boys performed significantly better in ball skill scores and manual dexterity scores
Wales	Stratton, Foweather and Hughes (2017)	N = 4,355 (51.6% boys)	10-12.9 years	Dragon Challenge			Boys performed better overall

							Boys performed better in technique, outcome, time and manipulative scores, Girls performed better in stability Boys achieved gold or platinum (47%) Girls achieved gold or platinum (30%).
Northern Ireland	McPhillips and Jordan-Black (2007)	4 Primary Schools N = 258 (Year 1) N = 294 (Year 4)	Year 1 and Year 4	MABC			Significant main effect of gender and manual dexterity for Year 1 Significant main effect for gender for manual dexterity and balance for Year 4
Republic of Ireland	MacCobb, Greene, Nugent and O'Mahony (2005)	N = 76	9 years	BOTMP	Sample above average		
Republic of Ireland	O'Brien, Belton and Issartel (2016a)	N = 85 (63.5% boys)	12–14 years	TGMD TGMD-2 GSGA (skip, run, gallop, hop, leap, horizontal jump, slide, striking a stationary ball, stationary dribble, catch, kick, overhand throw, underhand roll, vertical		Boys higher MVPA Girls total skill and locomotor medium and positive correlation with vigorous PA	Significant difference in object control

				jump and static balance)			
Republic of Ireland	O'Brien, Belton and Issartel (O'Brien et al., 2016a)	N = 242 (52% boys)	12–13 years	Republic of Ireland	Low levels of FMS 11% M/NM		Boys performed significantly better in total FMS Boys performed significantly better in object control No significant difference in locomotor *Girls performed significantly better in skip *Boys performed significantly better in overhand throw and horizontal jump
Republic of Ireland	McGrane, Belton, Powell and Issartel (2017)	20 schools N = 395	13.78 ± 1.2 years	TGMD-2 Victorian Fundamental Motor Skills Manual TGMD			Boys performed significantly better in total FMS
Republic of Ireland	Lester, McGrane, Belton, Duncan, Chambers and O'Brien (2017)	2 Secondary Schools N = 181 (Boys 59.7%)	14.42 ± 0.98 years	TGMD-2 Victorian Fundamental Motor Skills Manual (skip, run, horizontal jump, two-handed strike, stationary dribble, catch, kick and overhand throw,	No child achieved mastery* Low levels of FMS Poorest performed skills were overarm throw, vertical and horizontal jump		

				balance and vertical jump)			
Republic of Ireland	Farmer, Belton and O’Brien (2017)	N = 160 Girls only*	10.69 ± 1.40 years	TGMD-2	98.1% did not achieve the FMS proficiency expected for their age		
Republic of Ireland	Kelly, O’Connor, Harrison and Ní Chéilleachair (2019)	N = 198	Year 2 to Year 7 9.0 ± 1.7 years	TGMD-3, Victorian Fundamental Movement skills Manual GSGA	M/NM one-handed strike (28.6%), horizontal jump (47%), and catch (73.5%)		Boys better at object control Girls better at locomotor skills
Republic of Ireland	Bolger, Bolger, O'Neill, Coughlan, O'Brien, Lacey, Burns (2018)						Boys better at object control Girls better at locomotor skills
Republic of Ireland	Behan, Belton, Peers. O’Connor and Issartel (2019)	N = 2098	5–12 years	TGMD-3, BOT-2 and Victorian Fundamental Movement skills manual			Boys performed better in total FMS (11 and 12 year olds) Boys better at object control Girls better at locomotor skills and balance
				Europe			
Germany	Ehl, Roberton, and Langendorfer (2005)	1 Junior High School N= 52gh	Boys mean 18.8 years Girls 14.0 years	Throwing*			Boys better at object control (throwing*)
*Estonia	Raudsepp and Paasuke (1995)	N = 60 (55% boys)	8 years	EUROFIT* medicine ball throw			No sex differences locomotor (run) Boys better at object control (overhand throw)
Belgium	Bardid, Huyben, Lenoir, Seghers, De	N = 1614	3-8 years	TGMD-2	Skill proficiency with age		Boys performed better in object control

	Martelaer, Goodway and Deconinck (2016)				(3 - 6 years for locomotor skills) (3 - 7 years for object control skills) Belgian children lower levels of FMS than USA norms		
Italy	Milanese, Bortolami, Bertucco, Verlato and Zancanaro (2010)	N = 152	6-12 years	Standing long jump 30m sprint			Boys total FMS better than girls (significantly)
Portugal	Lopes, Stodden, Bianchi. Maia and Rodrigues (2012)	N = 7,175	6 years and 14 years	KTK			Boys performed better in total FMS
Portugal	Lopes, Santos, Pereira and Lopes (2012)	13 elementary schools N = 213	9 – 10 years	KTK		Girls lower levels of total FMS and MVPA (Sedentary time significantly discriminates between children with high motor control and low motor control)	Boys performed better in total FMS (motor control)
Portugal	Freitas, Lausen, Maia, Lefevre, Gouveia, Thomis, Antunes, Claessens, Beunen and Malina (2015)	N = 429	7-10 years	KTK, TGMD-2	Low levels of FMS		
Norway	Vedul-Kjelsås, Stensdotter and Sigmundsson (2013)	1 Primary School N = 67 (58.2% boys)	11 years	MABC			Boys performed better in balls skills Boys performed better in one balance task (jumping and clapping)

							No significant difference in manual dexterity tasks or total FMS
Finland	Laukkanen, Pesola, Havu, Saakslahti and Finni (2014)	19 Kindergartens 37 Primary Schools N = 84	5–8 years	KTK	Normally developed*		Boys performed better in total FMS
Finland	Slotte, Sääkslahti, Metsämuuronen and Rintala (2015)	N = 304	Mean 8.6 years	TGMD-2			Boys performed better in total FMS Boys performed better in object control skills Girls performed better in locomotor skills
				South America			
Brazil	Spessato, Gabbard, Valentini and Rudisill (2013)	N = 1248 (51% boys)	3–10 years	TGMD-2	Low level FMS (compared to norms)		Boys better total FMS Boys performed better in object control Boys performed better in locomotor
				North America			
USA	McKenzie, Alcaraz and Sallis (1998)	7 schools N = 403	Grade 4 and Grad 5	Throwing, catching and kicking. (SPARK PE curriculum)			Boys performed better in total FMS
USA	Wrotniak, Epstein, Dorn, Jones and Kondilis (2006)	N = 65	8-10 years	BOTMP		Significant associations with total FMS and PA and MVPA and sedentary time	No sex differences found Boys had scored higher in throwing and were faster in running
USA	Erwin and Castelli (2008)	4 Elementary Schools	9-12 years	South Carolina PE			Boys performed better in total FMS

		N = 180		Assessment Program (SCPEAP)			
USA	Butterfield, Angell and Mason (2012)	1 School N = 186	5-14 years	TGMD-2			Boys performed better in total FMS Boys performed significantly better in throwing and striking
USA	De Meester, Stodden, Goodway, Brian, True, Cardon, Tallir and Haerens (2016)	1 School	Mean 9.45 years	TGMD-2		Boys more PA Higher total FMS related to PA (combination)	Boys and girls had similar levels of total FMS
USA	Runion, Roberton, and Langendorfer (2003)	N = 89 (52.8% boys)	13 years*				Boys better at object control
USA	Carson and Sackett (2019)	N = 448	Minimum 18 years	TGMD-2 BOT-2		Girls object control performance predictive of PA	Boys performed better in locomotor but no significant difference in locomotor
Canada	Wright and Bos (2012)	1 School 1 Community Group N = 84	8-11 years	Community Balance and Mobility Scale (CB&M)			No significant sex differences
	LeGear, Greyling, Sloan, Bell, Williams, Naylor and Temple (2012)	8 schools, Kindegarten N = 260 (52% boys)	Mean age 5 years 9 months	TGMD-2	Low level total FMS		
			Asia				
Hong Kong	Choi Tse (2004)	N = 30	6-11 years	TGMD-2	Poor level of motor competence (below average)		No significant differences in sex for total FMS
	Pang and Fong (2009)	6 Primary Schools	6-9 years	TGMD-2	High level FMS		

		N = 167			Locomotor skills performed better than object control skills	
	Mei Yung Lam and Schiller (2013)	8 Primary schools N = 320	5–6 years	BOTMP	Running speed and agility below average	Boys better running, and agility Boys better strength and upper limb coordination Girls better in balance and coordination
Indonesia	Bakhtiar (2014)	N = 67	6–7 years	TGMD-2	Some children measured as Advanced Motor Skills (urban)	Boys perform better in locomotor skills (non significant) Girls perform better in manipulative skills (non significant)
Singapore	Mukherjee, Ting Jamie and Fong (2017)		6–9 years		Low levels FMS	
India	Abas, Shanker, Tedla and Krishnam (2011)	4 schools N = 197	9.5–14.5 years	BOTMP		Significant differences 9.5-10.5 years running agility and upper limb coordination Significant difference 10.5-11.5 years speed Significant differences 12.5-13.5 years in bilateral coordination and upper limb coordination In Significant differences 13.5-14.5 years 13 running agility and upper limb
Tehran	Khodaverdi, Bahram, Stodden and Kazemnejad (2015)	N = 352 Girls only*	Grade 3 8-9 years	TGMD-2	Total FMS higher than age specific norms	

Appendix II: Validation Studies

Study	*Authors*	*FMS Assessment*	*Validated Sample*
Construct Validity of the Test of Gross Motor Development: A Cross-Validation Approach	Evaggelinou et al. (2002)	TGMD	(Greek children*) N = 324 3-10 years
Confirmatory Factor Analysis of the Test of Gross Motor Development-2	Wong and Cheung (2010)	TGMD-2	Hong Kong Chinese children N = 614 6.45 ± 2.10 years
Aspects of reliability and validity of the TGMD-3 in 7–10 year old children with intellectual disability in Belgium	Simons and Eyitayo (2016)	TGMD-3	Belgian children with intellectual disability N = 19 7-10 years
Test of Gross Motor Development-third edition: Establishing content and construct validity for Brazilian children	Valentini et al. (2017)	TGMD-3	Brazilian children N = 597 3–10 years
Multivariate Associations Among Health-Related Fitness, Physical Activity, and TGMD-3 Test Items in Disadvantaged Children From Low-Income Families	Burns et al. (2017)	TGMD-3	Disadvantaged children N = 1,460 8.4 ± 1.8 years
Psychometric Properties of the Test of Gross Motor Development, Third Edition (German Translation): Results of a Pilot Study	Wagner et al. (2017)	TGMD-3	German children N = 189 7.15 ± 2.02 years

Validity and Reliability of the Spanish Version of the Test of Gross Motor Development – 3	Estevan et al. (2017)	TGMD-3	Spanish children N = 178 3-11 years
A Peek at the Developmental Validity of the Test of Gross Motor Development – 3	Temple and Foley (2017)	TGMD-3	(American children*) N = 277 Grade 3 to Grade 4
Psychometric Properties of the Test of Gross Motor Development-3 for Children with Visual Impairments	Brian et al. (2018)	TGMD-3 (TGMD-2*)	Children with visual impairments N = 66 12.93 ± 2.4 years
Evaluation of the Psychometric Properties of the Persian Version of the Test of Gross Motor Development – 3rd Edition	Mohammadi et al. (2019a)	TGMD-3	Persian children N = 1600 6.56 ± 2.29 years

Appendix III: Protocol Booklet

FMS ASSESSMENT PACK

Protocol Handbook

CONTENTS

Maeve Murray

TGMD-2 Object Control and TGMD-3 Balls Skills Scoring Script

TGMD-2 Object Control Skills			TGMD-3 Ball Skills			
Skill		**TGMD-2 Performance Criteria**	**Skill**		**TGMD-3 Performance Criteria**	***Research Team Notes***
Striking a stationary ball	C1	Dominant hand grips bat above nondominant hand	Two Handed Strike	C1	Child's preferred hand grips bat above non-preferred hand.	
	C2	Nonpreferred side of body faces the imaginary tosser with feet parallel		C2	Child's non-preferred hip/shoulder faces straight ahead.	*Change of action for feet*
	C3	Hip and should rotation during swing		C3	Hip and shoulder rotate and derotate during swing.	*Change of full action for swing*
	C4	Transfers body weight to front foot		C4	Steps with non-preferred foot.	*Change of action for foot*
	C5	Bat contacts ball		C5	Hits ball sending it straight ahead.	*Outcome change*
[redacted]			One-hand forehand strike of self-bounced ball	C1	Child takes a backswing with the paddle when the ball is bounced.	
				C2	Steps with non-preferred foot.	
				C3	Strikes the ball toward the wall.	
				C4	Paddle follows through toward non-preferred shoulder.	
Stationary Dribble	C1	Contacts ball with one hand at about belt level	One-hand stationary dribble	C1	Contacts ball with one hand at about waist level	*Change of term for belt level as waist level*
	C2	Pushes ball with fingertips (not a slap)		C2	Pushes the ball with fingertips (not slapping at ball)	
	C3	Ball contacts surface in front of or to the outside of foot on preferred side		C3	Maintains control of the ball for at least four bounces consecutively without moving their feet to retrieve the ball	*Removal of action for ground contact for ball*
	C4	Maintains control of ball for four consecutive bounces without having to move the feet to retrieve it				

Catch	C1	Preparation phase where hands are in front of the body and elbows are flexed	Two-hand catch	C1	Child's hands are positioned in front of the body with the elbows flexed	
	C2	Arms extend while reaching for the ball as it arrives		C2	Arms extend reaching for the ball as it arrives	
	C3	Ball is caught by hands only		C3	Ball is caught by hands only	
Kick	C1	Rapid continuous approach to the ball	Kick	C1	Rapid, continuous approach to the ball.	
	C2	An elongated stride or leap immediate prior to ball contact		C2	Child takes an elongated stride or leap just prior to ball contact	
	C3	Nonkicking foot placed even with or slight in back of the ball		C3	Non-kicking foot placed close to the ball	*Change of wording for foot placement*
	C4	Kicks ball with instep of preferred foot (shoe-laces) or toe		C4	Kicks ball with instep or inside of preferred foot (not the toes)	
Overhand Throw	C1	Windup is initiated with downward movement of hand/ arm	Overhand Throw	C1	Windup is initiated with a downward movement of hand and arm	
	C2	Rotates hip and shoulders to a point where the nonthrowing side faces the wall		C2	Rotates hip and shoulder to a point where the non-throwing side faces the wall	
	C3	Weight is transferred by stepping with the foot opposite the throwing hand		C3	Steps with the foot opposite the throwing hand toward the wall	
	C4	Follow-through beyond ball release diagonally toward the nonpreferred side		C4	Throwing hand follows through after the ball release, across the body toward the hip of the non-throwing side	*Slight change of action for end direction of throw towards hip for TGMD-3*
			Underhand Throw	C1	Preferred hand swings down and back reaching behind the trunk.	
				C2	Steps forward with the foot opposite the throwing hand.	
				C3	Ball is tossed forward hitting the wall without a bounce.	

				C4	Hand follows through after ball release to at least chest level.	
Underhand Roll	C1	Preferred hand swings down and back, reaching behind the trunk while chest faces cones				
	C2	Strides forward with foot opposite the preferred hand toward the cones				
	C3	Bends knees to lower body				
	C4	Releases ball close to the floor so ball does not bounce more than 4 inches high				
		Total Number of Object Control Skills	6		Total Number of Ball Skill	7
		Maximum Score	48		Maximum Score	54

TGMD-2 and TGMD-3 Locomotor Skill Scoring Script

TGMD-2 Locomotor Skills			TGMD-3 Locomotor Skills			
Skill		**TGMD-2 Performance Criteria**	**Skill**		**TGMD-3 Performance Criteria**	***Research Team Notes***
Run	C1	Arms move in opposition to legs, elbows bent	Run	C1	Arms move in opposition to legs with elbows bent	
	C2	Brief period where both feet are off the ground		C2	Brief period where both feet are off the surface	
	C3	Narrow foot placement landing on heel or toe (i.e., not flat-footed).		C3	Narrow foot placement landing on heel or toes (not flat-footed).	
	C4	Nonsupport leg bent approximately 90 degrees (i.e., close to buttocks)		C4	Non-support leg bent about 90 degrees so foot is close to buttocks.	
Gallop	C1	Arms bent and lifted to waist level at takeoff	Gallop	C1	Arms flexed and swinging forward	*Change of terms for arm action*
	C2	A step forward with the lead foot followed by a step with the trailing foot to a position adjacent to or behind the lead foot		C2	A step forward with lead foot followed with the trailing foot landing beside or a little behind the lead foot (not in front of the lead foot)	
	C3	Brief period when both beet are off the floor		C3	Brief period where both feet come off the surface	
	C4	Maintains a rhythmic patter for four consecutive gallops		C4	Maintains a rhythmic pattern for four consecutive gallops	
Hop	C1	Nonsupport leg swings forward in pendular fashion to produce force	Hop	C1	Non-hopping leg swings forward in pendular fashion to produce force	
	C2	Foot of nonsupport leg remains behind body		C2	Foot of non-hopping leg remains behind hopping leg (does not cross in front of)	
	C3	Arms flexed and swing forward to produce force		C3	Arms flex and swing forward to produce force	

	C4	Takes off and lands three consecutive times on preferred food		C4	Hops four consecutive times on the preferred foot before stopping	*Difference in product outcome from 3 hops to 4*
	C5	Takes off and lands three consecutive times on nonpreferred foot				*Removal of fifth criteria and focus on hopping on both feet*
[redacted]			Skip	C1	A step forward followed by a hop on the same foot	
				C2	Arms are flexed and move in opposition to legs to produce force	
				C3	Completes four continuous rhythmical alternating skips	
Horizontal jump	C1	Preparatory movement includes flexion of both knees with arms extended behind body	Horizontal Jump	C1	Prior to take off both knees are flexed and arms are extended behind the back	*Change of terminology for placement of arm i.e., body and back*
	C2	Arms extend forcefully forward and upward reaching full extension above head		C2	Arms extend forcefully forward and upward reaching above the head	
	C3	Take off and land on both feet simultaneously		C3	Both feet come off the floor together and land together	
	C4	Arms are thrust downward during landing		C4	Both arms are forced downward during landing	
Slide	C1	Body turned sideways so shoulders are aligned with the line on the floor	Slide	C1	Body is turned sideways so shoulders remain aligned with the line on the floor (score on preferred side only)	*Scoring on preferred side only for TGMD-3*
	C2	A step sideways with lead foot followed by a slide of the trailing foot to a point next to the lead foot		C2	A step sideways with the lead foot followed by a slide with the trailing foot where both feet come off the surface briefly (score on preferred side only)	*Scoring on preferred side only for TGMD-3*
	C3	A minimum of four continuous step-slide cycles to the right		C3	Four continuous slides to the preferred side	

	C4	A minimum of four continuous step-slide cycles to the left		C4	Four continuous slides to the non-preferred side	*Distinguishing preferred and non preferred sides from left and right*
Leap	C1	Take off on one foot and land on the opposite foot				
	C2	A period where both feet are off the ground longer than running				
	C3	Forward reach with the arm opposite the lead foot				
		Total Number of Locomotor Skills	6		Total Number of Locomotor Skills	6
		Maximum Score	48		Maximum Score	46
		Gross Motor Quotient Max Score	96		Gross Motor Quotient Max Score	100

TGMD-2 and TGMD-3 Materials & Instruction

	SKILL (Known As)	FMS	TGMD	MATERIALS	INSTRUCTIONS
1	Underhand Throw	Object Control / Ball Skills	TGMD-3	Tennis ball 2 cones Wall (15 ft (4.6m) of space)	Attach a piece of tape 15 feet from the wall. Have the child stand behind the tape line facing the wall. Tell the child to throw the ball underhand and hit the wall. Repeat a second trial.
2	Underhand Roll		TGMD-2	Tennis ball 2 cones Wall (25 ft of clear space)	Place 2 cones against a wall so that they are 4ft apart. Measure and mark 20ft from the wall. Tell the child to underhand roll the ball to the wall between the cones. Repeat a second trial.
3	Overhand Throw		TGMD-2 TGMD-3	Tennis ball Wall (20ft of clear space)	Attach a piece of tape on the floor 20ft from a wall. Have child stand behind 20-foot line facing the wall. Tell child to throw the ball hard at the wall. Repeat a second trial.
4	Two handed strike		TGMD-2 TDMD-3	4inch lightweight ball, plastic bat, batting tee or other device to hold ball stationary	Place ball on batting tee at the child’s waist level. Tell child to hit the ball hard. Repeat second trial.
5	One handed strike		TGMD-3	Tennis ball Small plastic tennis bat Wall	Hand the plastic paddle and ball to child. Tell child to hold ball up and drop it (so it bounces at waist height); off the bounce, hit the ball toward the wall. Point toward the wall. Repeat a second trial.
6	Dribble		TGMD-2 TGMD-3	8inch/ 10inch (20.3 – 25.4 cm) playground basketball Flat hard surface	Tell the child to dribble the ball four times without moving feet, using one hand and then stop by catching the ball. Repeat a second trial.
7	Catch		TGMD-2 TGMD-3	A 4-inch (10.2-centimenter) plastic ball, 15 feet (4.6 meters) of clear space, and tape or a marker	Mark off two lines 15 feet apart. The child stands on one line and the tosser stands on the other line. Toss the ball underhand to the child aiming at the child’s chest area. Tell the child to catch the ball with two hands. Only count a trial in which toss is near child’s chest. Repeat a second trial.
8	Kick		TGMD-2 TGMD-3	8/10inch ball (20.3 – 25.4 cm) Tape or marker Wall	Mark off one line 20ft (6.1m) away from wall and second one 8ft (2.4m) beyond the first line.

				30ft of clear space	Place ball on spot. Tell child to stand on other line 8ft away. Child is to run up and kick the ball hard toward the wall. Repeat for a second trial.
9	Run	Locomotor	TGMD-2 TGMD-3	60ft (18.3m) of clear space 2 cones	Place 2 cones 50ft (15.2m) apart. Make sure there is at least 8-10 ft (2.4-3.1ft) of space beyond cone for a safe stopping distance. Enough space for child to run around the cone. Tell the child to run as fast as they can from one cone to the other when you say “Go”. Repeat for a second trial.
10	Skip		TGMD-3	A minimum of 30 feet (9.1 meters) of clear space, and two cones or markers	Place two cones 30 feet apart. Mark off two lines at least 30 feet apart with cones/markers. Tell the child to skip from one cone to the other cone. Repeat a second trial.
11	Gallop		TGMD-2 TGMD-3	25 feet (7.6 meters) of clear space, and two cones or marker	Place two cones 25 feet apart. Tell the child to gallop from one cone to the other cone and stop. Repeat a second trial.
12	Hop		TGMD-2	A minimum of 15 feet (4.6 meters) of clear space, and two cones or markers	Tell the child to hop three times on his or her preferred foot (established before testing) and then three times on the other foot. Repeat a second trial.
			TGMD-3		Place two cones 15 feet apart. Tell the child to hop four times on his/ her preferred foot (established before testing). Repeat a second trial.
13	Slide		TGMD-2 TGMD-3	A minimum of 25 feet (7.6 meters) of clear space, a straight line, and two cones or markers	Place two cones 25 feet apart on a straight line. Tell the child to slide from one cone to the other cone. Let the child decide which direction to slide in first. Ask the child to slide back to the starting point. Repeat a second trial.
14	Horizontal Jump		TGMD-2 TGMD-3	A minimum of 10 feet (3.1 meters) of clear space, and tape or marker	Mark off a starting line on the floor, mat, or carpet. Position the child behind the line. Tell the child to jump far. Repeat a second trial
15	Leap		TGMD-2	A minimum of 20 feet of clear space	Child stand 10ft away from crossing point. Child asked to run and leap over the point. Repeat for a second trial.

<u>Session Plan</u>

Project Title:	Developing objective assessment methods of fundamental movement skills through visualisation			
Testing Date:	Wednesday 1st November 2017		**Time:**	(11am) 11am – 1:30pm
Venue:	Bay Campus Sports Hall		**Researchers:**	Maeve Murray Phil Hill
Participants:	4		**Main Equipment:**	Video (Recording) x1 Actilink GTX9 Accelerometers x 7 Accelerometer straps, clips Badminton Court
Test of Gross Motor Development – 2nd Edition	*Object Control:* 1. Striking a stationary ball 2. Stationary dribble 3. Catch 4. Kick 5. Overhand Throw 6. Underhand throw	*Locomotor:* 7. Run 8. Gallop 9. Hop 10. Leap 11. Horizontal jump 12. Slide	**Fundamental Movement Skills Assessment**	
			Object Control Assessment:	**Locomotor Assessment:**
Test of Gross Motor Development - 3rd Edition	*Object Control:* 1. Underhand throw 2. Overhand throw 3. Two handed strike of stationary ball 4. One handed strike of self bounced ball 5. One handed stationary dribble 6. Two handed catch	*Locomotor:* 8. Run 9. Skip 10. Gallop 11. Hop 12. Slide 13. Horizontal jump	1. Underhand throw 2. Underhand roll 3. Overarm throw 4. Two handed strike of stationary ball 5. One hand forehand strike of self bounded ball 6. One handed stationary dribble 7. Two handed catch 8. Kick stationary ball	9. Run 10. Skip 11. Gallop 12. Hop 13. Slide 14. Horizontal jump 15. Leap

	7. Kick stationary ball		
Testing Session			
Time:	**Task**		**Notes**
11.00am	Equipment set up	Video camera Accelerometers x 7 (10) Wrist/ ankle straps x 16 Waist and Chest straps x 8 Stopclock Time clock Notepad (notes, assessment order booklet) Sports equipment*	Final run through
11:30am	Participants arrive	Consent forms collect Checks made (fit to participate, inhalers, first aid etc)	Engineering Reception meeting point Note taken of dominant/ preferred hand
11:45am (10 minutes)	Testing intentions overview and Warm up	Pulse raiser Mobility Flexibility	Fun emphasis Enjoyable
11:55am (5 minutes)	Demonstration of Skills	Each skill is demonstrated in the area that it will be performed, key points for participant performance are highlighted	15 skills run through in area of performance
12:00pm (10 minutes)	Placement of Accelerometer Straps	Participant 1, 2, 3 and 4 will have watch straps, ankle straps fitted to cover the 7 assessment points	Participants can feel comfortable wearing these for their practice before performing in both trials
12:10pm (10 minutes)	Practice 1	Participants will practise each skill one after the other in the	*Safety; positioning of next participant waiting on turn

		area that they are to be performed	
12:20pm (15 minutes)	Participant 1: Trial 1(videoed and accelerometer recording) Participant 1: Trial 2 (videoed and accelerometer recording)	Participant 1 will have accelerometers fitted at 7 points. Completes each of 15 skills twice e.g. each skill at the same spot twice. Times are recorded for start and stop of each. Participant 2, 3 and 4 are sitting on bench at safe distance	Researchers check straps are tight and tape used for sternum if required. Camera positioning check as trial 1 takes place (using notes on dominant hand placement)
12:35pm (15 minutes)	Participant 2: Trial 1(videoed and accelerometer recording) Participant 2: Trial 2 (videoed and accelerometer recording)	Participant 1 accelerometers are removed and placed directly onto Participant 2 fitted at 7 points. Completes each of 15 skills twice e.g. each skill at the same spot twice. Times are recorded for start and stop of each. Participant 1, 3 and 4 are sitting on bench at safe distance	Researchers check straps are tight and tape used for sternum if required. Camera positioning check as trial 1 takes place (using notes on dominant hand placement)
12:50pm (15 minutes)	Participant 3: Trial 1(videoed and accelerometer recording) Participant 3: Trial 2 (videoed and accelerometer recording)	Participant 2 accelerometers are removed and placed directly onto Participant 3 fitted at 7 points. Completes each of 15 skills twice e.g. each skill at the same spot	Researchers check straps are tight and tape used for sternum if required. Camera positioning check as trial 1 takes place (using notes on dominant hand placement)

		twice. Times are recorded for start and stop of each. Participant 1, 2 and 4 are sitting on bench at safe distance	
1:05pm (15 minutes)	Participant 4: Trial 1(videoed and accelerometer recording) Participant 4: Trial 2 (videoed and accelerometer recording)	Participant 3 accelerometers are removed and placed directly onto Participant 4 fitted at 7 points. Completes each of 15 skills twice e.g. each skill at the same spot twice. Times are recorded for start and stop of each. Participant 1, 2 and 3 are sitting on bench at safe distance	Researchers check straps are tight and tape used for sternum if required. Camera positioning check as trial 1 takes place (using notes on dominant hand placement)
1:20pm (10 minutes)	End of TGMD-2 & 3 Testing	Participant 4 has accelerometers and straps removed. Cool down and debrief	Equipment removed and stored safely
1:30pm	Move to Research laboratory Sport & Exercise Sciences	Height and Weight recordings are taken for Participants 1, 2, 3 and 4.	
2:15pm	Testing finished		

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)

Sport and Health Portfolio, College of Engineering ***RISK ASSESSMENT 2017/ 2018***

FMS Research:	TGMD-2 & TGMD-3 Assessment	**Project Title:**	Developing objective assessment methods of fundamental movement skills through visualisation
Approval Number:	2016-113	**Researchers:**	Phil Hill *(DBS and First Aid)* Maeve Murray (*DBS and First Aid*)
Age Group:	6 – 16 year olds (Male & Female) 4/5 participants	**Venue:**	Bay Campus: Sportshall Sports Centre & Biomechanics Lab

Identified Hazards	(2) Severity 1-5	(3) Likelihood 1-5	(4) Risk Factor (Severity x Likelihood)	(5) Further measures required (Yes/ No)	(6) Hazards scoring 12 or more	(7) Existing Precautions	(8) Additional Actions	(9) Action By When
Participant previous injury	2	3	6	No Action completed Signed consent from parent/ guardian to participate	n/a	Recruitment of participants with full fitness	n/ a	Start of November 2017 (by first testing date)
Slips, Trips Falls	3	2	6	No Warm up undertaken and safe practice completed in demonstration and trial 1 and trial 2 performance	n/a	Shoe laces tied; removal of jewellery Equipment placed in safe area	First aid available at reception	Preparation time before each research session
Late parent pick up	2	1	2	Researcher waits with participant in reception area and has emergency contact details for parents	n/a	Parents aware of pick up times and participants reminded to have contingency plan *parental consent form	n/a	Research session
Non-participant safety	2	2	4	Clear instructions beginning session regarding “taking turns”	n/a	Bench for non-participants away from performance area on court	n/a	Research session

(a) Identified health and safety issues covered by this assessment

Participants are given an order of practice and performance. As pairs, one participant performs as their partner retrieves equipment (ball) and returns to performer or places back on safety marker.

Placement of equipment with care on clear markers. Balls and bats are moved safely away from participant performance area when not in use. Non-participants are seated on bench in safe area away from performance.

Reducing risk of injury covered in a warm up.

Parents are involved in the notification of research sessions day and times. Consent forms are signed prior to participation.

(b) Persons/ Property exposed to risk

Four or five participants taking part in research session. Researchers involved in coordinating and leading the session.

(c) Those involved in the assessment/ role:

Research team carries out the risk assessment in line with discussion and coordination with managers and supervisors in the public venues. This is also shared with supervisors and A-Stem Sports Science department.

(d) Background context/ any history of health and safety incidents/ events

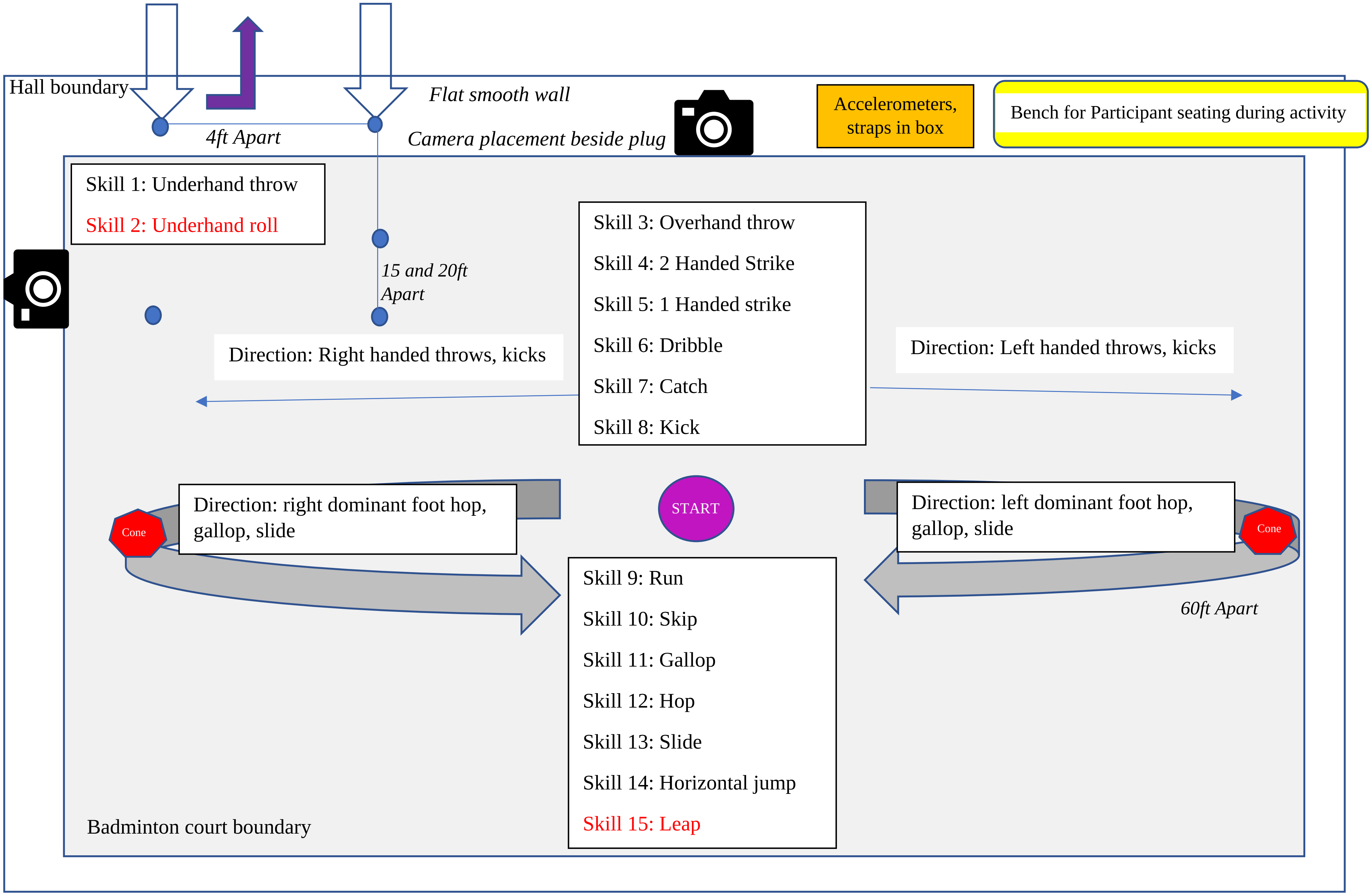
Refer to recording in Accident report held in Sports Science and Sports Centre.

Swansea University
Prifysgol Abertawe

[redacted]

[redacted] School Research Session Layout

Time		Group 1	**Time**	Group 2
9:30am		Arrival	**9:30am**	Arrival
		Welcome and brief in Psychology laboratory for Groups		
		VO2 Max Research Session 1 -6 *Research Laboratory* Pupils are partnered 1&2, 3&4, 5&6		**FMS Research Session** 7-12 *Biomechanics Laboratory*
9:45am	*Measurement 1*	Participant 1 performs VO2 Max (with participant 2 support/ shadowing Sport Science researcher)	**9:45am**	Participant 7-12
10:15am	*Measurement 2*	Participant 2 performs VO2 Max (with participant 1 support/ shadowing Sport Science researcher)	**10:30am**	Session structure: *Fun Warm up* *Skills demonstration* *Practice* *Performance* *Fun Cool down*
10:45am	*Measurement 3*	Participant 3 performs VO2 Max (with participant 4 support/ shadowing Sport Science researcher)	**11:15am**	
11:15am	*Measurement 4*	Participant 4 performs VO2 Max (with participant 3 support/ shadowing Sport Science researcher)	**12:00pm**	
11:45am	*Measurement 5*	Participant 5 performs VO2 Max (with participant 6 support/ shadowing Sport Science researcher)	**12:45pm**	
12:15pm	*Measurement 6*	Participant 6 performs VO2 Max (with participant 5 support/ shadowing Sport Science researcher)		Lunch Break 1pm Group 2 *Psychology Laboratory*
1:00pm		End of VO2 Max research Group 1	**1:00pm**	Start of VO2 Max research Group 2
		Lunch Break Group 1 (45 minutes) *Psychology Laboratory*		**VO2 Max Research Session** 7-12 *Research Laboratory* Pupils are partnered 7&8, 9&10, 11&12
1:45pm	*Measurement 7*	**FMS Research Session** 1-6 *Biomechanics Laboratory*	**1:15pm**	Participant 7 performs VO2 Max (with participant 8 support/ shadowing Sport Science researcher)
3:45pm	*Measurement 8*	Session structure: *Fun Warm up* *Skills demonstration* *Practice* *Performance* *Fun Cool down*	**1:45pm**	Participant 8 performs VO2 Max (with participant 7 support/ shadowing Sport Science researcher)
4:30pm	*Measurement 9*		**2:15pm**	Participant 9 performs VO2 Max (with participant 10 support/ shadowing Sport Science researcher)
5:45pm	*Measurement 10*		**2:45pm**	Participant 10 performs VO2 Max (with participant 9 support/ shadowing Sport Science researcher)
6:30pm	*Measurement 11*		**3:15pm**	Participant 11 performs VO2 Max (with participant 12 support/ shadowing Sport Science researcher)
3:00pm	*Measurement 12*		**3:45pm**	Participant 12 performs VO2 Max (with participant 11 support/ shadowing Sport Science researcher)
3:30pm			**4:15pm**	Finish
4:00pm		Finish		
4:30pm		Leave Campus		Leave Campus


Hall boundary
4ft Apart
Flat smooth wall
Camera placement beside plug
Accelerometers, straps in box
Bench for Participant seating during activity
Skill 1: Underhand throw
Skill 2: Underhand roll
15 and 20ft Apart
Skill 3: Overhand throw
Skill 4: 2 Handed Strike
Skill 5: 1 Handed strike
Skill 6: Dribble
Skill 7: Catch
Skill 8: Kick
Direction: Right handed throws, kicks
Direction: Left handed throws, kicks
Direction: right dominant foot hop, gallop, slide
START
Direction: left dominant foot hop, gallop, slide
Cone
Cone
60ft Apart
Skill 9: Run
Skill 10: Skip
Skill 11: Gallop
Skill 12: Hop
Skill 13: Slide
Skill 14: Horizontal jump
Skill 15: Leap
Badminton court boundary

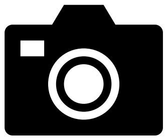
Floor Plan

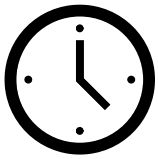
***Order of Assessment* (TGMD-3) with Video Recording & Accelerometer placement**

START

Jump to ready the muscles!

The video starts recording, stopclock is pressed by researcher and the time of day is noted. The participant jumps to initiate a spike on the accelerometers.





To Do:

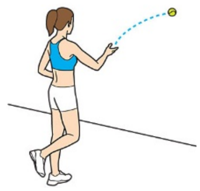
Participant Number and ID noted on camera recording

Trial 1 noted on camera, clock and timer

Trial 2 noted on camera, clock and timer

1. **Underhand throw to wall:**
   - Participant 20ft from wall
   - Camera angled at dominant hand of participant
   - Camera captures side view

Time noted at start of performance of skill and end of skill



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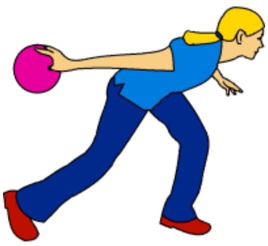
2. **Underhand roll to wall:**
   - Participant 20ft from wall
   - Camera angled at dominant hand of participant
   - Camera captures side view

Time noted at start of performance of skill and end of skill



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3. **Overhand throw (to space):**
   - Participant stands in centre of court
   - Throwing arm is closet towards camera
   - Participant throws in the direction of choice from the centre of the court at flat marker

Time noted at start of performance of skill and end of skill

4. **<u>Two handed strike of stationary ball</u>**
    - Batting tee (large cone) placed in centre of court with light 4 inch ball on top
    - Participant faces camera so striking ball can be towards either side of hall

Time noted at start of performance of skill and end of skill

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5. **<u>One-handed forehand strike of self bounced ball</u>**
    - Participant stands in middle of court at flat marker
    - Preferred hand holding racket closest to camera
    - Performance of skill facing camera/ side on to camera to give full picture

Time noted at start of performance of skill and end of skill

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6. **<u>One-handed stationary dribble</u>**
    - Participant stands centre of court
    - Facing camera to perform skill
    - 8-10inch ball

Time noted at start of performance of skill and end of skill

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7. **<u>Two-handed catch</u>**
    - Participant stands centre of court
    - Participant side on to camera
    - Ball is thrown to them by researcher

Time noted at start of performance of skill and end of skill

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8. **Kick of stationary ball**

- Participant centre of court
- 8-10inch ball on ground on flat marker
- Preferred kicking foot closest to camera
- Participant runs up to ball to kick to side of hall

Time noted at start of performance of skill and end of skill

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9. **Run**

- Participant centre of court and walks to their preferred side to start a run. Cones place 50ft apart.
- Camera captures continuous running action from one side of court to other
- Camera captures side on view
- Accelerometer picks up change of walking to running movements*

Time noted at start of performance of skill and end of skill

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10. **Skip**

- Participant centre of court and walks to their preferred side to start a skip
- Camera captures continuous skipping action from one side of court to other
- Camera captures side on view
- Accelerometer picks up change of walking to skipping movements*

Time noted at start of performance of skill and end of skill

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11. <u>Gallop</u>

- Participant starts centre of court and walks to the side of hall to start a gallop, making sure preferred leg is furthest from camera. Cones 25ft apart.
- Camera captures continuous galloping action from one side of court to other
- Camera captures side on view
- Accelerometer picks up change of walking to galloping movements*

Time noted at start of performance of skill and end of skill

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12. <u>Hop</u>

- Participant starts centre of court and walks to their preferred side to start hopping. Hop four*/three* times on preferred leg then switch to other foot*. Making sure preferred leg is furthest from camera to show technique
- Camera captures continuous hopping on the same foot from one side of court to other
- Camera captures side on view
- Accelerometer picks up change of walking to hopping movements*

Time noted at start of performance of skill and end of skill

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13. <u>Slide</u>

- Participant centre of court and walks to side of court so they start facing the camera to start slide (side step). Cones 25ft apart slide from one cone to other and then back.
- Camera captures continuous sliding action as participant faces camera to perform
- Camera captures side on view
- Accelerometer picks up change of walking to sliding movements*

Time noted at start of performance of skill and end of skill

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14. <u>Horizontal jump</u>

- Participant starts in centre of court at flat marker
- Jumps to preferred side of hall once
- Side on to camera
- *Jump marks end of accelerometer recording

Time noted at start of performance of skill and end of skill

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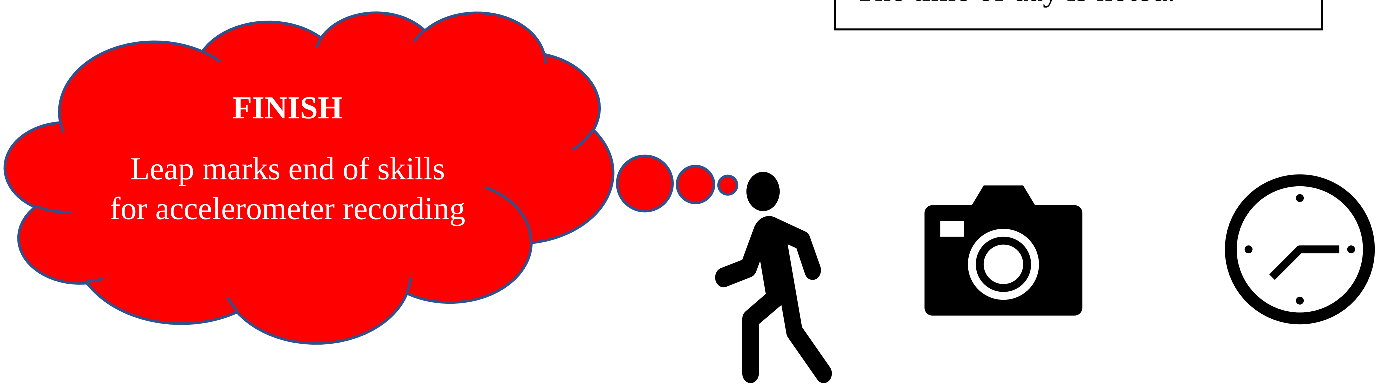
15. <u>FINISH: Leap</u>

- Participant starts centre of court at line
- Participant runs 10ft towards bean bag and jumps over and then repeats
- Side on to camera
- *Leap marks end of accelerometer recording

Time noted at start of performance of skill and end of skill

The video stops recording, stopclock is stopped by researcher and the total time of assessment of skills for that participant is noted. The time of day is noted.



Ref: *Ethical Approval 2016-113 (27th September 2017)*

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

CHILD INFORMATION SHEET
(*Version 1.0:* Date: *18/09/17***)**

Study title
Developing objective assessment methods of fundamental movement skills through visualization.

Principal investigators

Name:	[redacted]	[redacted]
Address:	[redacted]	[redacted]
Telephone:	[redacted]	[redacted]
Email:	[redacted]	[redacted]

Please read this information sheet carefully and think about whether you are happy to take part. Feel free to ask questions about any information included in this document or discussed by the researchers.

What is the study about?
We want to see how we can make the way that teachers assess how you move better through pictures.

Why have I been asked to take part?
You have been asked if you would like to take part because you are healthy and aged 6-16 years old. You should also not have any problems that change the way you move.

What will happen if I decide to take part?
If you decide to take part, we will measure how tall you are when sitting and standing and how heavy you are. We will also measure the circumference of your waist. You will be asked to also complete a handedness questionnaire so we can work out which hand you use most. During the testing, we will give you 7 monitors to wear, one on each wrist, hip and ankle and one on the chest which you will wear whilst you complete 13 fundamental movement skills. We will show you what you need to do before each skill and you will then try each one three times while we video record you doing it.

The skills we will ask you to perform will be a run, gallop, skip, hop, horizontal jump, slide, two-handed strike of a stationary ball, one hand forehand strike of self-bounced ball, one hand stationary dribble, two hand catch, kick a stationary ball, overhand throw and underhand throw. You will have an opportunity to practice the skill after it has been demonstrated by the researcher.

Lastly, we would like to measure your physical activity levels. To help in this, you will be asked to wear a physical activity monitor for 7 days. You will also be asked to keep an activity log to record when they remove the monitor. Handing out and collecting the accelerometers will take approximately 1 hour.

What are the possible risks and discomforts**?**

Don't worry there aren't any significant risk or discomforts within the study. When you follow our instructions and complete the proper warm up then there is even less risk of any injury. The activities you will do are just like the skills you would perform in a PE class at school.

Will I benefit from taking part in this study?

You will get to find out how we can measure how you move and how this can be turned into pictures!

Do I have to take part in this study?

It is totally up to you if you want to take part in this study and you can stop at any time. Please feel free to ask any questions before agreeing to take part and at any time during the study.

Can my participation in the study end early?

If you decide to take part in the study that is great and even if you sign up you can withdraw whenever you like!

Will my participation in the study be kept confidential?

Yes! No one will know who you are in the study as we don't use your name. The researchers will allocate an ID code to your name that will link with the data we collect so that your name is never used. We will not share any personal information about you with anyone.

What if I have questions?

If you have questions about the study, either now or in the future, you can contact the study's principal investigator [redacted] Should you have any concerns regarding an ethical aspect of this study please contact [redacted]

Thank you for your time and we look forward to your response.
We hope you will want to participate!

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

PARTICIPANT ASSENT FORM

(*Version 1.0:* Date: 18/09/2017**)**

Project Title:

Developing objective assessment methods of fundamental movement skills through visualisation.

Contact Details:

Name: [redacted] [redacted]

Address: [redacted] [redacted]

Telephone [redacted] [redacted]

Email: [redacted] [redacted]

		Please initial box
1	I confirm that I have read and understood the information sheet for this study and have had the opportunity to ask questions.	
2	I know that it is my choice to take part and that I can stop doing so at any time, without giving any reason, and without any problems.	
3	I am happy to have my picture taken and be video recorded.	
4	I understand that sections of the data collected will be looked at by responsible individuals at Swansea University or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records and understand that analysis will be done on anonymous data where my name is unknown.	
5	I understand that the findings of this study may be published and that all data is anonymous.	
6	I agree to take part in the above study.	

Name of Participant   Date   Signature

Name of Person taking consent   Date   Signature

Researcher   Date   Signature

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

PARENT/ GUARDIAN INFORMATION SHEET
(*Version 1.0:* Date: 18/09/2017**)**

Project Title:

Developing objective assessment methods of fundamental movement skills through visualisation.

Principle Investigators:

Name:	[redacted]	[redacted]
Address:	[redacted]	[redacted]
Telephone	[redacted]	[redacted]
Email:	[redacted]	[redacted]

Thank you for being interested in our project. Please read this information sheet <u>carefully</u> and think about whether you are happy for your child to take part. It is important to say at this point that the decision to take part is entirely up to you and that your child will not be at a disadvantage for future studies should you decide for them not to participate.

What is the purpose of the study?
The purpose of the study is to investigate the assessment of fundamental movement skills proficiency in children using objective measures. Secondly, to ascertain whether the skill proficiency of the children changes as they grow and their physical activity habits change.

Why has your child been chosen?
Your child has been asked if they would like to take part because they are 6-16 years old and free of any physical or neurological conditions that affect the way they move. However, this does not mean your child has to take part in the study. This is voluntary and you have the right to withdraw them from the study at any time.

What will happen to your child if they take part?
If you decide for your child to take part, we will measure their sitting and standing height, weight and waist circumference, before asking them to complete a handedness questionnaire for us to work out their dominant hand. Following this, we will give your child 7 monitors to wear, one on each wrist, hip and ankle and one on the chest. They will wear the monitors whilst they complete 13 fundamental movement skills. Before performing the skills, a demonstration will be given to your child by the researcher. After this, your child will be asked to perform each skill three times while they are observed by the researchers and video recorded.

The skills we will ask your child to complete are: run, gallop, skip, hop, horizontal jump, slide, two-handed strike of a stationary ball, one hand forehand strike of self-bounced ball, one hand stationary dribble, two hand catch, kick a stationary ball, overhand throw and underhand throw.

Following on from their participation in the movement assessment, children will be asked to wear a physical activity monitor for 7 consecutive days. They will also be asked to keep an activity log to record when they remove the accelerometer. Handing out and collecting the accelerometers will take approximately 1 hour.

What are the possible disadvantages of taking part?
There aren't any significant risks or discomforts associated with the study. If your child follows our instructions which will ensure that they are appropriately warmed up for the activity, then the risks will be minimised. There is a reduced risk of injury from the activity (as in any Physical Education class) and there will be trained first aiders on hand to deal with any injuries should they occur.

What are the possible benefits of taking part?
Your child might find it interesting to see how we assess movement proficiency and how this leads to unique visualization tools!

Do they have to take part in this study?
Their participation in this study is completely voluntary and you are free to withdraw them at any time, for any reason, without penalty or prejudice from the investigator and/or research assistants. They will not be treated differently if at any time you wish to withdraw them from the study. Please feel free to ask any questions of the investigator and/or research assistants before signing this form and at any time during the study.

Can their involvement in the study end early?
If you provide permission for your child take part in the study, you still have the right to decide at any time that you no longer wish them to continue to take part.

Who will see the information that is collected?
All information gathered will be stored on password protected hard drives using unique participant ID codes. The original copy aligning your child's participant ID code and identifying information will be stored in a locked office at Swansea University. Their information will be combined with information from other children taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. Individuals will not be identified in these written materials. We may publish the results of this study; however, we will keep all names and other identifying information private.

What if I have questions?
This study has been approved by Council of Engineering Research Ethics Committee and if you have specific concerns or if you have questions about the study, you can contact the study's principal investigator, [redacted] Should you have any concerns regarding an ethical aspect of this study please contact [redacted]

Thank you for your time and we look forward to your response

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)
Sport and Health Portfolio, College of Engineering

PARENT/GUARDIAN CONSENT FORM
(*Version 1.0:* Date: *18/09/17***)**

Project Title:
Developing objective assessment methods of fundamental movement skills through visualisation.

Contact Details:

Name:	[redacted]	[redacted]
Address:	[redacted]	[redacted]
Telephone	[redacted]	[redacted]
Email:	[redacted]	[redacted]

	Name of Child (participant): ________________________________	**Please initial box**
1	I confirm that I have read and understood the information sheet dated 18/09/17 (Version: 1.0) for the above study and have had an opportunity to ask questions.	
2	I understand that my child's participation is voluntary and that they are free to withdraw at any time, without giving any reason and without their medical care, school work or legal rights being affected.	
3	I agree for my child to have their photo taken and to be video recorded.	
4	I understand that sections of the data collected will be looked at by responsible individuals at Swansea University or from regulatory authorities where it is relevant to my child's participation in the research project. Analysis will be done on anonymous data. I give permission for these individuals to have access to these records.	
5	I understand that the findings of this study may be published and that all data is anonymous.	
6	I agree for my child take part in the above study.	

Name of Parent/Guardian	Date	Signature
Name of Person taking consent	Date	Signature
Researcher	Date	Signature

Ref: *Ethical Approval PG2018-065 (5th July 2018)*

Applied Sports Technology Exercise and Medicine Research Centre (A-STEM)

Sport and Health Portfolio, College of Engineering

PARENT/ GUARDIAN INFORMATION SHEET

(*Version 1.0:* Date: 18/09/2017**)**

Project Title:

Developing objective assessment methods of fundamental movement skills through visualisation.

Principle Investigators:

Name:	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
	[redacted]	[redacted]
	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]
[redacted]	[redacted]	[redacted]

Thank you for being interested in our project. Please read this information sheet carefully and think about whether you are happy for your child to take part. It is important to say at this point that the decision to take part is entirely up to you and that your child will not be at a disadvantage for future studies should you decide for them not to participate.

What is the purpose of the study?

The purpose of the study is to investigate the assessment of fundamental movement skills proficiency in children using objective measures. Secondly, to ascertain whether the skill proficiency of the children changes as they grow, and their physical activity habits and parameters of health status change.

Why has your child been chosen?

Your child has been asked if they would like to take part because they are 6-16 years old and free of any physical or neurological conditions that affect the way they move. However, this does not mean your child has to take part in the study. This is voluntary and you have the right to withdraw them from the study at any time.

What will happen to your child if they take part?

If you decide for your child to take part they will be asked to complete the fundamental movement skill assessment, together with the physical activity monitoring at 5 points across the study. We will measure their sitting and standing height, weight and waist circumference, before asking them to complete a handedness questionnaire for us to work out their dominant hand. Following this, we will give your child 7 monitors to wear, one on each wrist, hip and ankle and one on the chest. They will wear the monitors whilst they complete 13 fundamental movement skills. Before performing the skills, a demonstration will be given to your child by the researcher. After this, your child will be asked to perform each skill three times while they are observed by the researchers and video recorded.

The skills we will ask your child to complete are: run, gallop, skip, hop, horizontal jump, slide, two-handed strike of a stationary ball, one hand forehand strike of self-bounced ball, one hand stationary dribble, two hand catch, kick a stationary ball, overhand throw and underhand throw.

At two points during the research study your child will then be asked to do an incremental cycling test which starts very easy and gets harder, like pedaling up a hill. The test is stopped when they can't keep going. The test lasts approximately 10 minutes. Whilst the final stages of this test are uncomfortable, the discomfort is very short and they will recover within minutes of completing the test. The exercise is no harder that they will do in training!

During these tests they will be asked to:

- Wear a face mask so we can measure the air that they breathe in and out. This mask does not make breathing any harder and they can talk through it and remove it at any time if they feel uncomfortable about wearing it.
- Have 3 small electrodes placed on the upper body so we can see how the heart works during exercise. These electrodes are just like sticky plasters.
- Have a small device stuck to their leg to measure how oxygen is used in the muscles.
- Allow a fingertip blood sample (only a few drops of blood) to be taken after the test is finished so we can measure how hard they worked. They can choose not to do this part too.
- Have their photo taken for their personal certificates!

Finally, after 15 minutes rest, we will ask them to do another short test to check the results of the first test. This will mean cycling for 3 minutes at a really easy resistance which will then increase to just above the highest work rate they got to in the test before. We will then ask them to keep cycling for as long as they can! After this, they will have a little cool down before we give them a monitor to wear at home. The monitor, shown on the right, will be worn for 7 days continuously, except when they bath, shower or go for a swim.

You are welcome to come to the University with your child but there will always be two DBS checked adults with them at all times if you cannot attend.

Following on from their participation in the movement assessment, children will be asked to wear a physical activity monitor for 7 consecutive days. They will also be asked to keep an activity log to record when they remove the accelerometer. Handing out and collecting the accelerometers will take approximately 1 hour.

What are the possible disadvantages of taking part?

There aren't any significant risks or discomforts associated with the study. If your child follows our instructions which will ensure that they are appropriately warmed up for the activity, then the risks will be minimised. The cycle will be hard work but they will recover quickly, and there is a reduced risk of injury from the activity (as in any Physical Education class), trained first aiders on hand to deal with any injuries should they occur.

What are the possible benefits of taking part?

Your child might find it interesting to see how we assess movement proficiency and how this leads to unique visualization tools!

Do they have to take part in this study?

Their participation in this study is completely voluntary and you are free to withdraw them at any time, for any reason, without penalty or prejudice from the investigator and/or research assistants. They will not be treated differently if at any time you wish to withdraw them from the study. Please feel free to ask any questions of the investigator and/or research assistants before signing this form and at any time during the study.

Can their involvement in the study end early?

If you provide permission for your child take part in the study, you still have the right to decide at any time that you no longer wish them to continue to take part.

Who will see the information that is collected?

All information gathered will be stored on password protected hard drives using unique participant ID codes. The original copy aligning your child's participant ID code and identifying information will be stored in a locked office at Swansea University. Their information will be combined with information from other children taking part in the study. When we write about the study to share it with other researchers, we will write about the combined information we have gathered. Individuals will not be identified in these written materials. We may publish the results of this study; however, we will keep all names and other identifying information private.

What if I have questions?

This study has been approved by Council of Engineering Research Ethics Committee and if you have specific concerns or if you have questions about the study, you can contact the study's principal investigator, [redacted]

Thank you for your time and we look forward to your response!

Swansea University
Prifysgol Abertawe

ADOLESCENT ASSENT FORM
(Version 1.1, Date: 01/06/2018)

Project Title:
Swansea University Research Engagement Week

Contact Details:
[redacted]

Please initial box

1. I confirm that I have read and understood the information sheet dated 01/06/2018 (version number 1.1) for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that sections of any of data obtained may be looked at by responsible individuals from the Swansea University or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to these records. ☐

4. I give permission for my academic records to be accessed by the primary researcher, for my latest academic achievement to be accessed. This will not affect your education or your ability to take part within this study. ☐

5. I understand that data I provide may be used in reports and academic publications in anonymous fashion ☐

6. I am happy to take part in the physical activity monitoring part of this study and wear an accelerometer for 7 days. I also understand that it is my responsibility to bring this back into school before the end of the current term ☐

7. I agree to being video recorded whilst I perform the movement skills ☐

8. I understand that the heart and lung function stations are for research only and cannot tell me if I have an illness or not ☐

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

______________________________	_________________	__________________________
Name of Participant	Date	Signature
______________________________	_________________	__________________________
Researcher	Date	Signature

Swansea University
Prifysgol Abertawe

PARENT/GUARDIAN CONSENT FORM
(Version 1.1, Date: 01/06/2018)

Project Title:
Swansea University Research Engagement Week

Contact Details:
[redacted]

[redacted]

Please initial box

1. I confirm that I have read and understood the information sheet dated 01/06/2018 (version number 1.1) for the above study and have had the opportunity to ask questions. ☐
2. I understand that my child's participation is voluntary and that they are free to withdraw at any time, without giving any reason, without their medical care or legal rights being affected. ☐
3. I understand that sections of any of data obtained may be looked at by responsible individuals from the Swansea University or from regulatory authorities where it is relevant to my child taking part in research. I give permission for these individuals to have access to these records. ☐ ☐
4. I understand that data collected on my child may be used in reports and academic publications in anonymous fashion
5. I understand that the research techniques used in this study are for research purposes only and not for diagnosis of any condition ☐
6. I give permission for my child to be video recorded during the fundamental movement skills station for research analysis purposes only ☐
7. I agree for my child's physical activity levels to be monitored by an activity monitor for 7 days. If I agree to this, I also understand that it is my child's and my responsibility to ensure the return of the monitor by the end of the current half term. ☐
8. I agree to my child taking part in the above study. ☐

______________________________	________________	__________________________
Name of Parent	Date	Signature
______________________________	________________	__________________________
Name of child giving consent for	Date	Signature
______________________________	________________	__________________________
Researcher	Date	Signature

Swansea University
Prifysgol Abertawe

College of Engineering
Research Ethics and Governance Committee

CHILD ASSENT FORM
(Version 1.1, Date: 01/06/2018)

Project Title:
Swansea University Research Engagement Week

Contact Details:
[redacted]

Please initial box

1. I confirm that I was at the assent assembly / have read and understood the participant information sheet given to me (dated: 01/06/2018, version number 1.1) for this study and have had the opportunity to ask any questions

2. I understand that taking part is my choice and that I can choose to stop taking part at any time, without giving a reason, and it won't affect my participation in other research studies in the future.

3. I understand that information collected about me by the researchers will only be looked at by people who can do so. I am happy for them to have access to it

4. I am happy for my latest grades to be looked at by the researchers and I understand that it will not affect my education or effect my participation within this study

5. I understand that the information collected by the researchers may be used in their work and published, but the information will be anonymous. This means that the information will not have my name on it or any information that links it to me.

6. I am happy to take part in the physical activity monitoring part of this study and wear an accelerometer for 7 days. I also understand that it is my responsibility to bring this back into school before the end of the current term.

7. I agree to being video recorded whilst I perform the movement skills.

8. I understand that the heart and lung function stations are for research only and cannot tell me if I have an illness or not

9. I agree to take part in the above study.

Name of Participant	Date	Signature
Researcher	Date	Signature