PHD

The Influence of Growth, Maturation and Relative Age on the Physical Fitness of Adolescent Schoolchildren

Yorston, Corinne

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THE INFLUENCE OF GROWTH, MATURATION AND RELATIVE AGE ON THE PHYSICAL FITNESS OF ADOLESCENT SCHOOLCHILDREN

VOLUME 1 OF 1

CORINNE LOUISE YORSTON

A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department of Health

OCTOBER 2021

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I am the author of this thesis, and the work described therein was carried out by myself personally, with the exception of the creation of developmental trajectories in Chapters Seven and Eight, which was conducted with the assistance of consultants from the Bath Institute for Mathematical Innovation.

Candidatures Signature…. [redacted]

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GLOSSARY OF TERMS

Abbreviation	Meaning
ACL	Anterior Cruciate Ligament
ALPHA-FIT	Assessing Levels of Physical Activity and Fitness
ANOVA	Univariate Analyses of Variance
AVENA	Alimentación y Valoración del Estado Nutricional en
BA	Biological Age
BANES	Bath and North East Somerset
BASES	British Association of Sport and Exercise Sciences
BMI	Body Mass Index
CA	Chronological Age
CMJ	Counter Movement Jump
COM	Centre of Mass
CV	Coefficient of Variation
e.g.,	For Example
EPPP	Elite Player Performance Plan
FA	Football Association
FMS	Fundamental Movement Skills
GCT	Ground Contact Time
GH	Growth Hormone
GTO	Gotov k Trudu i Oborone – Ready for Labor and Defense of the USSR
HELENA	Healthy Lifestyle in Europe by Nutrition in Adolescence
HPG	Hypothalamic-pituitary-gonadal axis
ICC	Intraclass Correlation
IGF	Insulin-Like Growth Factor
MVPA	Moderate-to-Vigorous Physical Activity
NGB	National Governing Body
PA	Physical Activity
PAS	Predicted Adult Stature
P. E	Physical Education
PHV	Peak Height Velocity
PWV	Peak Weight Velocity
RA	Relative Age

RAE	Relative Age Effect
RFD	Rate of Force Development
RSA	Relative Skeletal Age
SA	Skeletal Age
SES	Socio-Economic Status
SSC	Stretch-Shortening Cycle
SSCO	School Sports Coordinator
SPSS	Statistical Package for the Social Sciences
SEBT	Star Excursion Balance Test
SPSS	Statistical Package for the Social Sciences
TS	Tanner Stage
TV	Television
TW1	Tanner-Whitehouse Method 1
TW2	Tanner-Whitehouse Method 2
TW3	Tanner-Whitehouse Method 3
UK	United Kingdom
US	United States
USA	United States of America
WHO	World Health Organisation
YBT	Y-Balance Test

SYMBOLS AND SUBUNITS

Abbreviation	Meaning
cm	Centre metres
β	Beta Coefficient
©	Copyright
°	Degrees
df	Degrees of Freedom
η	Eta-Squared
F	F-Ratio (used in ANOVA)
>	Greater Than
≤	Greater Than or Equal To
Kg	Kilogram
<	Less Than
≥	Less Than or Equal To
M	Metre
M	Mean
R^2	Multiple Correlation
N	Number
%	Percentage
r	Pearson’s Correlation
p	p-value
±	Plus and Minus
S	Seconds
SD	Standard Deviation
SE	Standard Error
z	Z-score

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Yorston, C. L., Cumming, S. P., (2017). The Impact of Relative Age and Maturity Upon Fitness in Adolescent Males. Proceeding of the UKSCA 13th Annual Conference, Hinckley Island hotel, Leicestershire, August 2017.

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ABSTRACT

For those people working with youth populations, such as schoolteachers and coaches, who aim to develop and evaluate the physical fitness and activity levels of young people, there are challenges that arise during the dynamic adolescent period. Many of these challenges stem from individual differences in growth and maturation. The purpose of this thesis was to describe age-related changes in physical fitness in male and female youth, determine the contribution of relative age and maturation to fitness performance, create a developmentally adjusted strategy for more accurately evaluating fitness in youth populations and explore the use of a bio-banding strategy as a tool for developing youth fitness. Specifically, this thesis investigated the performance of adolescent schoolchildren in a variety of fitness tests that are routinely applied in athletic, elite populations. Chapters Four (males) and Five (females) evaluated the main and interactive effects of relative age and biological maturation upon fitness test performance in the schoolchildren. In both males and females, relative age and biological maturation were found to act independently from one and another on fitness performance. No interactive effects of relative age and maturation upon fitness were observed, with exception of upper body strength in males. Chapters Five and Six (males and females, respectively) used the physical fitness data to generate trajectories of age standards and investigated the extent to which biological maturity status impacted fitness relative to these trajectories. For both the male and female cohorts, evaluations of fitness performance varied relative to biological and chronological age. Chapter Seven examined the degree to which bio-banding restricted variance in body size and fitness performance in the schoolchildren. Bio-banding had a greater impact on the variation in fitness performance in the females than it did in the males. These findings highlight the importance to consider individual differences when evaluating the physical fitness performance of adolescents.

CHAPTER ONE

INTRODUCTION

1.1. RESEARCH CONTEXT AND RATIONALE

The development and understanding of the physical fitness of children and adolescents is ever increasingly prioritised within the context of health and sports performance due to reasons such as increasing obesity levels (Bürgi et al., 2011), rises in mental health and type II diabetes (Kohl et al., 2012), the decline in physical activity participation that occurs during adolescence (Allison et al., 2007) and increased investment in youth sport (Till et al., 2018). Increasingly, youth are displaying substandard levels of motor skill competency, physical fitness and muscular strength (Van Beurden et al., 2002; Tomkinson et al., 2003; Moliner-Urdiales et al., 2010; Runhaar et al., 2010; Cohen, D. et al., 2011). Physical fitness during adolescence is a strong predictor of health and fitness as an adult (Ruiz et al., 2009) and improving the physical fitness and physical activity levels of young people, two independent but related constructs (Malina, Bouchard and Bar-Or, 2004), can improve both the physical and mental health of the nation (Ortega et al., 2008). There are many barriers to adolescents engaging in sport and activity, including a lack of self-esteem, physical self-concept and body confidence (Cumming et al., 2012), as well as the desire for acceptance amongst peers (Patton et al., 2016), social distractions (Alderman and Breuner, 2019) and poor motor competency (Wang and Biddle, 2007). For those people that work with youth populations, increasing the understanding of adolescent fitness and the factors that influence it, and developing strategies to improve and monitor fitness in a more individualised manner, may overcome some of these barriers and improve adolescent engagement and enjoyment in physical activity and, as a result, improve adolescent health and fitness.

For those coaches and practitioners working with young athletes in sport, the assessment and monitoring of physical fitness is particularly important in talent identification, the processes of athlete selection and retention and the evaluation of physical development and/or conditioning programmes. An increased understanding of the factors that show the closest relationship to future success also contribute to an emphasis on the physical development of athletes to optimise progression through the sporting pathway (Till et al., 2018). Physical attributes such as speed, strength, agility and power contribute to success in many sports (Gravina et al., 2008; Till et al., 2010; Jalilvand et al., 2019) and are central components of long-term athletic development programmes (Lloyd and Oliver, 2012) and talent identification processes (Till and Baker, 2020).

A challenge for those developing, training, selecting and testing young people is that youth of the same chronological age (CA) can vary significantly in terms of both biological maturation and relative age (RA). Most sports, both elite and in school, select, train and compete in chronologically age-banded groups (Lloyd et al., 2014), however a large interindividual variation in biological maturation and RA can exist within these groups. Biological maturation is defined as the progress towards an adult state, and its timing and tempo will differ for each individual (Malina, Bouchard and Bar-Or, 2004). RA describes an individual's CA within their selective age group and, in contrast to biological maturation which is largely determined by genetics, RA is determined by birth date and selection cut-off date (Hill et al., 2019). Within a single year cohort, as often used in schools and sports, RA can vary by a maximum of 12 months between individuals, however maturational differences can be as large as six years between early and late maturing individuals (Johnson, 2015; Cumming et al., 2017). Variation in biological maturity is both age- and sex-associated and typically, females experience puberty one to two years earlier than males (Fechner, 2002).

This individual variation in biological maturity influences size, physique and functional capacities (Malina, Bouchard and Bar-Or, 2004). Early maturing boys and girls are, on average, taller and heavier than those that are on-time or delayed in their maturation (Malina, Bouchard and Bar-Or, 2004). Early maturing boys also outperform later maturing boys in tests of strength, power, and speed (Goto, Morris and Nevill, 2019). Whereas these maturational differences are not as obvious in females, early maturing females outperform later maturing peers in tests of strength (Myburgh et al., 2016). These functional, physical and anthropometrical differences can manifest themselves into more dominating displays in the sport itself (Cumming et al., 2017) and also result in maturity-associated selection/exclusion gradients in both male (Malina, 2002) and female sports (Erlandson et al., 2008; Myburgh et al., 2016). These differences are most evident during puberty (Malina, Bouchard and Bar-Or, 2004) and selection biases are more evident in sports where speed, strength and power have a large impact on performance (Whiteley, Johnson and Farooq, 2017).

The phenomenon known as the relative age effect (RAE) describes a selection bias towards athletes born earlier within the age group and has been documented in a number of sports (Musch and Grondin, 2001). The existence of a RAE in many sports is often attributed to the direct and indirect effects of advanced maturation (Baker, Schorer and Cobley, 2010). That is, relatively older individuals are assumed to be biologically more mature, displaying greater athletic capabilities and a more optimal physique for sports performance compared to their relatively younger counterparts (Wattie, Cobley and Baker, 2008). However, biological maturation and RA are two separate and independently acting constructs (Cumming et al., 2017). The main and interactive effects of biological maturation and RA on the physical fitness of adolescents are not fully understood. As a result, most athletic development programmes and physical education (P.E.) and fitness sessions do not account for the potential contributions of maturation, RA and/or the potential interactions between these constructs. Additionally, youth testing and selection decisions into sport do not account for these interactions and individual differences. For example, a child who is the oldest within their age group but also delayed in maturation may not hold an athletic advantage over a younger yet physically more mature peer (Cumming et al., 2017).

It is common when testing the fitness of young people, both elite athletes and the general population, to compare an individual's fitness scores against peers within the same sex and CA group, or against age-specific standards (Lloyd et al., 2014). Regular fitness testing takes place across elite sport and so much of the understanding of performance in athletic tests of fitness comes from elite youth populations. Elite sport, however, consists of pre-selected, homogenous athletes who have all been chosen for their excellent skills and fitness (Pearson, Naughton and Torode, 2006). Therefore, whilst it is useful to compare fitness amongst those individuals in direct competition with one and another, to better understand an individual's true physical capabilities, comparison against a normal population is needed. In addition, variation in both the timing of maturity and maturation status can mask or enhance functional capacities in young people (Lloyd and Oliver, 2012). This can make it difficult to assess an individual's true current physical ability and their future athletic potential (Cumming et al., 2018). Without consideration for biological maturation, it would not be clear whether performance advantages exist due to individual differences in maturity or in fact due to a superior physical profile (Malina et al., 2015). Many of the testing batteries carried out in normal youth cohorts focus on health-related qualities (Twisk, Kemper and Van Mechelen, 2002; Carrel et al., 2012; Keating et al., 2018). The HELENA (Francisco B Ortega et al., 2011), EUROFIT (Dobosz, Mayorga-Vega, & Viciana, 2015), IDEFICS (De Miguel-Etayo et al., 2014) and FITNESSGRAM (Morrow Jr, Going, & Welk, 2011) programmes have recently developed normative standards for adolescent health-related and athletic fitness. These programmes do not, however, consider the effects of relative age and/or biological maturation on physical fitness performance.

To address some of the issues described above, researchers have proposed the creation and utilisation of developmentally sensitive fitness standards that account for individual differences in biological maturation (Golle et al., 2015; Cumming et al., 2017; Till et al., 2018). The Premier League generated age- and maturation-specific standards as part of the Elite Player Performance Plan to create more accurate measurements of young, academy soccer players' fitness (https://www.goalreports.com/EPLPlan.pdf). Across research, only a small number of studies have created developmentally aligned performance curves to better assess athletic fitness in youth (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Votteler and Höner, 2014; Myburgh et al., 2020). The available evidence indicates that such strategies have inherent value, however, their application and relevance may be limited to the specific samples of interest and may not generalise to other sports or the general population.

Another strategy recently explored both in the research and practically in sport to address some of the aforementioned challenges pertaining to maturity-associated variations in body size and functional capacity is bio-banding. Bio-banding is the process of grouping individuals based upon maturity status and/or body size rather than CA and aims to restrict variance in maturation and as a result reduce the variance in size and/or athleticism (Cumming, Lloyd et al., 2017). Currently, research into, and application of, bio-banding strategies is limited to elite sport (Bengsch, 2016; Cumming, Brown et al., 2017; Abbott et la., 2019; Bradley et al., 2019; Bunce, 2019). No studies to date have examined the application of bio-banding in non-elite populations. Additionally, the majority of this work has explored the impact of bio-banding in a subjective manner, gaining feedback from athletes and coaches on the technical, tactical, physical and psycho-social benefits of bio-banding (Cumming, Brown et al., 2017; Bunce, 2019). Limited research exists examining the impact of bio-banding on physical performance in athletic tests of fitness (Johnson et al., 2019; Towlson et al., 2021).

In light of the preceding discussion, this thesis attempts to provide contemporary knowledge on the performance of normal adolescents in tests of athletic fitness that are important for the development of athletic competency. It provides novel evaluations of the main and interactive effects of relative age and biological maturation on adolescent fitness. In addition, it attempts to create developmentally adjusted methods to assess, evaluate and improve youth physical fitness. It is the hope that the studies in this thesis provide teachers and practitioners improved strategies and further understanding to help increase youth engagement and enjoyment in fitness, enhance the physical development of individuals and improve the evaluations of youth fitness. Additionally, sports coaches can employ the strategies in this thesis to develop superior talent identification systems and provide a more athlete-centered approach to athlete development.

1.2. RESEARCH AIMS AND HYPOTHESIS

The primary aim of this thesis is to better understand the contributions of maturation and relative age to fitness in the general paediatric population and create developmentally aligned strategies to better assess, monitor and develop youth fitness. Ultimately it is hoped this thesis will help practitioners to evaluate and interpret individual athlete data to enhance practise. Due to the differential impact of maturation and relative age upon fitness and performance in males and females, all male and female data will be assessed independently. Chapter Eight discusses bio-banding in both males and females; however the data was analysed independently for each sex.

The research questions of this thesis are:

Chapter Four

The age associated variance and main and interactive effects of relative age and maturation upon the performance of male adolescents in tests of athletic fitness.

Aims:

1) To investigate age associated differences in the performances of male adolescent schoolchildren aged 11 to 15 years on a series of athletic fitness tests.
2) Examine the main and interactive effects of relative age and biological maturation on the performance in athletic tests of fitness of male adolescent schoolchildren, aged 11 to 15 years.

Hypothesis:

1) Performance scores on all tests of fitness will increase across chronological age groups in this male cohort.
2) Older relative age and advanced maturation would be associated with superior performance on all tests of fitness.
3) The interaction between relative age and biological maturation will further enhance the prediction of variance in fitness test performance.

Chapter Five

The age associated variance and main and interactive effects of relative age and maturation upon the performance of female adolescents in tests of athletic fitness.

Aims:

1) To investigate age associated differences in the performances of female adolescent schoolchildren aged 11 to 15 years on a series of athletic fitness tests.
2) Examine the main and interactive effects of relative age and biological maturation on the performance in athletic tests of fitness of female adolescent schoolchildren, aged 11 to 15 years.

Hypothesis:

1) Performance scores on all tests of fitness will increase with chronological age in this female cohort, although there is a likelihood of a plateau in performance at the older age groups.
2) Older relative age and advanced maturation would be associated with superior performance on all tests of fitness.
3) The interaction between relative age and biological maturation will further enhance the prediction of variance in fitness test performance.

Chapter Six

The establishment of age-based fitness performance trajectories to evaluate the impact of biological maturation relative to chronological age in male adolescent schoolchildren.

Aims:

1) Create age-based trajectories for the physical fitness performance of adolescent boys aged 11 to 15 years in tests of athletic fitness of upper body strength, momentum, and balance.
2) Examine maturity associated differences in the discrepancies between assessments of physical fitness judged relative to chronological age and maturity specific standards.

Hypothesis:

1) Early maturing boys will perform worse in each fitness test when evaluated relative to biological maturity status compared to chronological age.
2) Later maturing boys will display superior percentile scores for each test when expressed relative to biological maturity status compared to chronological age.

Chapter Seven

The establishment of age-based fitness performance trajectories to evaluate the impact of biological maturation relative to chronological age in female adolescent schoolchildren.

Aims:

1) Create age-based trajectories for the physical fitness performance of adolescent girls aged 11 to 15 years in tests of athletic fitness of upper body strength, momentum and 30m maximal speed.
2) Examine maturity associated differences in the discrepancies between assessments of physical fitness judged relative to chronological age and maturity specific standards.

Hypothesis:

1) Early maturing girls will perform worse in each fitness test when evaluated relative to biological maturity status compared to chronological age.
2) Later maturing girls will display superior percentile scores for each test when expressed relative to biological maturity status compared to chronological age.

Chapter Eight

The impact of bio-banding on the variance in maturation, body size and fitness performance of male and female schoolchildren.

Aims:

1) To evaluate whether bio-banding through grouping individuals by maturity status, in comparison to existing school-year groupings, would restrict the variance in maturation, body size and fitness performance of the male and female schoolchildren.

Hypothesis:

1) The variance in maturation, size and physical fitness of male school children will be significantly lower when they are grouped relative to their biological maturity status and not their chronological age.
2) The variance in maturation, size and physical fitness of female school children will be significantly lower when they are grouped relative to their biological maturity status and not their chronological age

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

Physical fitness in youth is influenced by several factors, including growth of body size and composition, and biological maturity. This chapter introduces the concepts of growth and maturation, two biological processes that take place in every individual, from conception to adulthood. The factors that regulate growth and maturation, as well as the various methods of assessing these processes in adolescent populations, are discussed. In addition to biological maturation, relative age has been proposed as a potential contributor towards physical fitness in youth. Few studies have, however, considered the simultaneous effects of maturation and relative age upon physical fitness in the general population. Accordingly, the impact of both biological maturation and relative age on physical fitness, performance and sports selection will be considered in this chapter. The available research on the physical fitness testing of both general and elite paediatric populations, including the various methods to assess physical performance, will also be examined. Finally, the changes in physical capacity that occur during adolescence will be reviewed, specifically focusing on key physical attributes that are deemed important in sports and athletic performance.

2.2 GROWTH, MATURATION AND DEVELOPMENT DEFINED

The terms, growth, maturation and development are often used interchangeably when discussing children and adolescents. In particular, growth and maturation are commonly referenced together. They do, however, refer to different, specific biological processes (Malina, Bouchard and Bar-Or, 2004). Development refers to a broader concept and describes the qualitative changes in function that result from the interactions an individual has with their environment (Baxter-Jones, Eisenmann and Sherar, 2005). These concepts will be discussed in the following section.

2.2.1 Growth

Growth refers to a change in physique, body composition and size, either of the whole organism or a specific body part (Baxter-Jones, Eisenmann and Sherar, 2005). Three cellular process cause changes in size, namely, hyperplasia, hypertrophy, and accretion. Hyperplasia is an increase in cell number and is a result of mitosis. Hypertrophy is the increase in cell size and involves an increase in the cell's functional units. Accretion is the increase in both organic and inorganic intercellular substances which often function to bind cells within complex networks. All three processes occur during growth but differ in their dominance according to age and tissue (Malina, Bouchard and Bar-Or, 2004). These cellular processes also impact biological maturation and developmental differentiation, both of which are discussed later in this chapter.

As children and adolescents grow, they become taller and heavier, they increase in both lean mass and fat mass and their organs grow (Malina, Bouchard and Bar-Or, 2004). Different body parts grow at different rates and at different times, with the greatest physical and biological change taking place during adolescence. Growth occurs distally to proximally, resulting in more extreme growth of the legs and arms first during the growth spurt, followed by the trunk. The general pattern of growth however is similar for both body weight and other body dimensions, with exception of subcutaneous fat (Beunen and Malina, 2008).

Stature increases rapidly during the first year of life before decelerating through infancy and into early childhood where it maintains a steady velocity of approximately 5 to 6 cm. per year. This period of consistent growth is later interrupted by the onset of the pubertal growth spurt before decelerating as the individual nears the mature (i.e., adult) state (Rogol, Clark and Roemmich, 2000). The velocity of growth varies between sexes and across individuals. At birth, males grow slightly faster than females until around 7 months old where growth velocity then becomes roughly similar between sexes. This is then followed by a period whereby females grow more quickly until the age of 4 years. On average, children then grow at a similar rate until the adolescent growth spurt (Marshall and Tanner, 1969, 1970). The average age of onset of the adolescent growth spurt is age 10 in females and age 12 in males, with peak height velocity (PHV) occurring at 11.8 years and 13.8 years, on average, in females and males respectively (Malina, Bouchard and Bar-Or, 2004). The growth rate at PHV is, on average, 9 cm. per year in females who gain approximately 25 cm. during the pubertal growth period. Males achieve a slightly higher growth rate, attaining 10.3 cm. per year on average, and gaining a total of 28 cm. in height during this period (Marshall and Tanner, 1969, 1970). The average adult sex differences in height that are observed arise because boys experience a longer period of preadolescent growth and a slightly greater peak spurt than girls (Malina, Bouchard and Bar-Or, 2004).

During puberty, a rapid increase in reproductive organ size occurs. There is also a dramatic increase in growth of the parameters associated with body size, such as the bones, heart, lungs and muscle mass, resulting in an increase in height, weight and heart size (Baxter-Jones, Eisenmann and Sherar, 2005). Peak weight velocity (PWV), the period of peak weight gain, occurs approximately 0.5-1.0 years after PHV. On average, 9 kg/year of total mass is gained in males during PWV and this is predominantly fat-free, lean mass. Fat mass increases remain fairly stable during adolescence in boys, and this results in a decrease in body fat during male puberty (Rogol, 2002). In contrast, pubertal weight increases in females consists of a greater amount of fat mass and in total 8.3 kg/year of body mass is gained (Malina, Bouchard and Bar-Or, 2004).

Changes in physique occur during childhood and adolescence. Physique describes an individual's entire body shape rather than just specific features (Malina, Bouchard and Bar-Or, 2004). Changes in physique primarily result from the redistribution of subcutaneous adipose tissue, ratio changes of the legs relative to body height, and the development of muscle. Differences between genders are observed with females accumulating greater amounts of adipose tissue, whilst boys develop greater amounts of muscle mass. The relationship between the shoulders and hips also changes, with boys generally obtaining broader shoulders, and girls wider hips (Malina, Bouchard and Bar-Or, 2004).

2.2.2 Maturation

Biological maturation refers to the progression towards the adult (i.e., mature) state (Malina, Bouchard and Bar-Or, 2004). It is a continuous process occurring throughout childhood and adolescence, beginning prenatally and continuing through, on average, the first two decades of life (Malina, Bouchard and Bar-Or, 2004). Maturation occurs, and can be assessed, across multiple biological systems (e.g., skeletal, endocrinal, dental, sexual, somatic) and can be considered in terms of its status, tempo, and timing (Baxter-Jones, Eisenmann and Sherar, 2005; Malina, et al., 2015). These three processes vary according to the biological system being considered. Status describes the stage of maturation attained (e.g., pre-, circum-, post-pubertal), whilst tempo refers to the speed at which maturation progresses (Malina, Bouchard and Bar-Or, 2004). In contrast, timing refers to the age at which certain maturation events (e.g., puberty, menarche, peak height velocity) occur. The timing of maturation is determined by a combination of genotypic and environmental factors and can vary markedly among youth of the same chronological age, with some individuals maturing well in advance or delay of their peers (Malina, 2014). For example, two adolescents of the same chronological age and same body size could be at completely different points in their journey to their fully mature state.

Variation in biological maturity is both age- and sex-associated and typically, females experience puberty one to two years earlier than males (Fechner, 2002). Gender differences in growth and maturation exist from the start of foetal life. From birth, skeletal maturation is 4-6 weeks more advanced in females than males, a trend that continues throughout childhood and adolescence (Malina, Bouchard and Bar-Or, 2004). Growth and maturity-related differences between individuals and between sexes is due to a combination of genetic and environmental factors (Rogol, Roemmich and Clark, 2002).

2.2.3 Development

Development is a broader concept than growth and maturation and refers to the acquisition of behaviours and competences (Baxter-Jones, Eisenmann and Sherar, 2005). It describes the qualitative changes in function that occur as an individual interacts with their environment. Development of social, cognitive, emotional and motor competence takes place as a child begins to experience and adjust to their environment and learns to behave in culturally appropriate ways (Malina, Bouchard and Bar-Or, 2004). For example, as children develop cognitively, the strategies that they use to retain information or attribute successes and failures changes with age. Motor development is the change towards competence in motor behaviour (Gallahue, 2010). Movement skill acquisition is a progressive process with an individual acquiring rudimental movement skills during infancy, progressing to more advanced, fundamental motor skill development in early childhood and finishing with the development of more complex and specialised motor skills. The rate of motor development is highly variable and is influenced by cultural and ecological conditions, as well as by the biology of the individual and the complexity of the task itself (Gallahue, 2010).

2.2.4 Adolescent Development

Growth, maturation and development, in combination with the framework of chronological age, are used to define the various periods an individual will experience in life. Infancy is defined as the first year of life up to, but not including, the first birthday. Rapid growth of the various body systems and rapid development of the neuromuscular system occurs during infancy. Childhood takes place from the first birthday to the start of adolescence and is often separated into early and middle childhood. Early childhood sees the continuation of rapid growth and development, with middle childhood observing a more constant progress of growth, maturation and behavioural development. The fourth period is adolescence which precedes the final stage of life, adulthood (Malina, Bouchard and Bar-Or, 2004). Adolescence will be discussed in the greatest amount of detail due to the age range of the participants used in the studies in this thesis being of the adolescent age.

The word adolescence derives from the Latin word *adolescere* which means to grow up (Sawyer et al., 2018). Adolescence is the development stage that encompasses the period between childhood and adulthood and involves distinct changes in an individual's behaviours, social roles, psychology and biology (Sawyer et al., 2012; Blakemore and Mills, 2014). During adolescence the interactions an individual has with their environment shapes many of their capabilities that aid them to progress in life (Blakemore and Mills, 2014). Throughout this period, an individual aims to acquire the physical, cognitive, emotional, social, cultural and economic resources to establish health and well-being later in life (Patton et al., 2016).

Establishing a clearly defined age range for adolescence has proven difficult. Over 50 years ago, The World Health Organisation (WHO) defined it as the period between 10 to 20 years of age, beginning with puberty but with a less well-defined end point

(World Health, 1965). More recently, however, the ages of 10-24 years have been proposed to better reflect modern development of adolescents (Sawyer et al., 2018). Developmental differences exist throughout this dynamic period; thus, adolescence has been divided into sub-stages; namely early-, mid-, and late-adolescence. Each sub-stage reflects different physical, social, cognitive, and emotional needs, experiences and development (Curtis, 2015).

Early adolescence has been described as ‘beginning in biology and ending in culture’. It begins with the onset of puberty at age 10 to 11 years and ends upon transition to secondary school (or American High School) at age 14 (Steinberg, 2014). During this period, the need for belonging is high and strong friendships are sought after. Legally and socially early adolescents are highly dependable on adults and moral reasoning reflects the desire for parental and peer approval (Barrett, 1996). Brain development during early adolescence consists of predominantly pre-frontal cortex development, as well as a high degree of synaptic pruning, which enhances cognitive ability and continues the refinement of decision-making and thought (Steinberg, 2014). A combination of pubertal hormonal changes and social stressors can result in mood swings, emotional instability and reduced control of impulses during this period (Spear, 2000).

Rapid physical and sexual maturation occurs during early adolescence. Towards the start of adolescence, the acceleration in growth, termed the adolescent growth spurt, takes place and culminates in a peak with a subsequent deceleration of growth throughout the adolescent period towards full adult stature (Malina, Bouchard and Bar-Or, 2004). The defining event in adolescence with regards to sexual maturation is puberty. Puberty refers to the physiological and physical transformation to adulthood and it is marked by rapid changes in body size, shape and composition (Rogol, 2002). It results in the appearance of secondary sex characteristics, namely breasts and menarche in girls, testes and a penis in boys, and pubic hair in both sexes, as well as maturation of the reproductive system (Malina, Bouchard and Bar-Or, 2004). On average, girls enter and complete the various stages of puberty earlier than boys. The average age of onset of puberty is 11 years in females and 13 years in boys (Tanner et al., 1975). The timing and tempo of puberty and corresponding parameters of the growth spurt, adrenarche, and gonadarche, are determined by changes in multiple hypothalamic-pituitary end organs axes, especially the gonad and growth hormone (GH)- insulin-like growth factor (IGF)–I axis. During puberty, large changes in body composition and the regional distribution of body fat occurs which are closely related to changes in the hypothalamic-pituitary-gonadal (HPG) axis (Rogol, 2002).

The activation of the neuroendocrine HPG axis has historically been considered the biological event that begins puberty and adolescence due to the biological changes it elicits (Rogol, 2002). However, the age at menarche has reduced by 4 years in the last 150 years in early industrialised countries such as the United Kingdom (UK) (Patton and Viner, 2007). It has dropped even more drastically in China, reducing by 4.5 years in the last 25 years (Song et al., 2014). It is thought that improved childhood health and nutrition are the main factors driving these changes (Gluckman and Hanson, 2006). Therefore, whilst the timing of biological maturation may signal the onset of adolescence from a biological perspective, in modern times it may occur at an age where, socially, and culturally, the individual is still considered a child.

The mid-adolescent period is usually defined by education. It begins when an individual moves into high school, at about age 14 years, and ends when they finish it, at age 17 years (Curtis, 2015). Now the individual searches for uniqueness, trying to establish the special competencies, abilities, interests and aptitudes that develop their ‘self’ (Barrett, 1996). Amongst this, interest between peers increases and peer groups develop into cliques with increasing peer relationships (Neinstein, 2008). Considerable psychosocial development takes place during this period, and adolescents demonstrate the ability to maintain adult reasoning (Petersen and Leffert, 1995). Although reasoning capacity is improving, the efficiency and control of cognitive processes and impulses remains immature (Steinberg, 2014). Significant brain development continues and a possible period of vulnerability emerges with a balance between increased sensation seeking and a developing self-regulatory system (Steinberg, 2008). Individuals are becoming more used to their pubertal physique, however, concerns over body image and attractiveness are high during this period (Neinstein, 2008). New privileges, such as learning to drive and the entering of employment, are seen during mid-adolescence and an increased drive for independence from adult guardians is observed (Neinstein, 2008).

The biological changes associated with puberty continue during this stage of mid-adolescent life. Growth of stature and body size continues, leading to a progressive development of physique and body composition. The average girl, however, grows at a slower rate than is observed during early adolescence. In contrast, due to the later onset of the growth spurt in boys, rapid growth is likely still occurring during this phase in boys (Malina, Bouchard and Bar-Or, 2004).

Late adolescence is characterised by the development of social autonomy, increased independence and, in most cultures, a greater level of legal authority (Curtis, 2015). Although puberty has finished, biological maturation continues; for example, boys continue attaining body hair and muscle bulk (Christie and Viner, 2005). Adolescent brain development is shaped by a period of synaptic pruning as well as the refinement of brain function and structure, processes that continue into an individual's 20's (Simmonds et al., 2014). This neurodevelopmental plasticity enhances emotional and cultural adaptability, increasing the capacity for greater social and emotional engagement (Viner et al., 2012). Enhanced socio-emotional control aids decision-making, peer attachment, behaviour and well-being in later adolescence (Crone and Dahl, 2012). It is argued that, because of neural and cognitive development continuing well into the 20's, there is a need to define adolescence until this decade of life. Coupled to this, consideration for adolescence continuing into the second decade of life better reflects modern society. In modern, industrialised societies a longer time is now being spent in education, entry into full-time employment is beginning later, whilst the average age of marriage and of having children is now later than it previously was (Sawyer et al., 2018).

2.3 FACTORS INFLUENCING GROWTH, MATURATION AND DEVELOPMENT

Growth and maturation are dynamic processes and are influenced by several factors that act both independently and in concert. These factors can principally be grouped into environmental, genetic and hormonal factors (Rogol, Roemmich and Clark, 2002). An individual's genetic makeup establishes their potential for growth and maturation, whether that individual achieves that potential depends on the environment they are nurtured in (Malina, Bouchard and Bar-Or, 2004).

Genetic and environmental factors control and influence various growth processes differently. For example, the genetic control of the tempo of growth is independent to that of body size and shape (Tanner and Tanner, 1990). Secular trends in height and adolescent development show evidence for the impact of environmental factors on growth potential. Children's height has increased by 1 to 2 cm. each decade since the start of the 20^{th} century, on average (Tanner and Tanner, 1990). The same increase in adult height has not been observed, suggesting the trend towards a greater youth height may be due to earlier maturation and advanced attainment of adult height (Rogol, 2002).

Hormones are crucial for regulation of growth and maturation processes. For example, prepubertally, the GH and thyroid hormone influence normal growth. During puberty, the interaction of gonadal and adrenal steroid hormones with GH is critical to progress the adolescent growth spurt and sexual maturation (Rogol, Roemmich and Clark, 2002).

The key environmental factors that influence growth and maturation are nutrition and physical activity. Through its interactions with the genotype and hormones, an individual's nutritional status is important for the regulation of growth and maturation (Malina, Bouchard and Bar-Or, 2004). Good energy and nutrient intake are crucial for optimal growth and thus nutritional status can greatly impact progress to achieving full growth potential (Lifshitz, 2009). The general health and well-being of an individual can also impact normal growth; a slowing down of growth can occur during periods of very high catabolic stress or illness, although it appears that this stunted growth can be caught up upon attainment of normal health (Rogol, Roemmich and Clark, 2002).

Other environmental influences that can influence growth and maturation include socioeconomic conditions, family size and ethnicity (Malina, Bouchard and Bar-Or, 2004). Socioeconomic factors include level of parents' education and availability of food and healthcare and specifically, individuals from a lower socioeconomic status (SES) have a later age at menarche and, in general, may be smaller and lighter in size (Tanner, 1989). Lower SES is also associated with larger family sizes, which in turn has been shown to lead to a later age at menarche (Tanner, 1989). A family size of 5 children or more has a negative effect on height in families from a lower SES but has less impact on families from higher SES. This is likely due to an increased family size in combination with a lower SES leading to less food and resource available for each child (Malina et al., 1997). Additionally, the number of children may be an indirect measure of birth spacing. Birth spacing has been observed to have a small effect on growth and menarche, with smaller intervals between children at birth often resulting in in a smaller height and weight (Vaida, 2012) and slightly later age of menarche of the later born child (Malina et al., 1997).

Ethnicity is a contributing factor to growth and maturation. For example, Asian children, both males and females, tend to mature in advance of white European and American youth (Grgic et al., 2020). This has been shown to occur for both skeletal and sexual maturation (Malina, Bouchard and Bar-Or, 2004). Ethnicity can also, at times, be a confounding factor to SES. For example, in America, African American families are often from lower SES environments. However, black African American males and females, on average, reach both skeletal and sexual maturity in advance of white American males and females (Berkey et al., 1994). In general, however, variation in maturity status between ethnic groups is less pronounced than variation within populations (Beunen, Rogol, and Malina., 2006).

Questions are regularly raised as to whether physical activity or sports training influences the normal processes of growth and maturation of an individual. In females, a delay in sexual maturation and in growth is often reported in gymnasts, dancers and long-distance runners (Malina, 1994). Longitudinal studies on gymnasts have observed a decrease in predicted heights (Theintz et al., 1993) and slower growth velocities (Lindholm et al., 1994) over a prolonged period. Several studies have also reported a delayed age at menarche amongst female gymnasts compared to the general population (Theintz et al., 1993; Claessens et al., 1992; Baxter-Jones et al., 1994). These findings have been observed to a lesser degree in dancers and long-distance runners (Malina, 1994). Sports such as swimming and tennis appear to have minimal effects on both growth and age at menarche (Malina, 1994). It may be that the timing of intensive training may be important and strenuous training before menarche may be more likely to cause disruption to growth and development than if it were to happen later on (Warren, 1980).

Whilst it may appear conclusive that there is a relationship between intense training and pubertal growth and maturation in females, specifically female gymnasts, this is not the case. There are additional factors to consider, including; genetic predisposition, an individual's general state of health, psychological and emotional stressors associated with competitions, training, maintaining a low body weight and coaches demands may all also influence growth and pubertal timing (Malina, 1994). A key factor linking training and a possible influence on growth and maturation may be nutrition, specifically energy intake and intake of vital nutrients. Individuals who participate in a lot of activity may not meet the energy demands required for sport and/or daily life and may also not ingest the necessary amounts of micronutrients, such as calcium, needed for bone mineral accrual. This could have a large impact on growth and maturation if consistent over a prolonged period (Rogol, Clark and Roemmich, 2000).

A critical factor to consider when assessing whether there is a relationship between training and growth and maturation is sport selection biases. Certain sports favour certain physiques or the functional advantages shown by early or late maturing individuals (Malina et al., 2015). For example, adolescent female gymnasts are usually shorter and lighter than age-matched peers, a physique which favours late maturers, whilst swimmers are often taller and early maturing (Theintz et al., 1993). Therefore, it is often difficult to determine whether intense training or sport causes any variation in maturation, or whether early/late maturing individuals are preferably selected into sport due to their physique/functional attributes.

Males who participate in sport are generally on time or early maturing and usually have normal growth rates. The advantages of a greater body size and greater strength and power with earlier maturation are often preferred for sports where these physical qualities dominate (Malina, 2011; Malina et al., 2015). In contrast, however, later maturing boys are preferably selected into artistic gymnastics and long-distance running, and accordingly, questions have been asked as to whether the practice adopted in these sports leads to a slowing down of growth and maturation. Several studies have shown that, whilst individuals in these sports may be shorter or lighter than reference data, their growth rates do not necessarily differ significantly from the norm (Housh et al., 1993; Seefeldt et al., 1988). As described above for the selection bias towards late maturing females into dance and gymnastics, it is likely that these sports preferably select those individuals with desirable anthropometric and/or functional traits (Malina, 2009).

In summary, whilst some studies have reported a smaller stature and decreased body mass for participants in some sports, it is likely that a large part of this is due to a selection bias for those participants with favourable anthropometrics (Malina, 2009). Additionally, data from some sports suggest that there may be anthropometric differences between those athletes that continue along the pathway and those athletes that are 'cut' (Malina et al., 2013). Whilst it can be difficult to fully understand the impact of training in many sports, it does not appear that sports training alone impacts the rate of growth or adult stature of individuals, and additionally, skeletal or sexual maturation (Daly et al., 2000; Beunen and Malina, 2008; Malina et al., 2013). In addition, there is a possibility that individuals participating in sport may have a reduced nutrient and energy balance. Excessive physical activity in combination with poor nutrition can influence growth and maturation, in particular sexual maturation, through influencing energy balance (Rogol, Clark and Roemmich, 2000). Regular undernutrition is associated with a later age at menarche, whilst a regular positive energy balance, leading to obesity/being overweight, is associated with early sexual maturation (Forbes, 2012).

2.4 A SUMMARY OF GROWTH, MATURATION AND DEVELOPMENT

Adolescence is a period marked by dramatic changes in body size, shape, and composition (Rogol, Roemmich and Clark, 2002). Growth and maturation are dynamic, biological processes that underpin many of these changes (Malina, Bouchard and Bar-Or, 2004). Young people are often grouped according to chronological age in environments such as education and sport, however, children of the same age can vary markedly in their timing and status of biological maturation (Nahhas et al., 2013). This variation is both age- and sex-associated and is predominantly genetically predetermined, thus is largely out of the individual's control (Malina, Bouchard and Bar-Or, 2004). Earlier maturing individuals are, on average, taller and heavier than their later maturing peers from age six onwards. Although height differences are largely eliminated by young adulthood, differences in weight-for-height remain (Malina, Bouchard and Bar-Or, 2004). The timing of maturation (i.e., early, on-time, late) has important implications for psychological development (e.g., confidence, leadership, perceptions of self) (Cumming et al., 2012).

Individual variation in growth and maturation also has important implications for physical development (e.g., physique, strength, body size) and this will be further considered in subsequent sections. These differences may mask or enhance physical qualities and athletic performance in youth, and this is particularly evident during puberty, when maturity associated variance in body size and function is at its greatest (Lloyd and Oliver, 2012). Growth and maturation variance makes evaluating the physical performance of young people particularly difficult if assessed by chronological age. Practitioners can, however, accommodate for this variation and adjust expectations of individuals. To do this, an understanding of an individual's growth and maturation status is needed. This highlights the importance of assessing and monitoring growth and maturation of young people. Understanding of individual differences will allow for a more informed evaluation of an individual's physical capabilities.

2.5 ASSESSMENT METHODS OF BIOLOGICAL MATURATION

2.5.1 Introduction to Maturity Assessment

Biological maturation is a process that occurs across all the various biological systems, tissues, and organs in the body. Maturation across these different systems does, however, vary. The outcomes of the underlying processes of maturation can be measured to provide an indication of one's progress towards their mature state (Malina et al., 2015). As previously discussed, maturation can be assessed by two related but not equivalent processes; maturational status, that is the level of maturation at a specific chronological age, and maturational timing, that is the time at which specific maturational events take place (Malina, Bouchard and Bar-Or, 2004).

Given the variation in maturation that occurs across the body's systems, it is perhaps unsurprising that maturity can be assessed across all the various systems with a variety of different assessment methods. Some of these systems are closely related, such as somatic, skeletal and sexual, meaning maturity assessment of these systems are closely associated to each other. Whereas maturation of other systems are less related to these, for example dental maturation (Malina, Bouchard and Bar-Or, 2004).

The most common methods of measurement performed within the paediatric population are assessment of skeletal, sexual and somatic maturity which are underpinned by the maturation of the endocrine and nervous systems (Malina, Ackerman and Rogol, 2016). Several methods exist to assess skeletal, sexual, and somatic maturation in the paediatric population, and these will be described below. Although related, because maturation of these systems does not proceed equally, we would not expect the measures of maturation of the different systems to correspond exactly with one and another. Correlations between the various indicators of maturity are, however, generally moderate-to-high, suggesting if an individual is advanced in their somatic maturity they are also advanced in sexual maturity (Baxter-Jones, Eisenmann and Sherar, 2005). Correlations across indices are often greater for girls than they are for boys, and for both sexes, as adolescence progresses skeletal maturity increases in correlation to both sexual and somatic maturity (Malina, Bouchard and Bar-Or, 2004).

2.5.2 Assessment of Skeletal Maturity

Skeletal maturity is often considered the best method for the assessment of biological maturity status (Baxter-Jones, Eisenmann and Sherar, 2005). Skeletal age (SA) is a measure of skeletal maturation and assesses the developmental processes of bone through hand-wrist radiography (Malina et al., 2015). The bones of the skeleton change from their initial ossification state to the adult state over approximately 18 years, terminating in early adulthood (Nahhas et al., 2013). The rate at which bones progress from cartilage to their complete mature bone varies amongst bones, both within an individual and amongst individuals (Malina, Bouchard and Bar-Or, 2004). SA will vary amongst individuals of the same chronological age, for example, in a group of 13-to-14-year old's, skeletal ages can range from 9 to 16 years (Kemper and Verschuur, 1981). SA is expressed relative to the individual's chronological age. If the measured skeletal age is greater than the actual chronological age, the individual can be considered advanced in skeletal maturity. Similarly, if the skeletal age is lower than the actual chronological age, the individual will be considered as delayed in skeletal maturation (Malina, Bouchard and Bar-Or, 2004).

Relative skeletal age (RSA), the difference between the assessed skeletal age and the chronological age, is used to compare children within peer groups, as well as for comparison of a population to reference standards. RSA is expressed as zero when skeletal age is equal to CA, delayed maturation results in a negative RSA, whilst advanced maturation results in a positive RSA (Nahhas et al., 2013).

Genetic and/or environmental and nutritional factors may influence skeletal age and it has been shown that lower socioeconomic status leads to delayed maturation in many populations (Cole and Cole, 1992; Hawley et al., 2009). Identification of an individual's maturity status may be important for not only athletic development, training, competition, and selection processes in athletes, but also for health reasons. Potential health problems and possible solutions can be signaled if an individual is greatly ahead or delayed in their bone development. For example, dental implants or orthodontic appliances are treatments that can be used in children requiring bone growth interventions (Nahhas et al., 2013).

Skeletal maturation can be assessed by use of standardised X-rays or radiographs, with assessors requiring a good understanding of the developmental processes from early ossification to the fully mature skeleton to interpret radiographs (Malina, Bouchard and Bar-Or, 2004). The bones of the left hand and wrist are the most commonly used area to assess SA, with the hand-wrist area suggested to be typical of the rest of the skeleton (Malina, Bouchard and Bar-Or, 2004). This has however been disputed, with some research identifying differences of one or more years in the skeletal age following assessment of the knee and hand-wrist areas (Roche, Wainer and Thissen, 1975). The hand-wrist radiograph is, however, popular for assessment because it is easy to view and analyse (Baxter-Jones, Eisenmann and Sherar, 2005). A number of methods of assessment exist, whereby the radiograph is compared to a set of predetermined reference criteria, that is, individual features of the bone to indicate maturity (Malina, 2011). The first indicator is the initial appearance of bone centres on an X-ray and provides information on bone replacement of cartilage. The second is the definition and characterisation of the bone as it begins to shape to form its mature form. The final indicator involves the fusion of epiphyses with their respective diaphysis (Malina, Bouchard and Bar-Or, 2004).

There are three commonly used methods for SA determination from the hand-wrist, namely, the Greulich-Pyle method; the Tanner-Whitehouse method; and the Fels method. The Greulich-Pyle method (Greulich and Pyle, 1959) was developed from white American children of high socioeconomic status to produce standardised X-ray plates of skeletal levels at different chronological ages. From these, the assessed individual is compared to the reference plates and skeletal age is expressed according to the reference plate it most closely resembles. Concerns over this method arise from the lack of individual bone consideration, with the method assuming that all bones develop in a uniform manner (Lloyd et al., 2014). The Greulich-Pyle method has been shown to both over- and under-estimate maturation, and also may not be applicable to diverse ethnicities (Malina, Bouchard and Bar-Or, 2004).

The original Tanner-Whitehouse method (TW1) (Tanner and Whitehouse, 1962) was developed on a cross-sectional sample of British children. Since the original TW1 method was established two revisions have been developed, TW2 (Tanner et al., 1975) and TW3 (Tanner et al., 2001). In all revisions, the seven carpals and thirteen long bones of the hand-wrist area are assessed and written criteria for the developmental stages of each bone recorded with a specific maturation point score given to each stage for each bone. A skeletal maturity score can then be established from the summation of the individual bone scores, where zero identifies full immaturity and 1,000 indicates full maturity. This summed score is then converted to represent a SA value. The most recent TW3 version uses reference standards based on Italian, Spanish, Argentinian, American and Japanese children, and adolescents, as well as British. The TW3 Tanner-Whitehouse method is fairly complex and time-consuming and also requires an extent of subjective decision making (Lloyd et al., 2014).

The Fels method was established from the Fels Longitudinal Study in America carried out between the 1930s and 1970s (Roche, Thissen and Chumlea, 1988). This method uses assessment of the carpals and metacarpals, epiphyses and diaphysis of the radius and ulna and the phalanges of the first, third and fifth digits (Lloyd et al., 2014). The bones are graded according to age and sex and the ratios between lengths and widths of the epiphysis and metaphysis are also used (Lloyd et al., 2014). Statistical analysis of the maturity indicators results in the formation of the skeletal age alongside standard error of estimate, with different indicators utilised at different chronological ages. Whilst the Fels method is also complex and time-consuming, the use of a software tool for analysis and production of a standard error of estimate allows for increased reliability and a benefit to the tracking of maturation in children and adolescents (Lloyd et al., 2014).

All three methods are reasonably similar in principle, with the main differences existing in the criteria used for assessment and in the procedures used to construct the scale for SA determination. Limitations surrounding the cost, time, requirement for specialist equipment and the need for trained radiographs and practitioners to perform the techniques and analyse the radiographs lead to a reduction in the possible use of skeletal maturation as an assessment tool (Lloyd et al., 2014). Also, although exposure to radiation during the procedure is less than the normal background radiation associated with everyday life, concerns exist when carrying out skeletal assessments over the deliberate exposure to radiation (Malina, 2011).

2.5.3 Assessment of Sexual Maturity

Sexual age refers to the progress towards fully functional reproductive capability as an indicator of biological maturation (Malina, Bouchard and Bar-Or, 2004). It is a continuous process, beginning at sexual differentiation in the embryo, progressing through puberty and terminating at full sexual maturity and fertility. Maturation of the reproductive system occurs during puberty and results in the appearance of secondary sex characteristics (Cameron and Bogin, 2012). The monitoring of the secondary sex characteristics; breast development and menarche in girls; and penis and testes development in boys; and pubic hair growth in both sexes, are used as the assessment of sexual maturity (Spear, 2002). Only trained clinicians are able to assess sexual maturation in clinical environments and consent and assent must be provided by the parent and the child respectively (Lloyd et al., 2014). However, because of the invasive nature of visual observation, self-assessment techniques have been developed whereby the child compares their own sexual characteristics to those of reference drawings or photographs (Tanner, 1962). This method has been shown to be reliable and establish reproducible data (Matsudo and Matsudo, 1994) however it is typical that boys will overestimate sexual development, and girls will underestimate development (Leone and Comtois, 2007).

The most commonly used criteria for assessment of secondary sex characteristics are those described by Tanner. This involves comparison to five distinct reference stages, termed Tanner stages 1 to 5 (TS1, TS2, TS3, TS4, TS5) (Tanner, 1962). Limitations are associated with this method of assessment, namely; the method has an inability to differentiate children and adolescents within stages; no idea of tempo of maturation is provided; and Tanner assessment can only take place during the pubertal growth period due to the nature of assessment, thus rendering it ineffective for children and adolescents outside of this period (Baxter-Jones, Eisenmann, and Sherar, 2005). There are, however, advantages of using secondary sex characteristics for assessment including the ease of administration, its cost effectiveness, the lack of need for longitudinal monitoring and the non-invasive nature when self-assessment is carried out (Baxter-Jones, Eisenmann and Sherar, 2005).

In males, estimates of testicular volume provides an alternative method for sexual maturity assessment (Baxter-Jones, Eisenmann and Sherar, 2005). Volume is estimated from the size of the testes, using ellipsoid models of known volume, which have the shape of the testes. This method is normally used in clinical settings and not recommended for self-assessment (Malina, Bouchard and Bar-Or, 2004). Age at menarche provides an assessment method specific to females and is used to determine the age of the females first menstrual period (Malina, Bouchard and Bar-Or, 2004). The first menstrual cycle is a late occurring event within the scope of sexual maturation, typically occurring after PHV (Coleman and Coleman, 2002). This provides a retrospective measure of maturity assessment, and despite the error associated with memory recall, females are able to identify their first menstrual cycle to within approximately 3 months (Koo and Rohan, 1997). The accuracy of this method is therefore limited by memory of the individual and recall bias, which suggests the shorter the recall interval, the more accurate the recall (Livson and McNeill, 1962). Within this method, premenarcheal girls are excluded and it is primarily carried out in adults. Most studies involving age at menarche assessment within female athletes uses the retrospective method described above. However, there are two other forms of assessment, termed the prospective or longitudinal method and the status quo method that can be used. The prospective method involves the individual to be assessed regularly at short intervals in longitudinal studies, approximately every 3-6 months (Malina et al., 2015). During this assessment girls and/or their mothers are asked whether or not menarche has occurred, and if it has, further questioning establishes timing and age (Malina et al., 2015). The status quo method requires knowledge of chronological age and whether or not menarche has occurred within a sample of girls aged 9 to 17 years and establishes the median age at menarche within the sample (Malina et al., 2015).

2.5.4 Assessment of Somatic Maturity

There are several identified disadvantages associated with the invasive methods for maturity assessment described previously, namely, the perceived invasiveness of secondary sex characteristic measurement, the negligible radiation exposure with SA assessment, and the logistical difficulties of conducting longitudinal studies. With these in mind, non-invasive, anthropometric estimating methods for assessment of maturity status are often favourited (Malina et al., 2015).

Somatic age refers to the degree of growth in overall stature, or of specific body parts (Lloyd et al., 2014). Somatic growth follows a non-linear pattern, with periods of rapid growth interspersed with periods of slower growth (Rogol, Roemmich and Clark, 2002). The adolescent growth spurt in females starts on average, at about age 9 or 10 years, peaking at about age 12 years and stops by about age 16 years. In males this occurs approximately two years later, with the growth spurt beginning at about age 10 or 11 years, peaking at approximately age 14 years, and finishing by about age 18 years (Malina, Bouchard and Bar-Or, 2004). Early maturing youth reach PHV in advance of this point, approximately one year or more before the mean age at PHV. Whilst late maturing individuals exhibit an age at PHV of approximately one year, or more, later than the mean age at PHV (Baxter-Jones, Eisenmann, and Sherar, 2005). Many, but not all children, may experience a much smaller mid-growth spurt in height, usually at ages 6.5 years to 8.5 years (Rogol, Roemmich and Clark, 2002). Commonly, somatic growth is determined through longitudinal growth curves, predictions of age at peak height velocity, or through the use of percentages and predictions of adult stature (Malina, Bouchard and Bar-Or, 2004). These will be discussed now.

Longitudinally Tracking Growth

There are several indirect measures of body size and body proportions available to assess overall development (Lloyd et al., 2014). Anthropometric assessment includes the monitoring of overall stature and body mass, the sum of skinfolds to determine adiposity levels, or a combination of the two to estimate somatotype.

Growth curves can be established from the repeated measurement of height over a period of time, resulting in the determination of the magnitude and rate of change of height over time and comparison against the chronological age at PHV (Lloyd et al., 2014). From the height measurements obtained, increments can be plotted and information can be gained pertaining to age, size and rate of growth at take-off, and size and rate of growth at PHV and mature height (Malina et al., 2015). A limitation to this method is that regular longitudinal tracking of growth must occur, which is time consuming and a long process. Also, the point of PHV can only be seen retrospectively once a peak has been observed. With these limitations in mind, this manner of assessment is not particularly suited to use within an athletic setting, whereby athletes come into the programme at various points and limited data may be available on that athlete prior to this point (Lloyd et al., 2014). Therefore, in environments or situations where the longitudinal tracking of individuals is not possible, age of PHV can be calculated using various specific equations. These include the percentage of predicted adult height at assessment, as well as the predicted maturity offset before the age at PHV provides an estimate of timing.

The Mirwald Maturity Offset Method of Somatic Maturity Assessment

The Mirwald maturity offset method uses sex-specific equations, requiring chronological age, height, weight, sitting height and estimated leg length (Mirwald et al., 2002). From these equations, the age at PHV for a given time point is then estimated as chronological age minus the offset. Maturity offset is expressed in relation to PHV; pre-PHV, PHV, or post-PHV (Mirwald et al., 2002). Maturity offset equations have been shown to have a large associated error. In early maturing males and females predicted ages were observed to be later than actual ages at PHV. Whilst in late maturing individuals, predicted ages occur earlier than actual ages at PHV (Malina and Kozieł, 2014). Therefore, as a means of estimating maturity status in average maturing boys within a fairly narrow CA range of 13.00-14.99 years, the

Mirwald Maturity Offset method appears useful, outside of this range, error occurs (Malina et al., 2015). The maturity offset method also appears to overestimate age at PHV in girls more so than in boys (Malina and Kozieł, 2014). These errors highlight the limitations for use of this method in athletic populations, whereby early maturing males appear to dominate (Malina, 2011). Recently, the original maturity offset equations have been simplified with the removal of sitting height in some studies. However, there is still a need to validate these new equations with athletes and across ethnic groups (Moore et al., 2014).

Khamis-Roche Method of Somatic Maturity Assessment

Calculating the percentage of predicted adult stature is another commonly used method for assessing somatic maturity (Malina, Bouchard and Bar-Or, 2004). This method uses the principle that, the closer a child is to their mature height, the more mature they are. Within a group of individuals of the same chronological age this has value in determining the difference in maturation between the individuals. As an example, this would allow a coach to distinguish the difference between an athlete that is genetically predisposed to being tall, compared to an athlete that may just be ahead in maturity status. There are three commonly used methods for predicting adult stature that all require an estimation of skeletal age (Malina, Bouchard and Bar-Or, 2004). These are known as the Bayley-Pinneau method (Bayley and Pinneau, 1952), the Roche-Weiner-Thissen method (Roche, Wainer and Thissen, 1975), and the Tanner-Whitehouse method (Tanner et al., 2001) and all three methods have an associated error of between 3 to 5 cm. (Malina, Bouchard and Bar-Or, 2004).

The most commonly used method for predicting adult stature is the Khamis-Roche method (Khamis and Roche, 1994). Khamis and Roche developed a regression equation to predict adult height that includes current stature and weight of the child, as well as midparent height. This method is based on the premise that the parental height provides a target range within which the child is likely to mature to as an adult (Malina, Bouchard and Bar-Or, 2004). The individual's current height is then expressed as a percentage of the predicted adult stature (PAS) to provide an estimate of biological maturity based on two individuals having the same height, but one could be closer to their mature height than the other and thus be further advanced in maturity status compared to the other. The Khamis-Roche method of assessment also derives a Z-score which can be used to classify individuals according to their maturity status. Z-scores of +1 and -1 have historically been used for classification of early and late maturing individuals, respectively (Cumming et al., 2009). This traditional method, however, does not differentiate between two individuals who differ markedly in maturity (e.g., z-scores of +.99 and -.99), but who are both classified as on time maturers. More recently researchers have suggested the use of half-yearly intervals as a more sensitive method to better differentiate between maturity status. An individual would be classed as advanced in maturity if the z-score is > 0.5 year, delayed if the z-score is > -0.5 year and on time if the z-score falls between -0.499 and 0.499 years (Drenowatz et al., 2013). This half-yearly classification method has recently been used as part of the Premier League Player Management Application (Hill et al., 2019).

Recently researchers have translated percentage of predicted adult stature into an index of biological (i.e., somatic) age (Gillison et al., 2017). That is, percentage of adult height achieved at the time of assessment was compared to age- and sex-specific reference standards derived from the UK 1990 growth reference data to obtain a biological age for each participant (Freeman et al., 1995; Gillison et al., 2017). Reference standards for percentage of adult stature were calculated at 0.1 yearly intervals relative to the UK reference data. An individual's biological age was determined from the individual's percentage of attained adult height compared to the mean adult height attained at each age relative to the mean stature at/above 18 years of age.

Although percentage of predicted adult height attained is not a direct indicator of growth rate, it can be used to predict when an individual is entering, going through, and exiting the growth spurt. Longitudinal evidence suggests the peak period of adolescent growth occurs at approximately 91-92% of estimated peak adult stature (Tanner, 1962; Baxter-Jones, 2013). The growth spurt lasts approximately 24 months, beginning approximately 1 year before and finishing approximately 1 year after its peak (Stang and Story, 2008). Applying this two year band to longitudinal reference data (Tanner, 1962) and translating it to percentages of adult height suggests growth begins to accelerate at approximately 88-89% of peak adult stature and then decelerate at approximately 96% of PAS (Baxter-Jones, 2013). Establishing this information then allows the classification of an individual as being pre-, circa- and post-PHV, where an individual who is ≤ 88% is considered to be pre-PHV and an individual ≥ 96% considered to be post-PHV (Cumming et al., 2017).

The Khamis-Roche method of maturity assessment, therefore, allows the calculation of several useful pieces of information regarding an individual's growth and biological maturation. Specifically, it allows the establishment of an individuals predicted adult stature, their current percentage of this adult height, their biological age, their maturity status (early, on-time, or late) and an understanding of whether they have gone through, are yet to go through, or are going through the adolescent growth spurt. This method is also non-invasive and does not require skeletal assessment to be carried out, which can be difficult to administer (Malina, Bouchard and Bar-Or, 2004). It is, therefore, an accurate and useful method to assess biological maturation in a large cohort of young people.

Although skeletal age assessment is generally considered the best method for maturity assessment, it would not be an appropriate choice in my research due to its invasive nature, cost and requirement of specialist equipment and practitioners. Non-invasive methods would be more applicable for this study, of which the Khamis-Roche method appears to be the most reliable, usable and provides appropriate and valuable information. It will, therefore, be the method used in each of the studies within this thesis.

2.6 BIOLOGICAL MATURATION, RELATIVE AGE AND PHYSICAL FITNESS

This section of the literature review will focus on physical fitness during adolescence. It will begin by introducing the concepts of physical fitness and activity and explore factors that influence adolescent behaviours and interest in fitness. The majority of this section will focus on the impact of biological maturation and relative age on physical fitness, athletic performance, and selection into sports. In addition, the physical qualities important for athletic performance will be reviewed with an aim to establish a testing battery to be used within the thesis studies.

2.6.1 Physical Fitness and Activity Behaviours during Adolescence

Physical fitness describes a set of attributes that people have or achieve in relation to their ability to perform physical activity (Riddoch and Boreham, 1995). Physical activity (PA) and physical fitness are related constructs, with fitness being both a product, and a predictor, of PA. Physical fitness is an adaptive behaviour that varies both with growth and maturation and with habitual PA (Malina, Bouchard and Bar-Or, 2004). Despite PA levels declining during adolescence (Allison et al., 2007), physical fitness tends to increase, or at least stay the same, during this period (Malina, Bouchard and Bar-Or, 2004). The increases in physical fitness during adolescence, despite the decreases in PA behaviours, therefore, reflect the processes of growth and maturation (unless an intervention or training programme is implemented).

As mentioned above, adolescence is a period where individuals typically become less active (Eisenmann and Wickel, 2009). This is particularly evident in activities such as active play, a behaviour that is common amongst children and younger individuals yet declines in adolescence and into adulthood (Pellegrini and Smith, 1998). In recent years the levels of PA engagement of young people have declined (Hardman and Stensel, 2004). Globally, not enough adolescents achieve the recommended guidelines for 60 minutes of daily moderate to vigorous PA (MVPA) and in combination with this, the sedentary behaviour of youths is on the rise (Tremblay et al., 2016). This is likely the result of the many technological, social and environmental changes that have occurred recently (Fairclough et al., 2002).

There are many factors that contribute to an individual's PA engagement and participation, these include economic, cultural, biological, psychological and social factors (Bourdieu, 1984; Baxter-Jones, Eisenmann and Sherar, 2005). Psychosocial factors such as self-efficacy, social support, social barriers and self-regulatory strategies influence adolescent PA participation and general health behaviours (de Farias Júnior et al., 2014; Garcia et al., 2016). In particular, self-efficacy (Trost et al., 2002) and social interactions and support are key predictors of adolescent PA and sports participation (Van Der Horst et al., 2007; Sheridan, Coffee and Lavallee, 2014). A change in social support has been shown to lead to a change in PA behaviours in adolescent girls (Laird et al., 2016). Grouping various social factors into 'cultural capital', that is education, social associations, patterns of behaviours and values, has shown that those young people richer in cultural capital are more likely to be involved in activities due to family involvement or past experiences (Bourdieu, 1984). An individual's environment (e.g., walkability and access to shops, service and work, presence of bus stops, traffic density) can also play a role in shaping PA habits, however this has been shown to be less important in adolescents than in adults (Ding et al., 2011; Van Holle et al., 2021).

Factors associated with school and the school environment can play a large role in influencing adolescent PA participation. This is perhaps unsurprising given the time spent in this environment and the presence of possible influential people such as peers and teachers. PA in young people is strongly associated with schools' facilities, the schools' surrounding neighborhood and teacher SES (de Vet, Riddar and de Wit., 2011). Whilst school attendance (Liu et al., 2010), school engagement (Veloso et al., 2021), academic performance (Nelson et al., 2005) and education aspiration (Nuutinen et al., 2017) show positive associations with high levels of PA.

SES and class can influence a child's connection with PA and the habits formed, particularly by influencing the opportunities available to the child (Macdonald et al., 2005). A greater family income contributes to greater PA participation (Wilson, 2002) and young people from families of higher SES spend more time participating in MVPA than those from lower socioeconomic backgrounds (Duncan et al., 2004). Adolescents from a low socioeconomic background are twice as likely to be overweight as those from wealthier families (Wilson, 2002). This could be due to the greater number of barriers young people from lower SES families face to participation, including location challenges, a lack of equipment and transportation to facilities (Duncan et al., 2004). Social class can also influence PA participation (Green, Smith and Roberts, 2005). Those young people richer in 'economic capital', that is financial assets, are more likely to take up activities because of the social value attached to it, with upper class people often tempted to participate in more costly activities and undertake new activities, whereas working class people participate more often in 'working class', less expensive sports, such as football (Bourdieu, 1984).

In addition to the psychosocial and environmental factors described above, and more important for consideration in this thesis, are the biological factors that can influence the participation of adolescents in PA and sport. These biological factors include both the direct effects of biological maturation and indirect maturity-related effects, such as physical self-concept, body image and self-esteem (Cumming et al., 2012). Adolescents are more likely to partake in risk-taking behaviours, such as the use of drugs, alcohol and smoking (Alderman and Breuner, 2019) and a greater influence is exerted from media and peers, rather than family (Patton et al., 2016). It is also the period where sexual experimentation and sexual relationships are likely (Neinstein, 2008). These factors all influence PA behaviours and habits in adolescents and consequently, when considering an individual's connection with PA and fitness, it is important to consider it from a 'biocultural perspective', that is, consider all the psychological, social, environmental and biological factors (Cumming et al., 2009). Much of the research studying PA in the paediatric population has, however, focused on psychosocial and environmental contributions, such as motivation, social support, beliefs and surrounding environment (Malina, 2008). Despite being less well researched than the other influential factors, biological factors are very important when considering individual PA habits (Baxter-Jones, Eisenmann and Sherar, 2005).

The Biocultural Model of Maturity Associated Variance in Physical Activity argues that maturation can have both direct and/or indirect effects on youth PA levels (Cumming et al., 2012). It proposes that an individual's perceptions of the pubertal changes that occur during adolescence may be as important, if not more important, than the actual physical changes themselves in predicting engagement with PA. In support of this, the perception one has of their own self physical self-concept is a key determinant of the beliefs and attitudes an individual has towards PA and to PA participation (Petersen and Taylor, 1980). A positive perception of self predicts a greater involvement in MVPA (Sabiston and Crocker, 2008) and body dissatisfaction is associated with lower levels of PA (Neumark-Sztainer et al., 2006). This is particularly evident in females, and studies have shown that changes in physical appearance are considered more important to teenage girls than changes in functional capacity and sports competence (Sherar et al., 2010).

As noted, adolescence is a developmental stage where physical fitness in girls generally improves or is maintained with age (Malina, Bouchard and Bar-Or, 2004). However, girls self-perception of physical fitness and sports competence generally declines through this stage of development (Cumming et al., 2011). This paradox may result from biological maturation. Sherar et al., have shown the decline in PA in both sexes may be associated with biological maturity (Sherar et al., 2007). Early maturing males and females are more likely to be classified as overweight or obese (Cumming, Gillison and Sherar, 2011) and early maturing girls are less active and more sedentary than their later maturing peers (Rodrigues et al., 2010). Cumming and colleagues (Cumming et al., 2020) recently showed earlier maturation to be associated with lower perceptions of body attractiveness and physical self-worth, which, in turn predicted lower MVPA levels. Other studies have shown that earlier maturation in females at age 11 predicted lower psychological well-being at age 13, which subsequently predicted lower enjoyment levels and reduced PA levels (Davison et al., 2007). Therefore, despite female fitness not decreasing during adolescence, girls' perception of themselves, and perhaps their fitness, appears to be important in predicting PA participation. This could be one of the primary reasons for the greater reduction in PA levels in female adolescents compared to males (Finne et al., 2011). Few studies have considered the relationship between these variables and further research, therefore, needs to be conducted to better understand the effects of the apparent paradoxes or contradictions.

Being mindful of the factors that influence PA participation described above, the importance of PE and school sport is brought to the fore. Sport and PA participation in schools offers a gateway to a lifelong, healthy lifestyle (Fairclough et al., 2003). However, understanding the psychological, social, environmental and biological factors that underpin adolescent engagement in sport is important and, crucially, providing strategies to employ within schools and physical activity/athletic development programmes will, hopefully, increase engagement on an individual level.

2.6.2 Impact of Biological Maturation on Physical Fitness and Sport Selection

As described in the previous section, physical fitness can be described as the set of attributes a person has or achieves to enable them to perform physical activity (Riddoch and Boreham, 1995). The physical fitness of an individual can therefore be both improved and reduced over a period of time. It varies with the growth and maturity status of the individual, as well as with their physical activity behaviours (Malina, Bouchard and Bar-Or, 2004). The implications of growth- and maturity-related differences in fitness will be discussed in the following section. Physical fitness can be measured through performance in standardised tests of a specific component of physical fitness. These will be discussed later in the thesis.

Young people are often grouped according to chronological age in society, for example at school or for developmental activities such as sports teams. This may serve as an appropriate strategy for grouping children in relation to factors that follow age, such as experience and social and cognitive development. However, it may be less suitable for grouping children in relation to factors that are less likely to follow age, such as biological maturation and growth (Malina, Bouchard and Bar-Or, 2004). Two individuals matched according to their chronological age can differ in levels of biological maturity reached by as much as five to six years (Johnson, 2015). Therefore, across the many sports that group individuals by chronological age, within a chronological age group cohort, individuals will vary according to stage of maturation. Early maturing boys and girls are, on average, taller and heavier than those individuals that are average or delayed with their maturation (Malina, Bouchard and Bar-Or, 2004). Maturity associated differences in body size become apparent by the age of 6 or 7 years, and these differences are most evident during adolescence (Malina et al., 2005). When assessing physical fitness in youth populations there is a need to consider individual differences in biological maturation due to the variation in the functional capacity these differences can lead to (Malina, Bouchard and Bar-Or, 2004). These physical, functional, and anthropometric differences can manifest themselves in maturity associated selection/exclusion gradients in elite sport. This is particularly common around the period of puberty and the adolescent growth spurt (Malina et al., 2015).

Boys of advanced maturity perform better on physical tasks requiring strength, power and speed compared with average or late maturing boys of the same age (Goto, Morris and Nevill, 2019). This can often result in differences in the performance of the sport itself, with boys advanced in maturity status producing more dominating displays in a match compared to later maturing individuals (Cumming et al., 2017). In support of this, earlier maturing boys in youth soccer age groups (Under-9 and Under-10) are selected to play for a greater number of playing minutes and cover a greater total distance than later maturing boys in the same team. At the Under-13 and Under-14 age groups, around the pubertal period, earlier maturing boys also performed greater high-speed running during matches than later maturing boys (Goto, Morris and Nevill, 2019). The physical advantages associated with earlier maturation may also impact coaches' perception of which individuals are talented (Cumming et al., 2017). In many sports, the purpose of talent identification during the adolescent phase is to select athletes with potential to enhance the chances of success as an adult athlete. However, without consideration for biological maturation within this talent identification process, athletes' who mature in advance of others may be at a short-lived competitive advantage (Malina, Bouchard and Bar-Or, 2004). Recent research has shown that biological maturation may also influence a coaches' evaluation of performance, which could likely have an impact in talent selection decisions and progression through sporting pathways. Soccer players of advanced maturation received better match performance grades and evaluations in Under-10, Under-14, and Under-15 age groups. That is, players who were advanced in maturity were considered to outperform their teammates (Hill et al., 2020).

Those boys who are advanced in maturity status are over-represented in most competitive, youth sports, particularly at the elite level (Malina, 2002). These selection biases are more obvious during puberty, however, between 16 to 18 years, maturity-related differences are reduced, and often eliminated (Malina, Bouchard and Bar-Or, 2004). At younger chronological ages (10-12 years), boys competing in many team and individual sports, such as swimming and athletics, span the spectrum of skeletal age from those delayed to those advanced in maturation. However, at increasing age, there is a decline in the number of late maturing individuals and an increase in those skeletally advanced of their chronologically age matched peers (Malina et al., 2015). It is also commonly observed across many sports, apart from artistic gymnastics, for boys to be further ahead than average in their somatic maturation, with a dominance of boys displaying an age at PHV associated with earlier maturation (Malina, 2015). These maturity-associated selection biases are particularly noticeable in sports where physical capabilities such as speed, strength and power are required for performance and are also generally greater with increasing level of competition (Whiteley, Johnson and Farooq, 2017). For example, the number of late-maturing males in swimming, athletics and in many team sports decreases between the ages of 11 and 12 years and 15 and 16 years, corresponding with an increase in early or on time maturing males (Malina et al., 2015). In male Spanish football academies, within a single-age chronological age group, there were four times as many early-maturing players compared to late maturing players between the ages of 13-14 years (Malina et al., 2010).

The competitive, physical advantage observed in early maturing male athletes often results in greater junior success. In many sports such as swimming, soccer and baseball, the most successful young male athletes have been shown to be, on average, advanced in maturity status (Malina, 1998). However, it may also come at a cost of neglecting the development of technical and tactical skills. The early maturing athlete may not feel the need to develop the important technical and tactical skills necessary for sports performance due to their dominance (Malina et al., 2015). The impact of this may not become evident until late adolescence or even adulthood, where it may then impact performance and success as an adult. In contrast, late maturing male adolescent athletes are, in general, disadvantaged physically and as a result are less often selected or progressed through youth talent pathways (Malina et al., 2015). Late maturing boys can reach elite levels in sport, however the possibility in some sports, such as football, is twenty times lower if a boy is a late maturer and is born in the fourth quarter of the age group (Cumming et al., 2017). In those sports where a maturity bias towards early maturing boys exists, those late maturing boys that do make elite levels do so through persistence and/or retention in sport. To be retained within elite sport, late maturing boys may need to compensate for their physical disadvantage by developing excellent technical skills and/or having a resilient psychological profile. This argument is central to the 'underdog hypothesis' which describes the development of advanced psychological and technical skills as a result of being physically weaker (Gibbs, Jarvis and Dufur, 2012). It is crucial however that these late maturing athletes are given the time to develop and 'catch up' the physical advantages that the early maturing athletes display in adolescence (Figueiredo et al., 2009). A recent study on Serbian footballers observed that at age 14 years there were twice as many early maturing players compared to late maturing players. However, upon tracking the same group of players 8 years later, 33% of them had achieved senior elite, professional status and of those, there were 6 times as many were late maturing adolescents compared to early maturing (Ostojic et al., 2014).

The functional advantages, maturity-associated selection biases, and greater performance evaluations in favour of earlier maturing males are not as well evidenced or obvious across female athletes. Whilst maturational timing has been shown to impact the athletic performance of female adolescent athletes, this impact is less clear than it is in male sports (Cumming et al., 2017). From the onset of puberty, early maturing females are normally taller and heavier than their later maturing counterparts with a peak period of height increase occurring between 11-12 years and a period of peak weight velocity occurring 6-9 months later (Malina, Bouchard and Bar-Or, 2004). The increase in body mass during puberty is predominantly that of fat mass, with girls achieving much lower gains in lean muscle mass than boys (Tønnessen et al., 2015). Body Mass Index (BMI) is positively associated with sexual maturity in girls (Beunen et al., 1997), with overweight and obese girls tending to be advanced in maturation, whilst having a more linear physique is associated with delayed maturation (McNeill and Livson, 1963). Early maturing girls, therefore, generally have a higher body mass and fat mass, and are more likely to have an endomorph somatotype, than later maturing girls, who often have a more ectomorph somatotype (McNeill and Livson, 1963).

Maturational timing impacts selection into sports for female adolescents. Somatic characteristics are considered to be an important determinant of success in gymnastics (Claessens, 1999) and result in an apparent selection bias towards gymnasts delayed in their age at menarche (Bacciotti et al., 2017). Similarly, divers and figure skaters display, on average, a later age at menarche than the general population (Malina et al., 2015), whilst artistic gymnastics across all measures of maturity favour later maturing girls (Malina, 2013). In contrast, the enhanced physical and functional characteristics, such as greater size and strength, observed with earlier maturation can offer a competitive advantage in sports where height and/or physical dominance is of increased importance, such as tennis (Myburgh et al., 2016) and swimming (Erlandson et al., 2008). In track and field athletes, skeletal ages of runners tended to be delayed of chronological age, whilst in jumpers and throwers it tended to be advanced (Malina et al., 2015).

2.7 RELATIVE AGE DEFINED AND ITS IMPACT ON PHYSICAL FITNESS AND SPORTS SELECTION

Biological maturation has been discussed extensively throughout this thesis thus far. Another factor that is frequently discussed in the athletic, paediatric literature, and which has been shown to contribute to athlete selection and performance, is relative age (RA). RA refers to an individual's chronological age within their competitive age group and it is determined by date of birth and selection cut-off date (Hill et al., 2019).

The relative age effect (RAE) describes the phenomenon whereby an individual is more likely to be selected, or has a performance advantage, due to their date of birth in relation to the selection dates imposed (Musch and Grondin, 2001). RAE's are more common in sports where physical ability offers a competitive advantage and thus being of an older RA contributes to this advantage. The likelihood of a RAE existing in sport increases as skill level increases (Cobley et al., 2009) and appears to occur more frequently in male sports compared to female sports. Across female sports, significant RAE's have been identified in football (Romann and Fuchslocher, 2013), ice hockey (Weir et al., 2010), handball (Schorer et al., 2009) and swimming (Costa et al., 2013). Other studies have, however, observed no RAE across female sports (Till et al., 2010; Nakata and Sakamoto, 2012). In contrast, evidence is more conclusive in male sports. From early childhood through to late adolescence, boys born within the first half of the selection year are more likely to be selected into, and represented on, elite level programmes in many sports (Votteler and Höner, 2014). A RAE has been observed in male football (Mujika et al., 2009), tennis (Edgar and O'Donoghue, 2005), ice hockey (Boucher and Mutimer, 1994), baseball (Grondin and Koren, 2000) and cricket (O'Donoghue, Edgar and McLaughlin, 2004).

Within elite sport, talent identification processes may play a role in influencing the existence of a RAE, selecting the best performers at an age group rather than considering long term potential (Hancock, Adler and Côté, 2013). RA differences may also be greater in sports such as triathlon that use two-year age groupings (Ortigosa-Márquez et al., 2018) or in programmes where there are not enough children from single year groups (e.g., rural communities). The popularity of a sport may also increase the likelihood of a RAE due to an increase in competition for opportunities (Musch and Grondin, 2001). The contrasting findings across female sports may reflect the nature of competition level and/or participation numbers. If either or both are too low a RAE may be less likely to exist.

RA is often confused with biological maturity by academics and coaches alike, however they are two separate constructs that act independently of one and another (Cumming et al., 2017). Whereas RA is determined by birth and age group selection dates, maturation has a biological, genetic basis (Malina, Bouchard and Bar-Or, 2004). An individual who is the oldest in their age group could also be the least mature, and vice-versa (Malina, 2014). There are also differences in variance between maturation and relative age. Within a single age cohort RA can vary between individuals by a maximum of 12 months. For example, one individual could be born on September 1st, the start of the academic calendar year, and another individual born on August 31st, the end of the year. In contrast, maturational differences of individuals of the same chronological age can be as great as five- to six-years between late and early maturing individuals (Johnson, 2015).

The existence of a RAE in many sports is often attributed to the direct and indirect effects of advanced maturation (Baker, Schorer and Cobley, 2010). That is, relatively older individuals are assumed to be biologically more mature, displaying greater athletic capabilities and a more optimal physique for sports performance compared to their relatively younger counterparts (Wattie, Cobley and Baker, 2008). As discussed, biological maturation and RA are two independently acting constructs, and an older RA does not imply an older maturity. Advanced maturation has been shown to elicit an athletic advantage during adolescence (Malina, Bouchard and Bar-Or, 2004). Early maturers exhibit greater size, strength, speed and power (Meylan et al., 2010) due to the earlier growth and maturation of the hormonal, skeletal and neuromuscular systems they experience (Malina, Bouchard and Bar-Or, 2004). Whilst it is often proposed that older RA results in superior physical performance, the evidence linking RA to fitness is limited and inconclusive. Several studies have observed no relationship between birth date distribution and physical fitness (Carling et al., 2009; Huertas et al., 2019; Parr et al., 2020). A recent study in Japanese schoolchildren has however observed a significant relationship between RA and tests of physical fitness across ages 7-10 years but not across ages 11-15 years (Nakata et al., 2017). This suggests a possible relationship between RA and fitness at some ages, although this evidence is currently outweighed by the research contradicting this. RA has, however, shown significant association with anthropometric measurements of height and weight, with relatively older athletes being taller and heavier (Carling et al., 2009). Thus, it is possible that a RAE may be more closely associated with individual differences in growth, rather than maturity-associated changes in physical fitness.

The independent nature of RA and biological maturation is further evidenced by the age of at which their selection biases emerge and in how these biases change with age. RAE's are more prevalent across younger age groups, more commonly being observed in early childhood and often remaining stable throughout adolescence (Helsen et al., 2012; Sierra-Díaz et al., 2017; Whiteley, Johnson and Farooq, 2017). For example in male soccer, RAE's have been observed in age groups as young as six years old (Helsen, Starkes and Van Winckel, 1998). Although a RAE may still be observed in adulthood, generally the bias is very small, if at all (Mujika et al., 2009). Maturity-associated selection biases, in contrast, emerge at the onset of puberty, at around 11 to 12 years of age and are associated with the gains in size and athletic prowess (Whiteley, Johnson and Farooq, 2017). Although RAE's can remain throughout adolescence, due to their early emergence in childhood it is unlikely they can be attributed to maturity-associated improvements in physical fitness. RAEs are instead thought to lead to a performance advantage as a result of an increased time and experience spent playing the sport (Hill et al., 2019) and potentially a greater behavioural, cognitive, emotional, neural, motor and/or social development, which are more likely to change with age (Helsen et al., 2000; Wattie, Cobley and Baker, 2008). These factors could contribute to relatively older players outperforming relatively younger players in an age group, resulting in an increased possibility they will be considered as talented and so selected into elite sporting pathways (Delorme, Boiché and Raspaud, 2010). The observation of RAEs in non-physical achievement domains (e.g., chess and academics) supports the suggestion that the phenomenon is not wholly attributable to developmental differences in size and physicality (Helsen et al., 2016).

Although RA and biological maturity are often talked about in tandem in youth athletic research very few scholars have considered the simultaneous or interactive effects of biological maturity and RA. Those studies that have, have generally failed to observe an interaction between the two constructs or have observed biological maturity to be a stronger predictor of physical performance than relative age (Whiteley, Johnson and Farooq, 2017; Parr et al., 2020). Further research is needed to understand the interaction between these two constructs.

2.8 THE ROLE OF PHYSICAL FITNESS TESTING IN YOUTH POPULATIONS

2.8.1 Fitness Testing in the General Paediatric Population

The 2015 International Olympic Committee consensus statement on youth athletic development states ‘The goal is clear: Develop healthy, capable and resilient young athletes, while attaining widespread, inclusive, sustainable and enjoyable participation and success for all levels of individual athletic achievement' (Bergeron et al., 2015). Despite this, over the past 20-30 years fitness levels in youth have deteriorated (Tomkinson et al., 2003) and recent evidence suggests a large percentage of children and adolescents regularly fail to undertake the recommended PA guidelines as proposed by the World Health Organisation (Griffiths et al., 2013). Physical inactivity contributes nearly $70 billion in global healthcare costs (Keating et al., 2018). Advances in technology, including computers, the internet, video gaming and TV, are contributing to this increasingly sedentary lifestyle and childhood obesity levels, partly caused by this increased inactivity, are becoming a greater problem in more and more countries around the world (Bürgi et al., 2011). In parallel, paediatric performance in physical fitness tests has declined over the last three decades (Catley and Tomkinson, 2011), with increases in the number of youths displaying substandard levels of physical fitness, muscular strength and motor skill competency (Van Beurden et al., 2002; Moliner-Urdiales et al., 2010; Runhaar et al., 2010; Cohen, D. et al., 2011). The physical fitness of a country's adolescent population is a key indicator of the general health and well-being of young people (Williams, 2001). Lower levels of muscular fitness are associated with non-communicable disease, reduced bone health, impaired motor skill and increased fat mass in adolescents (Ortega et al., 2008; Fedewa and Ahn, 2011; Smith et al., 2014; García-Hermoso, Ramírez-Campillo and Izquierdo, 2019). In addition, low physical fitness during adolescence is an important predictor of health as an adult and it has recently been estimated that health care costs in the UK due to muscle weakness, as defined by the Foundation for the National Institute of Health, are as high as £2.5 billion (Pinedo-Villanueva et al., 2019). Despite this, the benefits of muscular fitness are often not reflected in general PA guidelines and in paediatric fitness testing.

As described in previous sections, there are many factors that influence PA engagement (Bourdieu, 1984; Baxter-Jones, Eisenmann and Sherar, 2005) and many strategies have been implemented to try and increase adolescent fitness and PA participation globally, many of which take place in school settings (Van Sluijs et al., 2007; Dobbins et al., 2013). There is evidence to both agree, and disagree, with the role of fitness evaluations in improving fitness and PA participation in adolescents. Those against it highlight its potential in demotivating young people (Rowland., 1995; Corbin, Pangrazi and Welk, 1995; Keating, 2003), particularly individuals that are overweight or have lower competency levels (Chen, Harris and Cale, 2004). They also cite the challenges of conducting fitness testing in schools (Keating, 2003; Silverman, Keating and Phillips, 2008) and additionally, question the accuracy of data if motivation and effort levels of the schoolchildren participating are not maximal (Wiersma and Sherman., 2008). Advocates for fitness testing, however, suggest that it can be used to better understand national fitness levels (Ruiz et al., 2010; Tremblay et al., 2010; Pate et al., 2013) and help observe secular trends in fitness to improve public health (Pate., 1991; Fuhner et al., 2021). In support of fitness testing in schools, researchers have also highlighted it’s use as a tool to educate young people on physical fitness and activity (Silverman, Keating and Phillips, 2008), suggesting it can be a critical component within a physical education curriculum as well as sport (Liu, Keating and Shangguan, 2017). Additionally, fitness testing can be used to develop self-evaluation and problem-solving skills to enhance engagement and connection with a sustainable, physically active lifestyle (Naughton, Carlson and Greene, 2006). The evidence for and against fitness testing in schools will be discussed in further detail later in this thesis. The testing of adolescent physical fitness could play a positive role in engaging adolescents with their fitness and activity levels, critical for this, however, is the creation of a positive and supportive learning environment (Wiersma and Sherman., 2008). Governments and health organisations could use this comparable data on the health of nations and develop benchmarks to ensure all children meet basic fitness standards.

The tracking and assessment of adolescent physical fitness has existed for some time. Age-associated increases in strength (Froberg and Lammert, 1996), power

(Beunen and Malina, 1988; Deprez et al., 2015), speed (Vänttinen et al., 2011), agility (Zemková and Hamar, 2014) and momentum (Barr et al., 2014; Till et al., 2015) performance have been observed in adolescents. Over recent years many school-based fitness programmes have been implemented with the aim of improving cardiovascular health and enhancing PA levels, rather than achieving higher levels of muscular fitness (Kriemler et al., 2010; Ardoy et al., 2011; Resaland et al., 2011; Minatto et al., 2016). In addition, paediatric fitness testing in the normal youth population has historically focused on the relationship between physical fitness and cardiovascular health to determine health-related fitness profiles (Twisk, Kemper and Van Mechelen, 2002; Carrel et al., 2012). Reflecting this, many of the contemporary fitness assessment batteries in adolescents have been developed using tests of general fitness, cardiovascular health, and PA levels (Morrow Jr, Going and Welk, 2011; Ruiz et al., 2011; Pate, Welk and McIver, 2013). A recent study reviewed the four most widely used youth fitness testing batteries; China's National Physical Fitness Testing, the US FitnessGram, the ALPHA-FIT (Assessing Levels of Physical Activity and Fitness) and the Russian GTO testing battery and concluded that all four programmes placed a strong emphasis on health-related fitness components (Keating et al., 2018).

Given the complexity of adolescent development, understanding the influence of the key constructs of biological maturity and relative age on the development of fitness is an important consideration for those working with the paediatric population. Of those studies that have evaluated the fitness performance across more athletically focused tests as part of large-scale testing batteries within non-elite adolescent populations (Espana-Romero et al., 2010; Ruiz et al., 2010; Tremblay et al., 2010; Catley and Tomkinson 2011; Golle et al., 2015; Laurson et al., 2017), none have considered the main and interactive effects of relative age and/or biological maturation.

Fitness testing of youth populations has existed for more than 50 years (Silverman, Keating and Phillips, 2008). The feasibility of conducting a fitness testing battery within a school-based environment has been validated (ñ a-Romero and Artero, 2010), which is of importance for test repeatability, as well as for utilisation as a health and fitness tool within schools. Whilst the education system within the United Kingdom has the potential to address some of the health and fitness concerns described above, researchers have suggested that it is failing to promote youth fitness to appropriate standards (Moliner-Urdiales et al., 2010). The decline in paediatric health and fitness would support this notion. This substandard physical preparation of children upon leaving school has also been highlighted in the USA, where the preparedness of college freshmen for the exertions of college strength and conditioning programmes are suggested to be below adequate levels (Wade, Pope and Simonson, 2014). It has been proposed that poor preparation of schoolteachers to teach PE within the UK systems can explain a large proportion of the inadequate standards met (Lloyd et al., 2015). To enhance the effectiveness of fitness testing in schools, several factors have been deemed important, namely; ensuring the right fitness components are tested and appropriate tests used (Keating, 2003), that there is good availability of equipment and testing materials, that the use of testing results is effective (Keating and Silverman, 2009), and that the participants are educated on the benefits, relevance and importance of fitness testing (Silverman, Keating and Phillips, 2008).

2.8.2 Fitness Testing in Young, Elite Athletes

Whilst in the normal paediatric population fitness programming and assessment often focuses on improving general health and cardiovascular fitness, in elite, sporting adolescent populations the focus of fitness assessment is on monitoring and evaluating the physical qualities most relevant for performance in the sport (Pion et al., 2014). It is important for practitioners and coaches working with young athletes to obtain objective information about the physical capabilities of their athletes to cope with the demands of the sport and perform (Pion et al., 2014). It is sometimes considered that the sport itself provides the best test for an athlete, however fitness testing allows the integral components of athletic performance to be broken down, measured and monitoring objectively (Reilly, Morris and Whyte, 2009). This objective monitoring can develop short-, medium- and long-term training goals to enhance individual strengths and weaknesses, can maximise fitness programmes to enhance performance and can also reduce injury risk (Svensson and Drust, 2005). The objectivity that fitness testing provides is a useful tool to provide feedback to athletes and can be a powerful source of motivation for an individual to improve their fitness (Svensson and Drust, 2005).

As well as optimising training programmes and developing athletic performance, evaluating physical fitness is often used as part of talent identification and athlete selection processes (Till and Baker, 2020). Talent can be defined as "the presence or absence of particular skills or qualities identified at earlier time points that correlate to or predict expert future performance" (Cobley, Schorer and Baker, 2013) and appears to be influenced by both genetic and environmental factors (Elliott et al., 1989). The identification and development of talented individuals is a large focus for many professional sports teams and National Governing Bodies. Because of this, increased investment in talent programmes has led to the implementation of various testing batteries for the assessment and monitoring of physical fitness in youth (Till and Baker, 2020). Talent identification and development are not simple processes and are made even more difficult during adolescence where several physiological, psychological and social factors can influence the prediction of potential future talent (Cobley and Till, 2017). This complexity is highlighted in the appearance of RAE's and maturity selection biases, as previously noted, both of which are common problems within talent identification and selection of athletes across many sports, in particular male sports (Malina, 2002; Cobley et al., 2009). The effects of growth and maturation may mask or enhance assessments of athletic aptitude, especially during puberty when maturity associated variance in size and functionality is at its greatest (Lloyd and Oliver, 2012). This results in some individuals being advantaged and others being disadvantaged when athletic comparisons are made within chronological age groupings often found in sports (Malina et al., 2015). Therefore, rather than the evaluation of adolescent performance at one-off time points, the continued monitoring of athletes is needed. In addition, the development and implementation of fitness standards that consider and/or adjust for individual adolescent-related differences are beneficial (Cumming et al., 2017). The monitoring of changes over time, as well as the tracking against biological age in addition to chronological age, would add depth to the assessments of junior athletes, enhancing the understanding of an individual's both current performance and future potential (Till et al., 2018).

Scientific forms of talent identification were originally initiated by Eastern European countries, and involved large, structured, government-funded testing of youth (Claessens, 1999). The aim of these testing batteries was to identify and then navigate young people towards a sport that their specific skills best suited (Claessens, 1999). Recently, similar to this early Eastern European model, a form of 'talent orientation' was proposed in Flemish adolescents (Pion et al., 2014). This directed young athletes towards a sport that optimally suited their specific, individual characteristics determined following application of a generic fitness testing battery. Generally in more recent times, these large scale talent identification systems have been replaced by more sport-specific testing and monitoring methods (Matsudo, 1996), predominantly carried out on those individuals already competing within a sport or organisation, leading to testing in a pre-selected, more homogenous group (Pearson, Naughton and Torode, 2006). A lack of developmental control measures for assessing physical fitness was highlighted as a concern in the BASES Expert Statement on Trainability During Childhood and Adolescence (Barker et al., 2014). Comparison to a normative population would allow coaches and practitioners to better understand individual strengths, weaknesses, physical training programme success and establish whether an individual is performing above or below normal expected performance.

Different sports require expression of different physical characteristics for successful performance. Typically, sports will evaluate the characteristics deemed important for expert adult performance and extrapolate back for assessment at junior level (Pion et al., 2014; Till and Baker, 2020). It is common for the physical performance testing of children and adolescents to occur within elite sport. Talent identification systems then attempt to predict future potential through assessment against these characteristics most relevant for future success (Till and Baker, 2020). Whereas collision sports such as rugby (Till et al., 2010; Jones et al., 2016) and American football (Jalilvand et al., 2019) place a premium on greater size, strength, speed and power; aesthetic sports such as gymnastics, diving, and ballet typically place greater emphasis on flexibility, balance, and smaller size (Baxter-Jones, Thompson and Malina, 2002). Other commonly played sports such as tennis and soccer require high levels of aerobic fitness, speed, strength and agility (Paul and Nassis, 2015; Myburgh et al., 2016). Athletic testing batteries are employed for numerous reasons, including the assessment and monitoring of athletic aptitude, evaluations of athletes' strengths and weaknesses, and the evaluation of athletic development and/or conditioning programmes (Bergeron et al., 2015). As such, sports will implement the most appropriate tests to assess and monitor the physical fitness of their athletes.

The development of a broad range of athletic skills during childhood and adolescence is considered important to underpin the capacity to perform as an elite, adult athlete (Lloyd and Oliver, 2012). Commonly known as long-term athletic development, emphasising the holistic development of individuals is thought to improve the potential for future athletic success (Bompa, 2000; Lloyd and Oliver, 2012). In addition, developing athletic skills whilst young has been shown to increase the intrinsic motivation to exercise, develops positive behaviours (Wang and Biddle, 2007) and enhances individual well-being (Ryan and Deci, 2000). Thus, consideration for a multitude of athletic capabilities when conducting the physical fitness testing of children and adolescents is important for both elite sporting success and general health. The use of physical fitness testing as part of talent systems is, therefore, important for the identification and long-term development of athletes and careful consideration of both current performance and future potential is needed. As part of this, it is imperative that the influence of growth, maturation and relative age on the expression of physical qualities is considered within fitness testing and talent identification processes of adolescents (Vaeyens et al., 2008).

As described in the above sections, adolescent physical fitness is important to consider in elite sport for talent identification, athletic development and evaluations of sports performance. The monitoring and understanding of physical fitness is also important in the normal paediatric population for improving health, fitness and physical activity levels. As previously described, growth and maturation have a positive influence on many aspects of youth athletic development, which all need to be considered within the dynamic and multi-factorial environment that is adolescent fitness and sport. With this in mind, the remainder of this review will examine the development of physical fitness during adolescence. It will also consider the effects of growth and maturation on specific physical attributes and discuss how these can be translated into performance, training and talent selection.

2.9 THE ROLE OF BIOLOGICAL MATURATION IN PHYSICAL FITNESS PARAMETERS

2.9.1 Strength Development

Strength can be defined as the ability to produce force (Siff, 2000). Strength is widely recognised as an important factor in athletic performance (Malina, Bouchard and Bar-Or, 2004) and as an underlying component of all other aspects of physical (Lloyd and Oliver, 2012) and motor fitness (Tveter and Holm, 2010). High levels of muscular strength is beneficial for reducing injury risk, for contributing to health-related issues such as skeletal bone health improvements (Yu et al., 2005) and to serve as a factor to positive psychological health and well-being in children and adolescents (Padilla-Moledo et al., 2012). With this in mind, the WHO now includes resistance training for strength development as part of their physical activity guidelines for children and adolescents (Organization, 2010). However, despite this, in the general paediatric population, muscular strength levels are decreasing (Cohen et al., 2011).

Muscular strength is influenced by multiple muscular, neural and biomechanical factors (Armstrong and Van Mechelen, 2008). It increases in a linear fashion throughout childhood in both sexes; specifically, strength improvements are seen from age 6 to approximately the start of puberty in boys (ages 12-13 years) and to the end of puberty in girls (approximately 15 years of age) (Beunen and Thomis, 2000; Croix, 2007). Sex differences during childhood are fairly small, however, males consistently outperform females in strength and power related tasks throughout childhood (Malina, Bouchard and Bar-Or, 2004). At the onset of puberty, a performance spurt is observed in boys until the late teens leading to a greater difference between adolescent males and females strength performance (Malina, Bouchard and Bar-Or, 2004).

Childhood increases in muscle strength are predominantly due to maturation of the central nervous system (Granacher et al., 2011), with improvements in motor unit recruitment, firing frequency, synchronisation and neural myelination all contributing factors (Kraemer et al., 1989). These neural developments continue into adolescence where growth- and maturity-related factors now also contribute to further strength improvements (Parker et al., 1990). These adolescent factors are largely structural and architectural developments of the muscular system, including increases in muscle cross-sectional area, muscle pennation angle and continued motor unit differentiation, and lead to enhanced ability to produce force (Tonson et al., 2008). Changes result largely from increased hormonal concentrations, particularly of testosterone, growth hormone and insulin-like growth factor, which increase more greatly in males than females (Malina, Bouchard and Bar-Or, 2004). It is as a result of these developments that during the pubertal period large sex differences begin to emerge with males showing a more accelerated strength development (Beunen and Malina, 2008). In boys, a natural peak in strength performance is thought to begin around 1.5 years prior to PHV, peaking approximately 0.5-1.0 years after PHV (Beunen and Malina, 1988). In females, whilst strength continues to increase during adolescence, the magnitude of change is a lot less dramatic, and improvements continue in a more subtle, linear manner (Croix, 2007). Improvement with age may vary according to the type of test carried out; grip strength has been shown to increase linearly from ages 11 to 17 years in girls, whilst pushing strength plateaued by about age 13 to 14 years (Malina, Bouchard and Bar-Or, 2004).

Strength performance during adolescence is influenced by biological maturation. In males, early maturing boys demonstrate greater strength than on-time and later maturing boys across the entire adolescent period (Beunen and Thomis, 2000). This is observed in elite athletes (Matthys et al., 2012) as well as the general male adolescent population (Malina, Bouchard and Bar-Or, 2004). The greatest difference according to maturity status is usually around the pubertal period of 13 to 16 years in boys (Malina, Bouchard and Bar-Or, 2004). Early maturing boys have also been shown to outperform average or late-maturing boys in pushing strength tests even after controlling for body-size differences. However, in some tests of strength, such as an upper body grip strength test, when performance is expressed relative to body weight, late maturing boys tend to perform better (Malina, Bouchard and Bar-Or, 2004).

In females, the impact of biological maturation on strength performance is less apparent. Longitudinal data in normal adolescent populations shows early maturing girls tend to be slightly stronger than later maturing girls until the age of around 13 years (Little, Day and Steinke, 1997). These results are also replicated in elite athletes, with studies observing maturity associated advantages in strength tests favouring early maturing females (Malina et al., 2011; Myburgh et al., 2016). This advantage in early adolescence is thought to be due to the larger body size of early-maturing females, and with age, those girls who are delayed or on-time in maturity may catch up the early maturing girl's strength levels, possibly because this body size difference is reduced. When strength is expressed relative to body mass, those early maturing girls now perform worse than their on-time or late maturing peers (Malina, Bouchard and Bar-Or, 2004). Similar findings are observed in elite, female athletes. Emmonds and colleagues (Emmonds et al., 2018) showed that peak force was greater for early maturing female soccer players, however, this performance advantage was removed when peak force was expressed relative to body mass.

2.9.2 Power Development

Whilst maximal strength is widely regarded as an important factor for successful athletic performance, in many sports, the ability to express this strength explosively, across a continuum of force production is equally, if not more, important (Dotan et al., 2013). For example, the rate of force development (RFD), that is, the development of maximal force in minimal time, may be more important than one's maximal force capability in actions such as jumping and sprinting which are commonly performed in sporting and athletic movements (Mero, Komi and Gregor, 1992; Young, Mclean and

Ardagna, 1995; McLellan, Lovell and Gass, 2011). Power output is the product of force and velocity, and thus is defined and limited by the force-velocity relationship (Hill, 1938). Power can, therefore, be defined as the point where maximal or near maximal rate of force development occurs (Stone, Stone and Lamont, 1993). Power is regarded as a critical physical determinant for success in many elite sports (Meylan et al., 2012) and has been shown to distinguish between elite and sub-elite athletes across many male sports, for example in soccer (Le Gall et al., 2010). Despite this, compared to other aspects of youth physical fitness, power development is an under-researched area (Sander et al., 2013).

The assessment of power can be measured by brief, maximal intensity exercise such as cycling, sprinting or jumping (Meylan et al., 2014). "True" peak power assessment requires instantaneous force and velocity measurement (Van Praagh, 2008) and whilst isokinetic dynamometry is considered the gold standard for true power assessment, this is not practical for field-based scenarios of assessment or for large cohorts. Instead, maximal cycling on a cycle ergometer and jumping tests are commonly used methods for power assessment in adult and youth populations (Davies and Young, 1985; Martin et al., 2004; Williams, Oliver and Faulkner, 2011).

A countermovement jump (CMJ) is a form of vertical jump whereby an individual performs a movement in the opposite (counter) direction to achieve more height from the subsequent, desired, upward jump (Vanezis and Lees, 2005). This is commonly performed with the use of arms to measure total body power, and with the hands on the hips, to measure leg power only. The jumping mechanism involves utilisation of the stretch-shortening cycle (SSC) muscle action, which is characterised by a muscle lengthening eccentrically, a subsequent rapid, powerful isometric contraction, the initiation of a myostatic stretch reflex, and finishing with an enhanced concentric muscle contraction. This results in a fast, powerful muscular action taking place (Lloyd, Meyers and Oliver, 2011; Lloyd et al., 2011). The SSC can be characterised into a fast or a slow action typically, dependant on whether the ground contact time is faster or slower than 250 milliseconds (Lloyd, Meyers and Oliver, 2011). Vertical jumping height measured through performance of a CMJ is a reliable (Lloyd et al., 2009) and commonly used power assessment method within paediatric populations (Van Praagh, 2008). Variations of jumping as a measure of power output are considered some of the most explosive tests one can use due to their short duration and the high intensity nature of the jumping movement (Cormie, McGuigan and Newton, 2011). In support of their use, the force-velocity-power profile during explosive jumps has been shown to differentiate between stronger and weaker athletes (Samozino et al., 2012). In addition, the vertical jump is a consistent component in many sports' testing batteries including, rugby (Cronin and Hansen, 2005), soccer (Vescovi and McGuigan, 2008), cycling (Stone et al., 2004) and basketball (Chaouachi et al., 2009).

Muscular power improves greatly during adolescence and longitudinal data using a cycling ergometer test has shown 102% improvements in peak power in boys between ages 12 to 17 years old (Martin et al., 2004). In addition, cross-sectional data using the same method of assessment has observed increases of 67% between ages 10 to 15 years and 91% from 10 to 21 years (Santos et al., 2002). Similarly, CMJ performance specifically improves with age during childhood and adolescence (Kellis et al., 1999; Vaeyens et al., 2006). There are two periods where greater natural improvements are observed, one during childhood between the ages of 5 to 10 years in both sexes, and one between the age of 9 to 12 years in females and 12 to 14 years in boys (Beunen and Thomis, 2000). In general, a linear increase in CMJ scores is observed in boys up until approximately 18 years of age, with an accelerated period during puberty. In females, a linear improvement in CMJ scores occurs up until the age of 14 years and thereafter, smaller increases are observed (Beunen and Thomis, 2000).

In a similar manner to the physiological development that underpins the natural development of strength, power performance is influenced by many morphological and neural factors, both of which change during growth and maturation (Dotan et al., 2013). Childhood improvements in power are attributed to enhancements of the nervous system, such as improved motor unit recruitment and activation, neural coordination, and enhanced stretch reflex responses (Lloyd, Meyers and Oliver, 2011; Dotan et al., 2012). The accelerated development of power during adolescence is a result of a combination of neural, hormonal, muscular and mechanical factors, such as muscle-tendon architecture and size, tendon stiffness, and muscle mass (Kubo et al., 2007; Ford et al., 2011). Each separate component of power, that is, force and velocity, are likely influenced differently during adolescent development (Meylan, Cronin, et al., 2014). For example, an increased muscle cross-sectional area with age will influence the force component, whilst an increased sarcomere length will more likely influence the velocity component of power (Van Praagh and Doré, 2002). Whereas, some growth and maturity related factors may influence both the force and velocity components, such as enhanced motor-unit recruitment that occurs (Dotan et al., 2012).

In general, the research examining power performance and biological maturation in males provides positive evidence for a relationship between the two. Studies have demonstrated power performance to be significantly associated with sexual (Malina et al., 2004; Quatman et al., 2006), skeletal maturation (Carling, Le Gall and Malina, 2012; Myburgh et al., 2016), and somatic maturation (Till and Jones, 2015; Dobbs et al., 2020) showing males advanced in maturation to outperform those individuals that are delayed in maturity. In general, the largest differences between boys of the same chronological age but varying maturity status occurs around puberty, between ages 13 to 16 years (Figueiredo, Coelho e Silva and Malina, 2011; Dobbs et al., 2020). This relationship between maturity status and power appears to continue when body mass and stature are controlled for (Ford et al., 2011). Not all research, however, supports this, and some studies have shown no association between jump performance and sexual maturity (Coelho e Silva et al., 2008). In addition, Figueiredo and colleagues (Figueiredo et al., 2009) demonstrated jumping performance did not differ in 11–12-year-old young footballers of differing maturity status, however, in 13–14-year-old footballers, CMJ and squat jump performances were better in the early maturers.

Evidence is less conclusive in females and several studies have observed little difference across maturity status groups in jump performance in both the normal female adolescent population (Little, Day and Steinke, 1997; Quatman et al., 2006) and in elite female athletes (Myburgh et al., 2016; Emmonds et al., 2020). However, in some studies, although not significant, later maturing females have performed slightly better than early maturing females in tests of power (Malina et al., 2011). During adolescence, the changes in body mass and stature may account for the majority of variation in power performance in females (Jones, Hitchen and Stratton, 2000) and upon controlling for body mass, a small difference between maturity groups in females has been observed, with later-maturing females outperforming earlier-maturing females (Little, Day and Steinke, 1997). The sex differences described above are likely due to the hormonal changes that take place during puberty, with greater increases in testosterone and growth hormone levels seen in males resulting in greater improvements in strength and power (Lloyd and Oliver, 2012).

When considered relative to maturity timing, the peak period of muscular power performance occurs after the adolescent growth spurt (Beunen and Malina, 1988). In males, a natural peak in muscular power performance begins to occur approximately 1.5 years before PHV, peaking 0.5 to 1.0 years after PHV (Philippaerts et al., 2006; Meylan et al., 2014). This aligns to the period of peak weight increase and it has been demonstrated that muscular power is closely dependent on body mass (Meylan et al., 2014). Despite the negative effects that body mass poses in jumping ability, it is likely that the positive neuromuscular changes that are taking place during this period reduce the negative impact of increased body mass (Butterfield et al., 2004) and in males increases in power have been observed independent of anthropometrics (Martin et al., 2004; Meylan et al., 2014). This results in the greatest improvements in power performance, when considered relative to maturity timing, to occur from the pre-PHV period to mid-PHV (Meylan et al., 2014).

2.9.3 Speed Development

Speed has been identified as a determining factor of successful performance in many sports in both children (Gravina et al., 2008) and adults (Reilly et al., 2000). It is also considered an important aspect of long-term athletic development (Balyi, Way and Higgs, 2013). It is a fundamental locomotion skill important for young people to master both to allow subsequent development of more complex skills (Gallahue and Donnelly, 2007) and to enhance the likelihood of participation in physical activities requiring general locomotion and movement control (van Beurden et al., 2002). For these reasons speed is often a key component in youth strength and conditioning programmes and athletic development programmes (Lloyd and Oliver, 2012).

The term speed usually encompasses three main components, namely acceleration, maximal speed and change of direction speed (Little and Williams, 2005). Acceleration is defined as the rate of change of velocity (Little and Williams, 2005) and is usually assessed across a distance of 5-10m (Varley and Aughey, 2013). Speed is defined as the time taken to cover a certain distance, measured in metres per second (National Strength and Conditioning Association, 2013), whereby maximal speed is the velocity at which an athlete can no longer accelerate when performing an ‘all out’ sprint effort (Buchheit and Laursen, 2013) and is usually assessed across distances of 20 to 40m (Buchheit et al., 2012). Change of direction speed, or agility, will be discussed in the next section.

The natural development of speed is influenced by age. Increases in speed are observed through a young person's childhood and adolescent years (Schepens, Willems and Cavagna, 1998; Malina, Bouchard and Bar-Or, 2004). This natural development occurs in a non-linear manner, with periods of accelerated natural improvement occurring both in childhood and adolescence (Viru et al., 1999). The childhood period of accelerated improvement in speed is underpinned by similar physiological developments as those of strength and power, with nervous system adaptations at the centre of these childhood improvements (Viru et al., 1999). These central nervous system developments, such as enhanced motor recruitment and coordination, likely translate into sprint mechanical improvements by positively influencing upper and lower limb coordination (Borms, 1986). Neural adaptations continue into adolescence as children continue to refine their motor recruitment and coordination patterns (Malina, Bouchard and Bar-Or, 2004). Similar physiological changes to those underlying strength and power increases during adolescence also underpin the second period of accelerated speed increase. The adolescent performance spurt is maturity dependant and occurs around the onset of PHV and puberty. It is primarily the result of endocrine-mediated strength and power improvements, with increases in circulating hormonal levels (testosterone and growth hormone) fundamental to these physical changes (Oliver, Lloyd and Rumpf, 2013). In particular, increases in limb length, muscle mass, changes to the musculo-tendon unit and to anaerobic metabolism properties result in maturation having a large influence on speed development (Oliver, Lloyd and Rumpf, 2013).

Historically, the majority of research that has considered maturational influences on speed performance has previously been carried out in tasks such as plate tapping and shuttle running tests (Lefevre et al., 1990; Malina, Bouchard and Bar-Or, 2004), rather than maximal sprint running tests, which would be more applicable for athletic performance today. More recently, however, more studies are researching sprinting performance in young people, with a particular focus on the kinetics and kinematics of sprinting (Oliver, Lloyd and Rumpf, 2013; Rumpf et al., 2015; Meyers et al., 2017; Meyers et al., 2019).

When considering the underlying kinematics of sprinting fast, speed can be considered as the product of stride length and stride frequency (Mero, Komi and Gregor, 1992). Stride length and stride frequency change independently throughout childhood and adolescence and are underpinned by several factors (Schepens, Willems and Cavagna, 1998). Namely, anthropometric changes in leg length increases the distance covered during the aerial phase of a stride, whilst an improved ability to apply force into the ground increases contact length (the distance covered during the contact phase). These contribute to increasing step length and so improving speed in young people (Oliver, Lloyd and Rumpf, 2013; Rumpf et al., 2015). In addition, the force generating capacities of the individual, the rate of force development as well as leg stiffness, contribute to enhanced step length and frequency in young people (Oliver, Lloyd and Rumpf, 2013). Relative vertical stiffness and peak force are important determinants of sprint speed in adolescent boys aged 11 to 16 years (Meyers et al., 2019) and are significantly greater in individuals that have already passed through the growth spurt (Rumpf et al., 2015). Whilst horizontal force and power during sprinting are significantly greater in individuals both during and after PHV (Rumpf et al., 2015) and may explain all of the variance in maximal speed in children from the pre-pubertal stage to post-puberty (Oliver, Lloyd and Rumpf, 2013).

A threefold increase in maximal speed occurs from infancy to adulthood which has historically been largely attributed to increases in leg length and therefore stride length, rather than frequency (Schepens, Willems and Cavagna, 1998). Recent research has, however, proposed that speed may be more closely associated with step frequency prior to puberty and step length following puberty in boys (Meyers et al., 2015). Leg length, and thus step length, increases do not appear to translate into sprint performance improvements until PHV, when it is believed that the maturity-related increases in ground contact time (GCT) become stabilised (Meyers et al., 2017). Increased GCT has a negative effect on speed because it means a longer time is spent on the floor rather than moving forwards (Weyand et al., 2010). GCT increases up to PHV as a result of body mass increases, however it begins to stabilise around PHV (Meyers et al., 2015). This stabilisation likely occurs because force generating capacities, SSC function and lower limb stiffness improve during adolescence to negate body mass increases, leading to faster ground contact times and improved force generation with each stride, resulting in maturity-related speed improvements (Meyers et al., 2016). In support of this, recent longitudinal data has observed that anthropometric changes were not a significant predictor of changes in sprint speed in boys over a 21-month period, highlighting the importance of these other underpinning physical qualities (Read et al., 2016). Therefore, less mature boys may be more reliant on a high stride frequency to achieve maximal speed whereas more mature boys may rely on stride length. This is supported by younger children increasing their stride frequency to compensate for having shorter legs when compared to adolescents and adults (Oliver, Lloyd and Rumpf, 2013).

In general, early maturing males display superior speed than their later maturing counterparts. This has been observed in both elite and non-elite populations, and across various measures of maturity, namely skeletal (Carling, Le Gall and Malina, 2012; Myburgh et al., 2016), sexual (Malina et al., 2004) and somatic maturity (Meyers et al., 2015; Rumpf et al., 2015; Meyers et al., 2017). The research is, however, not entirely conclusive and some studies have observed no difference in speed across age-matched individuals of varying maturity status (Coelho e Silva et al., 2008; Figueiredo et al., 2009). Some studies have also shown some variability in results dependant on the age group tested; Figueiredo and colleagues demonstrated that skeletal maturity was significantly associated with superior speed performance in 13- to 14-year-olds but not in 11- to 12-year-olds (Figueiredo et al., 2010).

Research establishing periods of peak sprint speed development have not been conclusive although there is a recent sway towards a peak period of speed development in males occurring around PHV. Some studies have suggested the greatest improvements in sprint performance to occur 1.0-1.5 years after PHV (Yagüe and De La Fuente, 1998), whilst others have shown the largest improvements from 1.5-0.5 years prior to PHV (Yagüe and De La Fuente, 1998; Philippaerts et al., 2006). More recently, greater evidence is suggesting the greatest natural improvements in speed occur around PHV and just after. Rumpf and colleagues (Rumpf et al., 2013) observed speed performance increased substantially more from pre-PHV to mid-PHV, compared to mid- to post-PHV. Meyers and colleagues (Meyers et al., 2015) observed no speed improvement in adolescents up until 0.5 years before the growth spurt, but then observed an increase in maximal speed at PHV and after and attributed this to increases in stride length. A recent study demonstrated that boys who were going through their growth spurt increased their maximal sprinting speed by 10.4%, whilst those boys who had not yet gone through their growth spurt improved by 5.6% (Read et al., 2016). Whilst longitudinal studies monitoring boys across a 21-month period observed greater speed improvements in the group of boys who had passed through their growth spurt, compared to those who had not (Meyers et al., 2016). This evidence further highlights the influence of a maturational effect on sprinting speed in youth populations, in addition to the recent advancements in understanding the maturational influence on sprinting kinetics and kinematics (Meyers et al., 2015).

Much of the research described in this section has been conducted in young, male cohorts. There is, on the whole, a lack of research in female athletes and the physical performance of females (Emmonds, Heyward and Jones, 2019). Myburgh and colleagues have observed no significant association between sprint performance and maturity status in elite, female tennis players (Myburgh et al., 2016). This has also been observed in non-elite samples, whereby there was a non-significant tendency for average and late maturing females to be faster than early maturing individuals (Little, Day, and Steinke, 1997). BMI is positively associated with sexual maturity in girls, with early maturing girls more likely to be heavier, and even more overweight, than later maturing girls (Beunen et al., 1997). Sprinting involves moving your body mass as fast as possible, and therefore the greater the mass to move, the harder it will be, unless the individual has a greater underlying strength capability to negate the increased body mass. This may explain why early maturing females are generally not as fast as later maturing females, despite being slightly stronger. In support of this, a recent study evaluated the kinetic and kinematic changes during childhood and adolescence in females (Nagahara et al., 2019). More rapid increases in speed were seen up to age 12.7 years, after which speed improved at a lower rate. Although maturation was not measured, the greater speed improvements in younger girls coincided with greater increases in propulsive impulse and step length. These kinetic and kinematic differences were attributed to reduced limb growth and increases in fat mass in the older individuals (Nagahara et al., 2019).

In general, boys are faster than girls at all ages, however this becomes more evident around puberty (Malina, Bouchard and Bar-Or, 2004). Speed improvements also plateau earlier in females, at around 12 to 13 years in girls, whereas this occurs at age 15 years in boys (Papaiakovou et al., 2009). Differences in adolescent hormonal profiles contribute greatly to this performance difference. Boys experience a 10-fold increase in testosterone levels around puberty which leads to an increase in muscle mass, amongst other neuromuscular improvements (Meyers et al., 2015). This results in strength and power improvements which are likely to influence sprint speed (Lloyd et al., 2011; Meyers et al., 2015). As previously mentioned, girls do not experience this neuromuscular spurt during puberty and instead accumulate greater amounts of fat mass (Malina, Bouchard and Bar-Or, 2004). The increase in body mass experienced, combined with limited strength and power improvements, likely negatively impacts sprint performance improvements in adolescent females. This is supported by studies that have observed absolute force to increase in females but not relative force once body mass is accounted for (Emmonds et al., 2018).

Fluctuations in performance are often reported to occur around the period of peak growth, particularly in boys (Philippaerts et al., 2006; Meyers et al., 2015). This growth-related phenomenon is termed ‘adolescent awkwardness’ and can be defined as a temporary disruption to motor coordination resulting from rapid increases in limb length (Philippaerts et al., 2006). In addition, a lack of strength and effectiveness to apply force, as well as possible developmental changes of how the brain processes information about body positioning, may also contribute (Viel, Vaugoyeau and Assaiante, 2009; Meyers et al., 2015). These factors are thought to negatively influence neuromuscular control and proprioceptive ability, which may in turn, impact athletic performance measures. Although adolescent awkwardness is a commonly used term, there is a lack of clear evidence to support its existence and its transfer into athletic performance is still to be understood (Davies and Rose, 2000). Emerging evidence, however, appears to support at least a plateau in tasks requiring coordination and balance during the growth spurt in boys (Butterfield et al., 2004; Quatman-Yates et al., 2012; Ryan et al., 2018). Philippaerts and colleagues also reported a decline in 30m sprint performance around 12 months prior to PHV, which could coincide with the growth in limbs, with subsequent peak improvements around PHV (Philippaerts et al., 2006).

2.9.4. Agility Development

Agility has been defined as a rapid whole body movement with a change of direction or velocity in response to a stimulus (Sheppard and Young, 2006). Agility is an important physical quality for successful performance in many male and female sports (Jeffreys, 2006), including soccer (Stølen et al., 2005), basketball (Delextrat and Cohen, 2008) and lacrosse (Enemark-Miller, Seegmiller and Rana, 2009). Good agility ability allows an individual to evade an opponent or achieve positional space in match play situations often seen in sport (Chaouachi et al., 2012). There are two key components of agility, a speed component termed change of direction speed, and a perceptual, decision-making component (Lloyd et al., 2013). In sports performance, the variation in stimuli requiring an individual to make a decision about a change direction is vast (e.g., reacting to a ball, an opponent, a teammate).

A successful agility manoeuvre requires the performance of many sub-component skills, including the ability to accelerate, decelerate, change direction and reaccelerate in a predetermined manner (Cooke, Quinn and Sibte, 2011). Whilst this action does not have a reactive component and therefore does not take into account the variability of stimuli and openness seen in many sports, pre-planned agility based movements have been shown to play an important role in many sporting scenarios (Spiteri et al., 2013). In many multi-directional, agility-based team and individual sports, athletes are commonly required to perform a linear sprint of a fairly short distance (5-30m), they must then decelerate and subsequently change direction (Hewit et al., 2010). Agility assessments focusing on the change of direction speed element, such as the 505-agility test used in the studies in this thesis, measure agility performance without the perceptual and cognitive element. The movement is pre-planned in these tests, with an understanding of where to perform the fast change of direction i.e. on a line 10m ahead. Non-reactive agility tests, such as the 505-agility test, have been shown to distinguish between playing levels in youth sports such as soccer (Reilly et al., 2000) and basketball (Torres-Unda et al., 2013). From here on in, change of direction speed performance will be referred to as agility, and reactive agility will be referenced as such. The majority of this section will discuss agility performance without the reactive element.

Consistent with the previously discussed physical qualities of strength, power and speed, agility performance improves in a non-linear fashion throughout childhood and adolescence (Vänttinen et al., 2011). During childhood there is little difference in performance between genders (Eisenmann and Malina, 2003). Childhood improvements in agility are predominantly due to developments of the nervous system, with inter- and intramuscular coordination and motor control improvements enhancing the ability to change speed and direction (Lloyd et al., 2013). Around the pubertal period, sex differences in performance begin to appear. This is due to the hormonal changes that occur during puberty influencing neuromuscular developments to a greater extent in males than in females (Lloyd et al., 2013).

A peak in agility performance is believed to occur around the period of PHV (Vänttinen et al., 2011; Zemková and Hamar, 2014). After the peak period of growth, agility performance of females plateaus whilst males show a continued improvement (Eisenmann and Malina, 2003). In line with this, 14-year-old boys have a better agility performance than 12-year-old boys (Jakovljevic et al., 2012). Longitudinal tracking of young soccer players also demonstrated improved agility performance with both chronological and biological age until 3.5 years after the growth spurt (Carvalho et al., 2017). Contradicting this, Arede and colleagues found pre-PHV elite basketball players were more agile than post-PHV basketball players (Arede et al., 2019). However, these less mature players had more basketball training experience, which may have influenced results.

Agility performance in young athletes is one of the most under researched fitness components in paediatric literature (Lloyd et al., 2015). Various factors underpin agility performance, however the extent to which these have been studied in youth populations is sparce. In general, determinants of agility include muscle qualities such as leg strength, power and reactive strength (Young, James and Montgomery, 2002;

Spiteri et al., 2013), sprint speed (Vescovi and McGuigan, 2008), and anthropometrics (Lloyd et al., 2013). A relationship between agility and sprint speed (Condello et al., 2013) and agility and power has been demonstrated in young athletes (Negra et al., 2017). A recent study by Hammami and colleagues (Hammami et al., 2018) demonstrated the relationship between agility, speed and jumping was greater for post-PHV individuals compared to pre-PHV individuals, suggesting the relationship between agility performance and other physical qualities may depend on age or maturity status.

Concerning maturity timing and agility performance, males who are advanced in maturity status appear to perform better than those who are not (Malina, Bouchard and Bar-Or, 2004). This is supported by studies in athletic populations which have observed earlier maturing adolescent boys to be more agile than their later maturing counterparts (Matta et al., 2014; Guimarães et al., 2019). The two key physical factors closely associated with agility, namely linear speed and force production capabilities (strength and power) (Young, James and Montgomery, 2002; Vescovi and McGuigan, 2008; Spiteri et al., 2013) are closely related to maturation, especially in boys, as mentioned in previous sections. Maturity-associated performance variance of these qualities, therefore, likely influences agility performance. Boys of advanced maturity are both faster (Malina, Bouchard and Bar-Or, 2004) and stronger (Beunen and Thomis, 2000) than average and later maturing boys. Although further research is required to further the understanding of agility performance in male adolescents, the close relationship between growth and maturation and the underlying physical components of agility (speed, strength, and power) support observations that earlier maturing males are more agile than their later maturing counterparts.

The evidence for the influence of maturity status on female agility performance is not extensive nor conclusive. In contrast to the results described for male adolescents, later maturing adolescent females may be more agile than earlier maturing females

(Little, Day and Steinke, 1997). Coupled to this, there is a tendency for later maturing females to be faster than earlier maturing females (Little, Day and Steinke, 1997) which may assist a superior agility performance in late maturing females. In contrast to the results described by Little et al., (Little, Day and Steinke, 1997) recent studies in elite athletes have observed different results, with earlier maturing females outperforming their on-time and later-maturing counterparts (Myburgh et al., 2016; Emmonds et al., 2018). Further research is required to fully understand the influence of maturation on agility development in both sexes during adolescence.

When considering agility performance during adolescence, it is worth noting the impact of body mass. Agility-based actions require the acceleration, deceleration, and reacceleration of the body in space. When body mass is controlled for in strength tests, earlier maturing males still outperform later maturers (Malina, Bouchard and Bar-Or, 2004). Whereas in females, although heavier individuals produce more absolute force than lighter individuals (Malina et al., 2011), lighter females perform change of direction movements faster (Bourgeois et al., 2017). Further, the advantage of greater force production capacities with earlier maturation is removed when expressed relative to body mass (Emmonds et al., 2018), and later maturing females outperform earlier maturers in tests of strength (Malina, Bouchard and Bar-Or, 2004). This information suggests that later maturing females may perform better in agility tests than early maturers due to the impact of body mass in combination with the influence of growth and maturity on strength, speed and power, all of which have been shown to impact agility performance in youth.

2.9.5 Balance Development

Balance can be defined as the ability to maintain the body's centre of gravity over its base of support with minimal sway or maximal steadiness (Horak, 1987). Balance can be considered both in a static and dynamic form, and although not entirely mimicking the demands of sport, dynamic balance more closely represents athletic movement patterns and actions (Gribble, Hertel and Plisky, 2012). Static balance requires an individual to minimise body movement about the base of support and dynamic balance requires controlled movement about the base (Gribble, Hertel and Plisky, 2012). Faigenbaum and colleagues recently defined dynamic balance as the ability to maintain stability while anticipating and reacting to changes as the body moves through space (Faigenbaum et al., 2015). Much of the literature on balance often uses the term postural control or stability interchangeably with balance; postural control is the term used to describe the ability to maintain balance and sense shifts in balance; postural stability is the ability to maintain, achieve or restore a state of balance (Horak, 2006). Due to the interchangeable nature of these terms, for the purpose of clarity the remainder of this thesis will use the term balance when discussing this topic area.

Although balance is not a physical quality considered within the youth physical development model (Lloyd and Oliver, 2012), the ability to stabilise and balance dynamically is an important prerequisite for successful motor performance and motor skill acquisition, and as such, is often developed within strength and conditioning programmes (Favazza et al., 2011). Balance can, therefore, be classed as a fundamental skill (FMS); FMS's consist of locomotor (e.g., running and hopping), manipulative or object control (e.g., catching and throwing) and stability skills (e.g., balance and twisting) (Gallahue, Ozmun and Goodway, 2006). Development of FMS's provide the building blocks to perform more complex motor tasks and provide the foundations for an active life (Gallahue, Ozmun and Goodway, 2006). FMS are also considered to be important for a child's physical, cognitive and social development and therefore good balance performance is an important aspect of an individual's development as well as being essential for carrying out actions for normal, everyday living (Payne and Isaacs, 1995).

Dynamic balance is also often assessed by physiotherapists and athletic trainers in relation to injury prevention or rehabilitation (Gribble, Hertel and Plisky, 2012). Poor static balance has been identified as a possible predictor of ankle injuries (McGuine et al., 2000) and poor dynamic balance may predict lower limb injuries (Plisky et al., 2006), including the professional sports career threatening anterior cruciate ligament injury (ACL) injury (Paterno et al., 2010). Neuromuscular training programmes that enhance balance are often used in the prevention of injuries (Myer et al., 2011). Balance performance assessment can, therefore, provide useful information to aid with the evaluation of injury risk, assess changes following injury and assess improvement after injury rehabilitation interventions (Gribble, Hertel and Plisky, 2012).

As well as balance underpinning development of more complex movement skills and reducing the risk of injury, excellent balance performance may also transfer to the successful execution of other physical qualities. An individual's balance may enhance the effectiveness of the postures adopted and improve the efficacy of the directional change in agility performance (Sekulic et al., 2013). An association between balance, strength, and power performance in adolescent male soccer players has also been demonstrated, with a higher correlation at increasing maturation (Hammami et al., 2016). Whilst a strong correlation between balance and ice-skating speed in adolescent male ice hockey players has also been demonstrated (Behm et al., 2005). Question marks have, however, been raised as to whether the same results are observed in non-athletic populations (Muehlbauer, Gollhofer and Granacher, 2015). Therefore, given balance performance is an important FMS, used in injury rehabilitation programmes and is an important pre-requisite for more complex motor skills, the importance of evaluating balance for athletic performance of young people is justified.

Good balance performance is dependent on the central nervous system and involves the integration of information from the visual, vestibular, and proprioceptive systems

(Fong and Ng, 2012). A stimulus received from one of these systems then elicits a response from the neuromuscular system, resulting in adjustments of posture to maintain the body's centre of gravity over the base of support in response of the information received (Burton and Davis, 1992). Balance performance is, therefore, likely influenced by maturation of the neurological, visual, vestibular, and proprioceptive systems (Burton and Davis, 1992). The contributions of sensory inputs from these various systems are believed to change with growth and maturation (Assaiante and Amblard, 1995). For example, during periods of rapid pubertal growth or periods of 'adolescent awkwardness' individuals may neglect proprioceptive information and favour capturing information from other sensory systems, such as the visual system (Assaiante et al., 2005; Viel, Vaugoyeau and Assaiante, 2009). This possible maturational dependent difference in the strategies used to maintain and develop balance is supported by studies that have evaluated performance in balance tests. Adolescents are less readily able to use proprioceptive information during balance test execution when compared to adults (Viel, Vaugoyeau and Assaiante, 2009). Children also appear to have an increased reliance of visual cues when learning and mastering new skills and postural challenges (Assaiante et al., 2005). It has been proposed that this slower development of proprioceptive mechanisms could be detrimental to adolescent motor control progression, contributing to the 'athletic awkwardness' sometimes experienced during the growth spurt. As such, some aspects of motor skill development, such as neuromuscular control, postural stability and interlimb coordination may be negatively affected by a not yet fully mature sensorimotor system (Quatman-Yates et al., 2012).

Balance improvements are observed during childhood and into adolescence (Malina, Bouchard and Bar-Or, 2004; Mickle, Munro and Steele, 2011). Although a level of balance control is established around the ages of 7 to 10 years (Roncesvalles, Woollacott and Jensen, 2001), adults perform better in tasks requiring balance than children (Sakaguchi et al., 1994). Several studies have observed sex differences in the balance performance during childhood and adolescence. Although maturation was not assessed in these studies, the authors attributed the better performance of females in balance tests to the earlier maturation of the visual, vestibular, and proprioceptive systems (Cratty, 1979; Mickle, Munro and Steele, 2011). Other factors have been provided to explain the better performance of females, such as a lower attention span in boys (Steindl et al., 2006) and differences in body weight (Lee and Lin, 2007). Additionally, centre of mass (COM) heightens with skeletal growth (Quatman et al., 2005). A heightened COM negatively impacts postural sway, an underlying component of balance performance (Ojie, Saatchi and Saatchi., 2020). An increase in COM also reduces muscular control about the lower limb joints which may negatively impact balance performance (Quatman et al., 2005). These factors resulting from an increase in COM height may contribute to a superior balance performance in females than males. Balance development may also be influenced by interactions with the environment (Roncesvalles, Woollacott and Jensen, 2001). In support of this, one study observed no sex differences prior to puberty but then showed boys outperformed females from ages 11-12 years. The authors attributed this to differences in environmental interactions, such as an increased amount of active play and physical activity, rather than growth or maturation differences (Thomas and French, 1985).

There is little research examining the influence of maturation on balance performance. Rommers and colleagues (Rommers et al., 2019) demonstrated that later maturing adolescent boys outperformed earlier maturing boys in a balance test. In contrast, a recent study by Lesinski et al., (Lesinski et al., 2020) demonstrated performance in the Y-balance test of balance did not significantly change with maturity status, as assessed by the Mirwald maturity offset method, in both elite, athletic adolescent boys and girls. Additionally, a recent study evaluating the influence of maturity timing observed pre- and post-PHV boys performed better than circa-PHV boys in various tests of balance (Hammami et al., 2016). Unquestionably, further research is needed to explore the influence of growth and maturation on balance performance during adolescence.

2.9.6 Momentum Development

Momentum is the product of mass and velocity and is a particularly desirable physical attribute in impact sports such as rugby union (Baker and Newton, 2008), rugby league (Till et al., 2015), and American football (Jalilvand et al., 2019). Furthermore, momentum significantly differentiates playing levels in rugby players (Baker and Newton, 2008).

Limited research has explored momentum performance in adolescents, however given that momentum is a function of speed and mass, examining these two factors may offer insight into momentum performance. During adolescence, speed performance improves in males until approximately 15 years of age and until 13 in females (Papaiakovou et al., 2009). Body mass generally increases until ages 15 and 13 years in males and females, respectively, where it then begins to slow down into early adulthood (Malina, Bouchard and Bar-Or, 2004). As a consequence of these changes, it could be expected that momentum performance improves with age during the adolescent period. Although no studies have considered changes in momentum performance with age during the younger adolescent period, improvements in momentum performance have been observed in older adolescents, from 16 to 20 years (Barr et al., 2014; Till et al., 2015). No studies, to my knowledge, have considered momentum performance in female adolescents.

A limited number of studies have researched the relationship between biological maturation and momentum. Those studies that have assessed this relationship have found a relatively strong correlation between the two variables (Howard et al., 2016). That is, early maturing boys displayed a superior momentum performance than their later maturing peers. The authors of this study attributed this correlation to a greater mass with advancing maturation and when BMI was controlled for, the impact of maturity status on momentum was reduced. In support of this, a separate study compared differences between senior and junior rugby players who were travelling at the same speed and attributed differences in performance to differences in body mass, with heavier individuals demonstrating superior momentum performance than lighter individuals (Barr et al., 2014). Further research is required to add weight to the recent studies considering momentum performance during adolescence, particularly in female cohorts given the absence of any research in this field.

2.10 RELIABILITY AND VALIDITY OF FITNESS TESTING IN ADOLESCENT POPULATIONS

Physical fitness can be objectively and accurately measured in both laboratory and field settings. Often laboratory testing of a physical attribute provides the gold-standard methods of assessment, however, such tests are often not feasible for using in school environment or in studies with large cohorts. This is due to high costs, specialist equipment, the need for trained technicians and time constraints (Artero et al., 2012). Field based tests are, therefore, more routinely used.

Over the past thirty years numerous fitness testing protocols in youth populations have been developed (Castro-Piñero et al., 2010). The reliability and validity of tests are important to consider when choosing and administrating a test. Validity describes the ability of the test to measure what it is designed to measure. Reliability describes the reproducibility of the test and refers to consistency of measurements of the same test in the same individual (Heale and Twycross, 2015). A variety of testing methods will now be discussed focusing on the physical fitness components evaluated in the studies in this thesis.

2.10.1 Strength Testing

A variety of tests exist to assess upper body strength in adolescents in a field-based setting, however handgrip strength assessment, as measured with a dynamometer, appears to be the most commonly used in experimental and epidemiological studies of children and adolescents (Castro-Piñero et al., 2010; Ardoy et al., 2011; Ruiz et al., 2011). Validity and reliability of the handgrip test to measure adolescent upper body strength has previously been demonstrated (España-Romero et al., 2010). Reliability coefficients for use of this test in youth populations have been reported as 0.96-0.98 with non-significant differences ($p > 0.05$) between test and retest (España-Romero et al., 2008). Whilst some studies have questioned the validity of the handgrip test, suggesting posture (España-Romero et al., 2010) and grip span (España-Romero et al., 2008) can influence results, a recent study observed a strong association between hand grip strength testing and the gold standard laboratory isokinetic testing method, suggesting handgrip strength to be a valid field-based test for muscular strength (Artero et al., 2012). There is also an argument to suggest the handgrip test is the most feasible assessment to carry out within large groups due to its simple requirements of a very small space and small equipment (Saint-Maurice et al., 2015). The dynamometer should comprise four important properties; to be able to accurately determine and replicate hand grip strength; to function independent of handgrip size; to be comfortable to use; and to be small enough to be used for field-based measurements (Solgaard, Kristiansen and Jensen, 1984).

2.10.2 Power Testing

Laboratory tests, such as isokinetic dynamometry, are considered the gold standard assessment for muscular power, however, are impractical for use in field-based testing. Various measures for assessing power in youth populations have been used in the research, including bouts of maximal cycling, running tests and jump tests (Van

Praagh and Doré, 2002). Jump height is an indirect measure of muscular power and this method is commonly used in adolescent populations (Van Praagh, 2008). The standing countermovement jump is a type of vertical jump, as used in the studies in this thesis, and has been shown in various studies to be both a reliable (ICC = 0.95) and a valid (r = 0.806) method of assessing power in the paediatric population (Lloyd et al., 2009; Fernandez-Santos et al., 2015). A recent review of vertical jump performance in adolescents established a standardised movement profile that should be performed to produce more accurate results (Petrigna et al., 2019). This included starting the CMJ from a fully erect, upright position with hands on hips. This start position should be maintained for two seconds before descending to reach a knee angle of 90°. The individual must then perform a maximal effort jump of the floor and achieve a fully straight legged position in the air.

2.10.3 Speed and Momentum Testing

A variety of methods can be used to assess speed, such as timing lights, torque treadmills and nonmotorized treadmills, however the feasibility of conducting school-based fitness testing using treadmills is not possible. Overground sprinting is the easiest, most popular and accurate measurement of youth sprint performance (Rumpf et al., 2011). A recent review of the methods used to assess speed in athletic and non-athletic youth populations identified that the use of timing gates is the most commonly used form of assessment method and the fastest sprint time from multiple sprints is the preferred protocol for assessment (Rumpf et al., 2011). Reliability of overground sprinting in youth populations has been evidenced (Paul and Nassis, 2015) and intra- and interday CVs for distances of 10, 20, 30 and 40m were reported to range from 0.83-2.07% and intra- and interday ICCs ranged from 0.88 and 0.98 for 10-40m (Rumpf et al., 2011). A small amount of error is associated with using single beam timing systems, as used in the studies in this thesis, due to variance of the beam being broken by a limb as opposed to the torso (Earp and Newton, 2012).

However, the reliability of testing improves as sprint distance increases, possibly due to this error becoming negligible as sprint distance increases (Darrall-Jones et al., 2016).

Momentum assessment in youth athletes is novel with limited other studies in this area. Good reliability for momentum assessment has been observed in adult populations (Barr et al., 2014), however reliability and validity has yet to be proven in youth populations.

2.10.4 Agility Testing

There are many different agility tests that can be used within a testing battery, although, as previously discussed, the majority are change of direction tests without a reactive component resulting in perhaps an untrue reflection of the open and variable nature of sport (Sheppard and Young, 2006). Despite this, change of direction agility tests have been shown to distinguish amongst sports performance levels (Roetert et al., 1995; Sierer et al., 2008) and also distinguish between the amount of playing time athletes receive in various sports (Hoffman et al., 1996), and so are often used in tests of agility performance within sport. Although reactional agility tests provide accurate results in young populations, these tests require specialist, costly equipment to complete (Zemková and Hamar, 2014). Various change of direction based agility tests have shown good reliability in older adolescents, namely the Illinois, L-run, Pro-agility, T-test and 505-agility test (Stewart, Turner and Miller, 2014). Specifically, the 505-agility test has been shown to have very high reliability with an ICC of 0.88 (Stewart, Turner and Miller, 2014) and is a frequently chosen method to test agility in youth populations (Thomas, French and Hayes, 2009; Condello et al., 2013).

2.10.5 Balance Testing

In youth populations there are fewer established methods of assessing balance and dynamic postural control performance than most other measures of physical fitness testing. Balance assessments included in the paediatric literature include a single leg static stance for time (Atwater et al., 1990), time to stabilisation following a landing (Zech et al., 2014), unilateral balance tests with unstable surfaces (Emery et al., 2005), and the measure of postural sway during a single leg stance (Fong and Ng, 2012). Whilst some of these methods may be appropriate for use in field-based testing, others can be time consuming or have a need for specialist, expensive laboratory-based equipment.

The lower quadrant Y-balance test (YBT), as used in studies in this thesis, is a popular balance assessment method which has shown good reliability in adults (Kinzey and Armstrong, 1998) and is now commonly used in adolescent testing batteries. The YBT is reliable in adolescents (Plisky et al., 2006) and feasible and reproducible in children (Faigenbaum et al., 2014). Moderate to good reliability scores have been established with ICC scores ranging from 0.71-0.84 for children ages 6-11 years and 0.81-0.96 in adolescents ages 14-15 years (Filipa et al., 2010). Although reasonably cheap, the YBT requires a specific piece of testing equipment which could be a barrier in school environments or athletic development programmes. It is, therefore, not uncommon for practitioners to create their own device. A recent study by Faigenbaum and colleagues (Faigenbaum et al., 2015) provided evidence for good consistency of scores produced from both the standard YBT equipment and a homemade device, suggesting using a homemade device, as carried out in this thesis, is of sufficient standard.

2.11 Conclusion

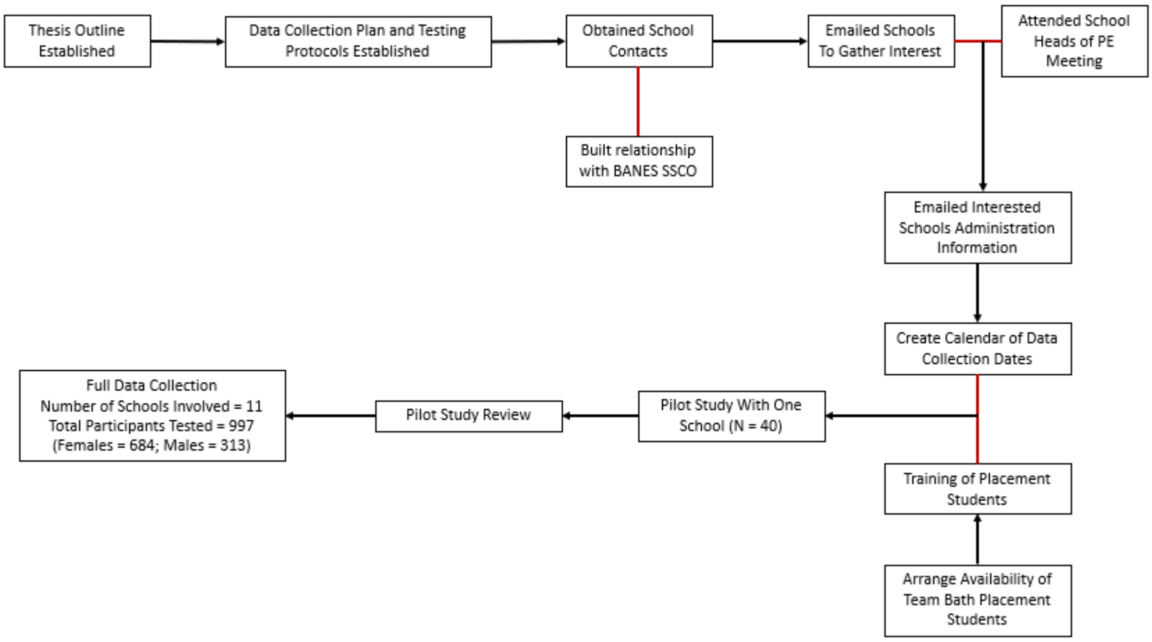
The natural development of physical fitness occurs throughout childhood and adolescence. Growth and maturation are biological processes that take place throughout a young person's childhood and adolescent years and it is evident that these biological processes contribute to changes in physical fitness. The extent of the contribution varies depending on the physical quality being considered (Malina, Bouchard and Bar-Or, 2004). Individuals of the same chronological age can differ in terms of their timing and tempo of maturation, and they can also vary in terms of their relative age, where one individual could be nearly 12 months older than a peer if grouped into a single year cohort. These individual differences in maturation result in some individuals within a single age group being advanced in their maturation, whilst others may be delayed (Malina, Bouchard and Bar-Or, 2004). Variation in growth and maturation can mask or enhance physical attributes in youth and this can lead to difficulties in understanding true, current athletic performance during adolescence, as well as challenges predicting future athletic potential (Cumming, 2018). This presents a challenge for coaches and practitioners working with young people, particularly in talent identification settings, and when considering the assessment, tracking and development of physical fitness (Bergeron et al., 2015).

In light of the preceding discussion, there is a need to better understand the influence of growth, maturation, and age on physical fitness development during the adolescent period to create a more developmentally accurate representation of physical fitness. Although several studies have recommended the consideration and/or adjustment for individual differences in biological maturation (Golle et al., 2015; Cumming et al., 2017; Till et al., 2018), none have reliably assessed the influence of biological maturation and relative age on the physical performance of normal adolescents in athletic fitness tests. The majority of studies have evaluated performance of elite youth populations. In addition, organisations such as the Premier League, have generated age- and maturation-specific standards to assess and monitor youth footballers (https://www.goalreports.com/EPLPlan.pdf). Whilst this provides useful insight pertaining to elite sport, it does not enhance knowledge of normal fitness development. Those studies that have evaluated normal, adolescent populations, have used the Mirwald Maturity Offset method to assess maturity (Till et al., 2018). Due to the unreliability of this method, inaccurate adjustments and assessment of fitness will have been made. Further, there is a clear need to establish more developmental aligned strategies and standards for considering youth physical fitness. These need to account for the changes in growth, maturation, and age. This will allow for a more accurate reflection of true fitness, improved monitoring of fitness, greater objectivity in fitness assessment, more targeted physical interventions and more informed talent identification and athlete management in elite, youth populations.

CHAPTER THREE

STUDY METHODOLOGY

This chapter describes the data collection methodology involved across all studies in this thesis. One data collection process, spanning two academic years, took place for all studies. Figure 3.1 outlines key parts of the administration and methodological process of data collection. Specific study methodological requirements are described in the relevant studies within this thesis (for example, maturity status calculation).



3.1 Flow diagram detailing the administration and methodological process of data collection for all studies

3.1 ADMINISTRATION

3.1.1 School Recruitment

Secondary schools in the South-West of England were contacted to obtain interest in being involved in the study. Schools contacts were obtained from The University of Bath networks and from connections made with the Bath and North East Somerset (BANES) School Sports Coordinator (SSCO). Attendance at a Schools' Heads' of PE meeting took place to talk through the study and enhance participation interest from schools.

In total, eleven schools were involved in the data collection for the studies in this thesis and one school took part in the pilot study. Those twelve schools were sent an extensive information pack detailing the aims, procedures and logistics of the data collection process. This included a School Participation Proposal; Head Teacher Consent Form; Teacher Information Sheet; Parental Information Sheet and Opt Out Form; Parental Heights Collection Sheet.

Data collection was carried out in the academic years of 2014-15 and 2015-16. To increase the reliability and accuracy of the data, as many schools as possible were recruited for data collection. The cessation at eleven schools was due to the time constraints associated with the data collection processes.

3.1.2 Participants

Across the eleven schools that took part in the testing, a total number of 997 schoolchildren, aged 11 to 15 years, participated. Of this, there were 684 females and 313 males. There were a greater number of females recruited due to two of the schools being all girls' schools.

3.1.3 Ethics and Consent

This study was approved by the Research Ethics Approval Committee at the host University. Informed written consent was obtained via the school's head teacher acting *loco parentis* and a parental opt out option was given to every individual. Self-assent was obtained for the participant. The participants' schoolteachers were informed about the procedures and aims of the study prior to completion and only those participants that indicated a willingness to take part were included.

3.2 PRE-DATA COLLECTION

3.2.1 Familiarisation Phase

Assistants were recruited to assist delivery of the fitness testing sessions at the schools and collect the data. These assistants were university students on a placement year at The University of Bath and in total, 6 students helped with the data collection. To ensure reliability of data collection, a familiarisation phase was carried out. This familiarisation process involved training the assistants on setting up and delivering each fitness test, the writing down of results, the warmup protocols and the instructions to use to the schoolchildren during fitness test completion.

3.2.2 Pilot Study

The familiarisation phase was finished with a pilot study whereby fitness testing and data collection was carried out on one school (n = 40). The fitness testing protocols were carried out as described below, however the data was not used in the studies. No amendments to the testing protocols were made following completion of the pilot study, however it provided an opportunity to practise delivering the testing session in its entirety.

3.2.3 Fitness Testing Set Up

All testing sessions took place within the usual P.E. lesson that the school children would be involved in. The setting up of the testing stations took place prior to the start of the lesson. Once all school children and their teachers were present, the testing session commenced. This began with a briefing to all children and the teachers present on the expectations of the testing session, the reasons for doing the tests and the outputs the children and schools would receive. Following the introduction, the schoolchildren were split into pre-allocated groups to perform the tests in a round-robin format. Each testing station was manned and delivered by two assistants; one assistant focused on instructing the school children to complete the test, the other on recording the data.

3.3 DATA COLLECTION

3.3.1 Measurements

Decimal age for each participant was calculated from date of birth and the date of which the measurements and tests were administered. The age range of the sample was 11-15 years and athletes were grouped according to whole age, whereby within an age group the chronological ages of the participants would be between .00 to .99 years of that age group. Height was measured using the stretch stature method for assessment (Tanner, 1962) using a Leicester height measure Stadiometer and was measured to the nearest 0.1cm. That is, participants stood barefoot with their feet together and arms by their sides and took a deep breath in while the assessor used minimal upwardly pressure on their face to ensure full stature was reached. The stadiometer headboard was then placed on the top of the participants head and measurement taken. Intra-investigator and inter-investigator technical error of measurement scores were 0.1 and 0.19 respectively. An electronic weighing scale (Seca scales 813 Robusta) was used for measurement of weight and measured to the nearest 0.1 kg. Participants stood barefoot on the scales and balanced their weight evenly prior to measurement being recorded.

3.3.2 Fitness Testing Protocols

After a standardised warm-up, the schoolchildren performed a series of physical fitness tests, namely tests of upper body strength, power, linear speed (incorporating acceleration speed at 10m and maximal speed at both 20m and 30m), agility, momentum, and balance. Familiarisation of each test was carried out prior to test completion. Familiarisation involved performing the test due to be completed several times, with minimal coaching received where the exercise was not understood.

Upper Body Strength

The handgrip strength test measures the maximal isometric force that can be generated by the upper body, mainly by the forearm. The participant stood in a standard bipedal position. The arm being tested gripped the dynamometer (physio med grip strength dynamometer) above the head without touching any part of the body and with the elbow fully extended, as described in previous literature (España-Romero et al., 2010). The participant was then instructed to grip the dynamometer and squeeze as hard as possible whilst moving the dynamometer from above the head to the side of the body. The dynamometer was adjusted to hand size for each child according to the sex-specific equations described by Ortega and colleagues (Ortega et al., 2008). The assessment was carried out on both arms and the score was calculated as the best effort of right and left handgrip strength; higher scores indicate better performance. Results were expressed in absolute terms and measured to the nearest 0.1kg.

Validity (España-Romero et al., 2010) and reliability (Teeple et al., 1975) of the handgrip test to measure upper body strength in adolescents has previously been demonstrated. The handgrip strength assessment, as measured with a dynamometer, appears to be the most commonly used in experimental and epidemiological studies of children and adolescents (Castro-Piñero et al., 2010; Ardoy et al., 2011; Ruiz et al., 2011). In addition, a strong association between the field-based hand grip strength testing and the gold standard laboratory isokinetic testing method has recently been observed (Artero et al., 2012). For further details, please see Chapter Two.

Speed and Momentum

The sprinting speed and momentum of participants was evaluated from performance of a maximal linear sprint effort. This provided information on the participant's ability to accelerate (10m speed), their maximum running velocity (20m and 30m speed) as well as their initial sprint momentum ability (momentum). Electronic timing gates (Brower Timing Lights) were positioned at 0m, 8m, 12m, 20m and 30m from a pre-determined static starting position placed at 1m behind the 0m timing gate. The participants were instructed to run as fast as possible from the starting point to the end point. Three sprint efforts were recorded for each participant and at least three minutes of recovery was given between sprint efforts. Speed was measured to the nearest 0.1s, with the fastest score from three trials used as the speed score.

Momentum was calculated by multiplying the mass of the athlete by the 10m velocity for each individual. Velocity was calculated as 1/(sprint time/4) resulting in $m \cdot s^{-1}$ over 8-12m. Velocity at 10m was calculated from an 8m to 12m average rather than a direct 10m time to provide a more accurate description of how the athlete was accelerating with increasing distance. This protocol for measuring momentum is similar to that used by Barr and colleagues (Barr et al., 2014). Momentum was measured to the nearest 0.1 $kg \cdot m^{-1} \cdot s^{-1}$.

The method described above for sprint assessment in adolescents is reliable and valid (Paul and Nassis, 2015). A recent review of the various sprint testing methods used to assess speed in youth populations identified that the use of timing gates is the most commonly used method to assess speed within this population (Rumpf et al., 2011). The fastest sprint time from multiple sprints is also as the most commonly used protocol for assessment and so was the protocol used in the present study (Rumpf et al., 2011). Few other studies have assessed momentum performance in youth athletes. Good reliability for momentum assessment has been observed in adult populations (Barr et al., 2014), however reliability and validity has yet to be proven in youth populations. See Chapter Two for further details.

Agility

The 505-agility test was used to assess the participant's agility performance. This assessed the ability to change body direction and reposition rapidly through the performance of a 5m sprint with a 180º turn of both legs, followed by a 5m reacceleration. Two electronic timing gates (Brower Timing Lights) were placed 5m from a designated turning point. The participants assumed a starting position 10m from the timing gates (and therefore 15m from the turning point). Participants were instructed to accelerate as quickly as possible from the static start position through the timing gates, performing a 180º cut on the turn line and sprint back through the timing gates as quickly as possible. Each participant performed four maximal effort sprints with two turns on each leg. Times were measured to the nearest 0.1s with the fastest value obtained from the two trials. There are a variety of agility focused testing protocols available to use, however, the 505-agility test is commonly used in elite team sport settings and has been shown to have very high reliability (Stewart, Turner and Miller, 2014). For further details, please see Chapter Two.

Power

The vertical countermovement jump (CMJ) was used to measure power. Two variations of this test were employed within this study and subsequent studies. A CMJ without the use of arms was used to measure lower body power and a CMJ with the use of arms measured total body power. A Smartmat 2 Jump mat system was used for both jumping assessments. The subject was instructed to stand on the jump mat and perform a maximal effort vertical jump from a standing upright position that included a countermovement prior to take-off (Komi and Bosco, 1978). A standardised movement pattern was instructed for each performance, that is, holding the fully erect, upright position start position with hands on hips for two seconds. The movement then requires a descent to reach a knee angle of 90°. The individual must then perform a maximal effort jump of the floor and achieve a fully straight legged position in the air (Petrigna et al., 2019). Following instruction on how to perform each test, participants performed practise jumps prior to being assessed. Each test was performed three times meaning six jumps in total were performed. Verbal encouragement was given during the test. The best of the three jumps was recorded for each jump. At least a 3 minute rest was given between performances of each jump type. Lower body power and total body power was measured according to vertical jump height, expressed to the nearest 0.1cm.

Laboratory tests, such as isokinetic dynamometry, are the gold standard tests for muscular power assessment, however, they are impractical for use in field-based testing (Heyward and Stalarezyk, 1991). Various measures for assessing power in youth have been used in the research, including bouts of maximal cycling, running tests and jump tests (Van Praagh and Doré, 2002). The vertical countermovement jump, as used in the current study, has been shown in various studies to be both a reliable and a valid method of assessing power in the paediatric population (Lloyd et al., 2009; Fernandez-Santos et al., 2015). See Chapter Two for further details.

Balance

The Lower Quadrant Y Balance Test was used to assess balance and postural stability by measuring single leg dynamic movements in three lower limb directions of the participants. Each participant undertook at least four practise trials in each direction to minimise a learning effect (Munro and Herrington, 2010). The participant stood on one leg on the designated start line and maintaining a single leg stance, reached with the free limb in the anterior, posteromedial and posterolateral directions in relation to the stance foot. The distance obtained by measurement of the big toe of the reach leg was recorded using affixed tape measurers in each orientation. The participant performed three trials of each direction on each leg. The measurement was deemed invalid if the participant failed to maintain a unilateral stance, failed to maintain reach foot in contact with the line or failed to return the reach foot to the starting position under control (Coughlan et al., 2012). Invalid trails were discarded, and participants repeated the trial. Reach distances from 3 trials in each direction were averaged and the sum of the average reach distance for each direction was calculated to give a total score. Values were expressed to the nearest 0.1cm.

In youth populations there are fewer established methods of assessing balance and dynamic postural control performance than most other measures of physical fitness testing. Alternative methods to the one used in the present study include; a single leg static stance for time (Atwater et al., 1990), time to stabilisation following a landing (Zech et al., 2014), unilateral balance tests with unstable surfaces (Emery et al., 2005) and the measure of postural sway during a single leg stance (Fong and Ng, 2012). Whilst some of these methods may be appropriate for use in field-based testing, they can be time consuming or have a need for specialist, expensive laboratory-based equipment. The lower quadrant Y-balance test is a popular method which has shown good reliability in adults (Kinzey and Armstrong, 1998) and is now commonly used in adolescent testing batteries (Faigenbaum et al., 2014; Read et al., 2019). Studies have observed moderate to good reliability scores, with Intraclass Correlation (ICC) scores ranging from 0.71-0.84 for children ages 6-11 years and 0.81-0.96 in adolescents ages 14-15 years (Filipa et al., 2010). See Chapter Two for further details.

3.4 REFLECTIONS OF THE DATA COLLECTION PROCESS

The data collection period was well organised and ran smoothly. However, fitness testing in school's was challenging due to the lack of time schools have to both complete the fitness testing within the school day, and the time needed to organise the logistics and administration of the process. With that in mind, a commitment was made to carry out data collection across two academic years and no longer. This resulted in 997 schoolchildren being tested. Whilst this, I believe, is a good number of participants, not all of these participants were able to be included in the studies due to having an incomplete data set. In particular, a greater number of male participants would have been preferable to increase the accuracy and reliability of data.

It is recognised that the ethnic diversity of schoolchildren within the cohort tested may not represent the diversity across the U.K. However, for the purposes of enhancing understanding of how growth and maturation influences fitness and developing standards that can be used across the U.K, the data collected in this thesis and the results produced provide a valuable initial step.

Similarly, the variation in SES of participants across the eleven schools involved in the study would not be wholly representative of the variation in SES across the U.K. Whilst the results developed in this thesis are limited to the population in the studies, I do not think a greater range of SES of participants would change the results.

However, future studies could include a greater range of both ethnicity and SES in participants to explore how these two factors influence the results.

CHAPTER FOUR

THE AGE ASSOCIATED VARIANCE AND MAIN AND INTERACTIVE EFFECTS OF RELATIVE AGE AND MATURATION UPON THE PERFORMANCE OF MALE ADOLESCENTS IN TESTS OF ATHLETIC FITNESS

4.1 ABSTRACT

PURPOSE: To establish the contribution of chronological age, and the main and interactive effects of relative age and biological maturity status, upon the performances on athletic tests of physical fitness among boys. **METHODS:** Standardised tests of linear speed, initial sprint momentum, agility, upper body strength, lower body, and total body power and balance were administered to 212 boys of 11 to 15 years. The main and interactive effects of relative age and biological maturity status (percentage of predicted adult stature attained at measurement) on fitness test performances were assessed concurrently using a series of multiple regression analyses. **RESULTS:** Univariate analyses of variance revealed significant differences across all fitness variables by chronological age ($p < 0.01$), with the mean values for all tests showing a trend towards improving. Correlations indicated no association between relative age and maturity status. The percentage of variance explained by the multiple linear regression models ranged from 21% (lower body power) to 48% (momentum). Advanced maturity status was positively associated with momentum and strength ($p < 0.001$) and inversely associated with balance ($p < 0.001$). An older relative age was inversely associated with sprint performance across 20m and 30m ($p < 0.05$), i.e., lower times or better performances, but negatively associated with balance ($p < 0.01$). The interaction of relative age x maturity status was a significant predictor of upper body strength ($p < 0.05$). **CONCLUSION:** Relative age and biological maturity status are independent constructs that differentially affect performances in several fitness tests among adolescent males. Practitioners should be aware of potential independent effects of relative age and maturity status when evaluating and monitoring the fitness of adolescent boys.

4.2 INTRODUCTION

Physical fitness describes a set of attributes that people have or achieve in relation to their ability to perform physical activity (Riddoch and Boreham, 1995). The physical fitness of young people is receiving ever growing interest due to the concerns over physical inactivity and obesity levels in the population (Bürgi et al., 2011; Griffiths et al., 2013). Coupled to this, youth fitness levels have declined over the last 30 years (Tomkinson et al., 2003) which coincides with a decline in paediatric performance in fitness tests (Catley and Tomkinson, 2011. The 2015 International Olympic Committee consensus statement on youth athletic development states 'The goal is clear: Develop healthy, capable and resilient young athletes, while attaining widespread, inclusive, sustainable and enjoyable participation and success for all levels of individual athletic achievement' (Bergeron et al., 2015). Recent years have seen improvements in youth physical development models (Lloyd and Oliver, 2012), an increased focus on using sport as a tool to increase physical activity (Blanchard, Shilton and Bull, 2013; Pate, 2009; Howie et al., 2020) and improved knowledge of talent identification and selection (Pearson, Naughton and Torode, 2006). This has allowed for more informed physical fitness testing, development, training and talent identification of young individuals.

Within schools, developmental programmes and sports clubs, youth are traditionally grouped by chronological age, e.g., U-11 or U-12 (Cumming et al., 2017). As such, youths train and compete, and are also compared, with peers within the chronological age range that defines the competitive age group. The latter, of course, depends upon the cut-off dates that define an age group; cut-off dates, however, may vary among sports. Nevertheless, young people in the same chronological age group not only vary in relative age but also in biological maturity status (Nahhas et al., 2013). As such, variation in relative age and maturity status within an age group may influence assessments of athletic aptitude and fitness in adolescents; the latter is especially marked during puberty when maturity-associated variance in size and function in fitness in considerable (Lloyd and Oliver, 2012). The latter reflects individual differences in maturity status *per se* and in the differential timing of growth spurts in size, aerobic capacity, strength and power (Malina, Bouchard and Bar-Or, 2004; Malina et al., 2019). The individual differences in maturity status and timing, and associated variation in behaviour, present a challenge for practitioners and teachers, especially in the context of fitness monitoring and talent evaluation (Malina et al., 2015).

Relative age refers to the difference in chronological age between individuals born in the same selection year; and is determined by date of birth and cut-off dates (Hill et al., 2019). As such, a young person born early in the selection year may be almost 12 months older than a child born at the end of the year, if they are within a single-year age group. Relative age differences may be greater in sports that use two-year age groupings (Ortigosa-Márquez et al., 2018) or in programmes with limited numbers of youths in single year groups (e.g., rural communities). An older relative age is well documented as a factor contributing towards athletic performance and selection among males; those born within the first half of the selection year are more likely to be selected into, and represented on, elite level programmes in early childhood through late adolescence (Votteler and Höner, 2014). This phenomenon, known as the relative age effect (RAE), has been documented in multiple sports and varies with selection or cut-off dates (Boucher and Mutimer, 1994; Edgar and O'Donoghue, 2005; Mujika et al., 2009). Relative age is also associated with height and weight and relatively older athletes are taller and heavier (Carling et al., 2009). In contrast, evidence linking relative age to fitness is inconclusive, and several studies have observed no relationship between birth date distribution and physical fitness (Carling et al., 2009; Huertas et al., 2019). Observations of RAEs in non-physical achievement domains (e.g., chess and academics) also suggest that the phenomenon is not entirely attributable to developmental differences in size and physicality (Helsen et al., 2016). Rather, it is more likely associated with age-related variation in experience and in cognitive, motor, and social aptitudes. This concept is further strengthened by the emergence of RAE's prior to puberty (Helsen et al., 2012; Sierra-Díaz et al., 2017).

Biological maturation refers to the progression towards the adult or mature state (Malina, Bouchard and Bar-Or, 2004). Maturation occurs in multiple biological systems (e.g., skeletal, endocrinal, dental, sexual, somatic) and can be considered in terms of its status, timing and tempo (Baxter-Jones, Eisenmann and Sherar, 2005; Malina et al., 2015). Maturity status refers to the state of maturation at the time of observation (skeletal age and pubertal status), while maturity timing refers to the age at which specific maturity milestones are attained (age at peak height velocity); maturity tempo, on the other hand, refers to the rate at which the maturation process progresses (Malina, Bouchard and Bar-Or, 2004; Malina et al., 2015; Malina, 2018, 2019). Maturity status and timing are largely influenced by genotypic factors in healthy, well-nourished youth (Malina, 2014).

Maturity status and timing impact strength and performance on a variety of fitness tests in males more so than females (Malina, Bouchard and Bar-Or, 2004), and also impact athletic performance and athlete selection in males (Cumming et al., 2017). Boys who mature early are taller, heavier and possess greater absolute and relative lean mass, and demonstrate superior performances on tests of strength, power, and speed (Malina, Bouchard and Bar-Or, 2004). Although the physical and functional advantages associated with advanced maturity status in males are maintained throughout adolescence, they may be attenuated and reversed in early adulthood (Lefevre et al., 1990). Not surprisingly, a selection bias towards males advanced in maturity status is evident in sports that place a greater premium on size, strength, speed, and power. This bias emerges with puberty, increases with age, and is accentuated in national and elite level programmes (Whiteley, Johnson and Farooq, 2017).

Contrary to lay opinion, and that of some scholars, relative age does not imply advanced maturation. Rather, relative age and biological maturation are separate constructs that operate independently of each other (Cumming et al., 2017). Relative age is a function of birth and cut-off dates, while maturity status and timing are largely based on genotype; as such, it is possible for the oldest player within an age group year to be the least biologically mature, and vice-versa (Malina, 2014). Within single-year age groups there is also greater potential for variation in maturation than relative age; the latter is limited to a maximum of one year, while biological maturity status can vary by several years among athletes of the same chronological age (Johnson, 2015). The independent nature of these constructs is further illustrated in selection biases and the age at which they emerge. RAE's are present from early childhood; whereas the bias towards earlier maturing males does not emerge until puberty/adolescence (Cumming et al., 2017).

Given the complexity of adolescent development and physical fitness, the influence of biological maturity and relative age on the development of fitness is an important consideration for practitioners working with the paediatric population. Whilst several studies have evaluated the performance of non-elite adolescents in more athletically focused tests (Espana-Romero et al., 2010; Ruiz et al., 2010; Tremblay et al., 2010; Catley and Tomkinson 2011; Golle et al., 2015; Laurson et al., 2017), they have not explored how the main and interactive effects of maturation and relative age contribute to fitness. The International Olympic Committee Consensus on Youth Athletic Development recently highlighted the complexity of assessing adolescent physical fitness, stating "athletic development is multidimensional and difficult to assess in youth" (Bergeron et al., 2015). Despite the research evaluating the impact of maturity status and relative age on fitness in athletic populations, the influence of these two constructs on physical fitness in school youth has not yet been considered. This, in combination with the routine fitness testing that occurs within elite settings, results in much of the understanding of performance across athletic fitness coming from a pre-selected, homogenous group of individuals in a specific sport (Barker et al., 2014). Indeed, the contribution of these two factors may be greater in non-athletic samples due to the increased heterogeneity of individuals resulting from the absence of athlete selection.

The purpose of this study is to develop contemporary data for the age-associated variance, and critically, evaluate the main and interactive effects of relative age and biological maturity status, upon athletic tests of physical fitness in a sample of adolescent male school children 11-15 years of age. In line with previous research, it is expected that strength, speed, power, momentum and agility performance will improve with age. Whilst less research exists in assessing balance performance during adolescence, the somatic changes that take place during adolescence lead to an elevation of centre of mass (COM) and this may have a negative impact on coordination and balance (Quatman et al., 2005; Ojie, Saatchi and Saatchi., 2020). It is, therefore, hypothesised that balance performance will not improve with chronological age in this male cohort. In addition, it is predicted that older relative age and advanced maturity status would be associated with better performances on tests of physical fitness in general, and that variance in performance on the fitness tests would be influenced by the interaction between relative age and maturity status.

4.3 METHODOLOGY

See Chapter Three for a more detailed description of study methodology.

4.3.1 Participants

The sample included 212 males of 11 to 15 years of age enrolled in schools located in the South-West of England in the 2014-15 and 2015-16 school years. Participants conducted the testing in their academic year groups. However, for analysis of data, participants were grouped into whole age cohorts according to their decimal age. For example, an individual that was 12.3 years of age would be evaluated within the 12-year age category.

4.3.2 Ethics and Consent

This study was approved by the Research Ethics Approval Committee at the host University. Informed written consent was obtained via the school's headteacher acting *loco parentis* and a parental opt-out option was given to every individual. Self-assent was obtained for each participant. The schoolteachers were informed about the procedures and aims of the study and only those participants that indicated a willingness to take part were included.

4.3.3 Maturity Status

Percentage of predicted adult height attained at the time of testing was used as the indicator of maturity status. Height (stretch-method, Tanner) and weight (Seca scales 813 Robusta) of each boy were measured. Decimal age, height, and weight of the individual, and mid-parent height, were used to predict mature, adult height for each participant using equations developed on the Fels Longitudinal Study sample in south-central Ohio (Khamis and Roche, 1994). Parental heights were self-reported prior to the testing session and were adjusted for overestimation (Epstein et al., 1995). Where this information was not possible, the participant could participate in the testing session, but his results were not used in the analysis. The current height of each participant was expressed as a percentage of his predicted adult height; by inference, the boy closer to mature height (higher percentage) is advanced in maturity status compared to the boy who is further removed (lower percentage). The percentage of predicted mature stature was also converted to a z-score to provide a means to classify participants by maturity status. Z-scores above +1 and below -1 are commonly used, respectively, to classify youth as early and late maturing; a z-score between +1 and -1 classifies youth as average or on-time (Cumming et al., 2009).

4.3.4 Biological Age

An estimate of biological age was calculated by comparing the percentage of peak adult stature to age- and sex-specific reference standards generated from the UK 1990 growth reference data (Freeman et al., 1995). Consistent with the method employed by Gillison et al., (Gillison et al., 2017), reference standards for the percentage of adult height attained at 0.1 yearly intervals were established. Percentages were based on mean values for stature attained at each age interval, as well as the mean value for stature at and above 18 years of age. For example, a boy of chronological age 12.5 years who was measured at 90% of his predicted peak adult stature (PAS) would have achieved a %PAS equivalent to the mean %PAS attained by a boy of 13.67 years of age. Consequently, he would be given a biological age of 13.7 years.

4.3.5 Relative Age

Relative age was calculated for each boy as the difference between birth date and the end date of the academic year (August 31^{st}), divided by the number of days within the year (Cumming et al., 2018). It was expressed as a decimal value between 0 and 0.99, with the lowest and highest representing the youngest and oldest individuals, respectively.

4.3.6 Fitness Tests

The fitness test battery adopted in the study was based on consideration of tests commonly used in athletic testing protocols to assess the most important fitness qualities for youth athletic development and performance in physical activity and sport. The battery included a handgrip strength test (dynamometer) as an estimate of upper body strength, a 30m linear sprint with 8m, 12m, 20m and 30m splits to determine 10m acceleration, 20m and 30m maximal speed and momentum, the 505-agility test as an indicator of agility performance, the vertical countermovement with and without arms to determine total body and lower body power, respectively, and the lower quadrant Y-balance test as an indicator of balance. For further details on the test protocols used see Chapter Three.

4.3.7 Statistical Analysis

All data were analysed using Statistical Package for the Social Sciences (SPSS) for Windows Version 23; minimal statistical significance was set at ($p < 0.05$). Descriptive statistics were calculated for all the variables. A series of univariate analyses of variance (ANOVA) were conducted to investigate the differences between chronological age groups and the various physical fitness attributes. Partial eta squared were conducted to examine the direction and magnitude of variance between each fitness attribute and age group. The criteria for effect size, as described by (Cohen, J., 1988) were set at: small = < 0.01; moderate= < 0.06; large = < 0.14. Post Hoc analysis of pairwise comparisons was conducted, with significance set at $p < 0.05$ to examine the difference between fitness variables and age groups.

Correlations were calculated to evaluate relationships (magnitude and direction) among the variables of interest. The criteria for magnitude of correlation, as described by (Cohen, 1988) were set at: small = 0.1; moderate = 0.3; large = 0.5. Finally, a series of stepwise multiple linear regression analyses, controlling for whole age cohort, were performed to investigate the main and interactive effects of relative age and maturity status upon each physical fitness variable. To reduce the risk of co-linearity among predictor variables, the relative age x maturity status interaction was derived from centred scores (relative age – mean relative age) x (z-score – mean z-score) and then included in the third and final stage of the model.

4.4 RESULTS

4.4.1 Descriptive Statistics

Descriptive statistics for chronological age, height, weight, relative age, biological age, percentage of predicted adult height, and maturity z-score are summarised by age group in Table 4.1. Mean values for height, weight, biological age, and percentage of predicted adult height increased with age group. The mean for maturity z-scores approximated or was above zero in all age groups. Descriptive statistics for fitness variables are presented in Table 4.2. The mean performances in all tests of fitness systematically increased with age.

Table 4.1. Descriptive statistics (mean ± standard deviation) for chronological age, body size, relative age, and estimated maturity status by age groups

	11 Years (n = 22)	**12 Years (n = 37)**	**13 Years (n = 34)**	**14 Years (n = 80)**	**15 Years (n = 39)**
Variables	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Chronological Age	11.6 (0.30)	12.5 (0.31)	13.6 (0.30)	14.6 (0.26)	15.4 (0.23)
Height (cm)	149.6 (6.86)	155.6 (9.72)	164.6 (8.03)	169.7 (7.44)	172.1 (5.94)
Weight (kg)	44.4 (11.65)	49.7 (12.83)	53.6 (9.58)	57.2 (10.76)	60.5 (15.77)
Relative Age	0.47 (0.32)	0.42 (0.34)	0.40 (0.33)	0.53 (0.31)	0.69 (0.24)
Biological Age	11.75 (1.00)	12.53 (1.07)	13.72 (0.94)	14.65 (0.77)	15.68 (0.90)
Predicted Adult Stature, %	83.26 (3.25)	85.81 (3.81)	90.36 (3.54)	93.81 (2.28)	96.65 (1.72)
Z-Score	0.12 (1.49)	0.05 (1.26)	0.23 (0.89)	0.21 (0.55)	0.36 (0.46)

Table 4.2. Descriptive statistics (mean ± standard deviation) for fitness tests by age groups

Variables	11 Years (n = 22) M (SD)	12 Years (n = 37) M (SD)	13 Years (n = 34) M (SD)	14 Years (n = 80) M (SD)	15 Years (n = 39) M (SD)
Lower Body Power (cm)	23.6 (5.6)	24.0[a] (4.7)	27.1 (6.2)	29.3[c] (6.0)	32.2[a] (5.1)
Total Body Power (cm)	26.0 (5.8)	27.9[a] (5.4)	31.4 (6.7)	33.6[c] (6.3)	36.9[a] (6.4)
10m Speed (s)	2.1 (0.2)	2.0 (0.1)	2.0[b] (0.2)	1.9 (0.1)	1.8 (0.1)
20m Speed (s)	3.9 (0.4)	3.6 (0.2)	3.5[b] (0.3)	3.4 (0.2)	3.2 (0.2)
30m Speed (s)	5.6 (0.6)	5.2 (0.4)	5.0[b] (0.5)	4.7 (0.3)	4.5[a] (0.3)
Agility (s)	3.1 (0.3)	3.0 (0.3)	2.9[b] (0.3)	2.8[a] (0.2)	2.7 (0.2)
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	207.6 (48.1)	238.3 (50.8)	273.6 (49.4)	305.8 (62.3)	332.8 (80.4)
Upper Body Strength (kg)	21.2 (4.5)	24.6[a] (7.9)	29.4 (7.3)	33.4[b] (8.7)	39.2 (8.3)
Balance (cm)	194.1[a] (31.5)	212.9 (25.2)	217.9[a] (22.4)	234.3 (18.6)	236.0 (21.6)
	[a] = n = 21	[a] = n = 38	[a] = n = 33 [b] = n = 35	[a] = n = 82 [b] = n = 84 [c] = n = 86	[a] = n = 38

4.4.2 Univariate Analyses of Variance

A series of univariate analyses of variance (ANOVA) were conducted to investigate age-related differences in fitness attributes. Significant differences were observed across all fitness variables by chronological age ($p < .01$). Specific details pertaining to each analysis are as follows:

Acceleration Speed

A significant main effect for age was observed for acceleration, as measured by speed at 10m, $F(4,208)=26.2$, $p < .001$, $\eta^2 = .34$. More specifically, mean values for acceleration decreased with age and age explained 34% of the variance in acceleration, demonstrating a large difference in acceleration across age group. Pairwise comparisons revealed significant differences in acceleration across a number of the age groups (See Table 4.3). More specifically, the greatest single age differences occurred between ages 13 to 14 years (0.11) (See Table 4.3).

Maximal Speed

A significant main effect for age was observed for maximal speed, both 20m and 30m maximal speed, $F(4,208)=33.8$, $p < .001$, $\eta^2 = .39$ and $F(4,207)=37.2$, $p < .001$, $\eta^2 = .42$ respectively. Mean values for maximal speed decreased with age and age explained 39% and 42% of the variance in 20m and 30m speed respectively, demonstrating a large difference in maximal speed across age group. Pairwise comparisons revealed significant differences in speed across a number of the age groups (See Table 4.3). Specifically, the greatest single age differences occurred between ages 11 to 12 years for both 20m and 30m speed (0.24 and 0.40 respectively) (See Table 4.3).

Agility

A significant main effect for age was observed for agility, $F(4, 210) = 18.0$, $p < .001$, $\eta^2 = 0.26$. Mean values for agility decreased with age and age explained 26% of the variance in agility, demonstrating a large difference in agility across age group. Pairwise comparisons revealed significant differences in agility across a number of the age groups (See Table 4.3). The greatest single age differences occurred between ages 11 to 12 years (0.19) (See Table 4.3).

Power

A significant main effect for age was observed for total body power, $F(4, 213) = 14.6$, $p < .001$, $\eta^2 = 0.22$ as well as for lower body power $F(4, 213) = 16.9$, $p < .001$, $\eta^2 = 0.24$. Mean values for power increased with age and age explained 22% and 24% of the variance in total body and lower body power respectively, demonstrating a large difference in power across age group. Pairwise comparisons revealed significant differences in power across a number of the age groups (See Table 4.3). The greatest single age differences occurred between ages 12 to 13 years for both total body and lower body power (3.48 and 3.11 respectively) (See Table 4.3).

Upper Body Strength

A significant main effect for age was observed for upper body strength, $F(4, 211) = 27.1$, $p < .001$, $\eta^2 = 0.34$. Mean values for upper body strength increased with age and age explained 34% of the variance in upper body strength, demonstrating a large difference in upper body strength across age group. Pairwise comparisons revealed significant differences in upper body strength across a number of the age groups (See

Table 4.3). The greatest single age differences occurred between ages 14 to 15 years (5.87) (See Table 4.3).

Balance

A significant main effect for age was observed for balance, $F(4, 205) = 19.1$, $p < .001$, $\eta^2 = 0.27$. Mean values for balance increased with age and age explained 27% of the variance in balance and demonstrated a large difference across age group. Pairwise comparisons revealed significant differences in balance across a number of the age groups (See Table 4.3). More specifically, the greatest single age differences occurred between ages 11 to 12 years (18.85) (See Table 4.3).

Momentum

A significant main effect for age was observed for momentum, $F(4, 207) = 22.78$, $p < .001$, $\eta^2 = 0.31$. Mean values for momentum increased with age and age explained 31% of the variance in momentum, demonstrating a large difference in momentum across age group. Pairwise comparisons revealed significant differences in momentum across a number of the age groups (See Table 4.3). More specifically, the greatest single age differences occurred between ages 12 to 13 years (35.25) (See Table 4.3).

Table 4.3. Differences in mean values for each physical test variable across multiple age groups

	11 v 12	11 v 13	11 v 14	11 v 15	12 v 13	12 v 14	12 v 15	13 v 14	13 v 15	14 v 15
Lower Body Power (cm)	0.46	3.57$_a$	5.74$_c$	8.59$_c$	**3.11$_a$**	5.28$_c$	8.13$_c$	2.17	5.03$_c$	2.86$_b$
Total Body Power (cm)	1.97	5.45$_c$	7.69$_c$	10.94$_c$	**3.48$_a$**	5.72$_c$	8.97$_c$	2.24	5.49$_c$	3.24$_b$
10m Speed (s)	0.10$_b$	0.15$_c$	0.26$_c$	0.32$_c$	0.05	0.16$_c$	0.22$_c$	**0.11$_c$**	0.17$_c$	0.06$_a$
20m Speed (s)	**0.24$_c$**	0.36$_c$	0.51$_c$	0.69$_c$	0.12	0.28$_c$	0.45$_c$	0.16$_b$	0.33$_c$	0.18$_c$
30m Speed (s)	**0.40$_c$**	0.62$_c$	0.94$_c$	1.13$_c$	0.22$_a$	0.54$_c$	0.72$_c$	0.32$_c$	0.51$_c$	0.19$_a$
Agility (s)	**0.19$_b$**	0.27$_c$	0.39$_c$	0.47$_c$	0.08	0.20$_c$	0.28$_c$	0.12$_b$	0.20$_c$	0.08
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	30.76	66.01$_c$	98.25$_c$	125.29$_c$	**35.25$_a$**	67.49$_c$	94.53c	32.24$_a$	59.28$_c$	27.04$_a$
Upper Body Strength (kg)	3.46	8.23$_c$	12.19$_c$	18.06$_c$	4.77$_a$	8.73$_c$	14.6$_c$	3.96	9.83$_c$	**5.87$_c$**
Balance (cm)	**18.85$_b$**	23.83$_c$	40.2$_c$	41.04$_c$	4.98	21.35$_c$	23.04$_c$	16.37$_c$	18.06$_c$	1.69

[a] $p < 0.05$ level
[b] $p < 0.01$ level
[c] $p < 0.001$ level
Text in bold represents value showing largest difference across consecutive age groups.

4.4.3 Correlations

Correlations are summarised in Table 4.4. Whole age was associated with superior performance on all tests of physical fitness. Of note, momentum and upper body strength were positively and significantly associated with maturity status, demonstrating a large and moderate relationship respectively, while relative age was not associated with the fitness variables. Interestingly, relative age was also not associated with maturity status.

4.4.4 Regression Analysis

Results of the linear regression analyses (step 3) for each fitness variable are summarised in Table 4.5. All models are statistically significant, and percentages of explained variance range from 21% (lower body power) to 48% (momentum). Controlling for whole age (step one), maturity status is a statistically significant and positive predictor of momentum and upper body strength, and a statistically significant but inverse predictor of balance; specifically, boys advanced in maturity status tend to perform better on the tests of momentum and upper body strength, but poorer on the test of balance. Relative age is inversely associated with 20m and 30m speed times and balance; relatively older boys perform faster in the sprints but poorer on the balance test. Of interest, relative age and maturity status interact significantly for upper body strength. Closer inspection of the results suggests that relative age has a limited impact upon upper body strength in earlier maturing youths, but a positive impact on upper body strength in later maturing youths.

Table 4.4. Summary of correlations between age, relative age, maturity status z-score and fitness tests in the total sample

Variables	Whole Age	Relative Age	Maturity z-score	Lower Body Power (cm)	Total Power (cm)	10m Speed (s)	20m Speed (s)	30m Speed (s)	Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	Agility (s)	Strength (kg)	Balance (cm)
Whole Age	-											
Relative Age	-.18[a]	-										
Maturity z-score	.08	-.02	-									
Lower Body Power (cm)	.46[c]	-.05	.04	-								
Total Body Power (cm)	.49[c]	.02	.03	.90[c]	-							
10m Speed (s)	-.58[c]	.03	-.08	-.75[c]	-.76[c]	-						
20m Speed (s)	-.62[c]	.00	-.10	-.73[c]	-.76[c]	.97[c]	-					
30m Speed (s)	-.64[c]	.00	-.10	-.72[c]	-.73[c]	.93[c]	.95[c]	-				
Momentum ($kg \cdot m^{-1} s^{-1}$)	.55[c]	-.09	.50[c]	.32[c]	.33[c]	-.46[c]	-.48[c]	-.50[c]	-			
Agility (s)	-.50[c]	.02	-.03	-.59[c]	-.62[c]	.79[c]	.78[c]	.76[c]	-.44[c]	-		
Upper Body Strength (kg)	.58[c]	-.02	.29[c]	.48[c]	.53[c]	-.55[c]	-.59[c]	-.59[c]	.73[c]	-.52[c]	-	
Balance (cm)	.50[c]	-.10	.07	.51[c]	.50[c]	-.57[c]	-.56[c]	-.60[c]	.38[c]	-.56[c]	.51[c]	-

[a] $p < 0.05$ level (1-tailed)
[b] $p < 0.01$ level (1-tailed)
[c] $p < 0.001$ level (1-tailed)

Table 4.5. Standardised β coefficients and standard errors from the final model hierarchical regression analyses for variables predicting fitness performances of boys 11-15 years

	Lower Body Power (cm)	Total Power (cm)	10m Speed (s)	20m Speed (s)	30m Speed (s)	Agility (s)	Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	Strength (kg)	Balance (cm)
Variable	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)
Age	.46[c] (.31)	.51[c] (.34)	-.59[c] (.01)	-.64[c] (.01)	-.66[c] (.02)	-.51[c] (0.1)	.52[c] (2.99)	.58[c] (.43)	-.26[c] (.19)
Relative Age	.04 (1.4)	.12 (1.47)	-.09 (.03)	-.12[a] (.06)	-.13[a] (.10)	-.08 (.06)	.02 (13.01)	.09 (1.82)	-.16[b] (.73)
Maturity z-score	.01 (.46)	-.01 (.50)	-.04 (.01)	-.05 .02)	-.05 (.03)	.00 (.02)	.41[c] (4.35)	.25[c] (.61)	-.43[c] (.25)
Relative Age x Maturity z-score	-.00 (1.47)	-.06 (1.59)	.09 (.04)	.08 (.07)	.08 (.11)	.11 (.06)	-.09 (13.88)	-.12[a] (1.94)	-.06 (.81)
R^2	.21	.26	.35	.41	.43	.27	.48	.42	.20
F Final	14.2[c]	18.3[c]	27.8[c]	36.3[c]	40.0[c]	18.9[c]	46.9[c]	37.5[c]	20.1[c]

Note: Relative Age and Maturity were centred at their means
[a] $p < 0.05$ level (1-tailed)
[b] $p < 0.01$ level (1-tailed)
[c] $p < 0.001$ level (1-tailed)

4.5 DISCUSSION

The direct and interactive effects of relative age and biological maturity status on the fitness of boys aged 11-15 years were considered. Relative age was unrelated to maturity status in this sample, which supports the notion that relative age and maturity status are separate constructs that exist and operate independently (Cumming et al., 2017).

Additionally, the age-related difference in fitness performance was evaluated. As expected, and in line with previous research, a trend towards improved fitness across age groups was observed, supporting the contention that functional capacity improves with age (Viru et al., 1999). A significant, large difference in all fitness test performances was observed with an increase in age. It has previously been observed that strength (Froberg and Lammert, 1996), power (Beunen and Malina, 1988; Deprez et al., 2015), speed (Vänttinen et al., 2011), agility (Zemková and Hamar, 2014) and momentum (Barr et al., 2014; Till et al., 2015) performance increase with increasing chronological age during adolescence. Improvement of physical qualities during adolescence is due to the natural development of several biological processes, namely; neural, metabolic, androgenic, cardiovascular, skeletal and muscular systems (Viru et al., 1999; Malina, Bouchard and Bar-Or, 2004).

The magnitude of the association between age and fitness was greatest for maximal speed and upper body strength, and chronological age explained 39%, 42%, and 34% of the variance in 20m speed, 30m speed and upper body strength, respectively. The magnitude of association was lowest for agility and power, with chronological age explaining 24%, 22% and 26% of the variance in total body power, lower body power and agility, respectively. The varying nature and complexity of tasks could explain the difference in association, whereby the agility and jumping tests may have an increased requirement for coordination of the body and limbs to execute the task compared to sprinting in a straight line or performing a grip strength test. As described above, the improvement of fitness during adolescence is due to the natural development of biological processes (Malina, Bouchard and Bar-Or, 2004). Anthropometric developments of an increased limb length, in combination with physiological developments such as an increase in muscle mass and enhanced muscle-tendon properties (Ford et al., 2011; Meyers et al., 2015), likely lead to improved stride length and stride frequency (Schepens, Willems and Cavagna, 1998) and thus contribute to increases in maximal speed during adolescence. Whereas, when performing an acute cutting movement, as is necessary during the agility test, enhanced limb length with increasing age may not be as beneficial due to the enhanced motor control and coordination required for performance. During adolescent growth, a period of co-ordination impairment, otherwise known as adolescent awkwardness, can take place in some individuals (Stafford, 2011) which could explain the reduced association between age and power and agility. In support of this, jumping with arms requires greater motor coordination than without arms and children display increased variability in performing a jump with arms than without compared to adults (Floria, Gómez-Landero and Harrison, 2014). Thus, during the adolescent period of constant body changes, it could be that performance improvements in more co-ordination complicated tasks are smaller, until a period of more stable growth is reached. The large association between age and strength was unsurprising given the robustness of evidence observing strength improvements with age in youth populations (Blimkie, 1989; Malina, Bouchard and Bar-Or, 2004). Testosterone underpinned enhancements of the neuromuscular system occur during adolescence with increases in lean muscle mass, muscle cross-sectional area, motor unit recruitment and firing frequency some of the contributing factors to age-related strength developments (Viru et al., 1999).

The age-related differences described above, that is a trend towards improving fitness with age, support those established in previous research in non-elite populations

(Adam et al., 1987; Ortega et al., 2008; Gulías-González et al., 2014). In contrast, there is less research describing the main and interactive effects of relative age and biological maturity on adolescent fitness. Importantly, in the present study relative age was found to be unrelated to biological maturation.

The independent nature of relative age and biological maturation was further illustrated in the respective correlations with specific physical fitness attributes. Relative age was unrelated to performances on the different fitness tests, although this may be contrary to expectations, it is consistent with previous research (Malina et al., 2007; Carling et al., 2009; Figueiredo et al., 2019). The finding also questions the assumption that RAE's result from age-related differences in physical aptitude. In contrast, RAE's may more likely result from age-related differences in experiences in sport and interactions with changes in cognitive, emotional, behavioural, motor and social development (Musch and Grondin, 2001; Helsen et al., 2016).

Of interest, advanced biological maturity status was associated with superior performance on tests of upper body strength and momentum. Research has consistently shown early maturation to be associated with greater strength (Jones, 1949; Malina, Bouchard and Bar-Or, 2004; Myburgh et al., 2016). Few studies have considered the association between maturity status and momentum, the product of velocity and body mass, which may be important in contact sports such as rugby and American football where a combination of greater size and speed are valued (Till et al., 2010; Jalilvand et al., 2019). Among rugby union players, those advanced in maturity status performed better than peers delayed in maturation on a momentum test (Howard et al., 2016), consistent with observations in the current study. As a consequence of maturity status displaying no association with velocity in the current study, it could be deduced that an increase in the boy's body mass is the greatest contributor to the maturity-associated increase in momentum performance.

Contrary to expectations, maturity was unrelated to performance on tests of speed and power in the current study. Observations in previous studies have both supported (Coelho e Silva et al., 2008; Figueiredo et al., 2009) and contrasted (Malina et al., 2004; Myburgh et al., 2016) the present study's associations between maturity status, speed and power. These studies, however, used skeletal age, or development of secondary sex characteristics, as the indicator of maturity status, whereas the present study used a non-invasive, anthropometric predicted estimate of maturity status. Several studies have observed a relationship between speed and anthropometric estimates of maturation, observing early maturing males to outperform later maturing males. These studies, however, have assessed maturity timing using the less reliable and inaccurate Mirwald Maturity Offset method (Meyers et al., 2015; Rumpf et al., 2015; Meyers et al., 2017). It is possible that associations between maturity status, on one hand, and speed and power on the other hand, may vary with the indicator of maturity status, or even maturity timing, and perhaps vary depending on whether the cohort is an athletic, or non-athletic sample.

The results of the regression analyses (Table 4.5) were generally consistent with the correlations (Table 4.4), though there were several important differences. Upon controlling for differences in whole age, relative age was positively associated with maximal sprint speed (20m and 30m) and inversely associated with balance; relatively older boys performed better in maximal sprinting but poorer in balance. The differences between analyses may be associated with "a net suppression effect", i.e., the nature and magnitude of associations among variables may vary when additional factors are statistically controlled. Specifically, a net suppression effect describes the observation of an association between variables, as a result of controlling for another variable. It was thus possible that the associations between relative age and fitness vary as a function of age. That is, the association between relative age and fitness performance may only exist within specific age groups.

Closer examination of this suggests the associations may vary with chronological age when whole age and biological maturity status are statistically controlled. A strong positive correlation was observed between relative age and 20m and 30m speed in the 12- and 15-year-olds, whilst a strong negative correlation was observed in the 11-year-olds, meaning relatively younger boys were faster at 12 and 15 years but relatively older boys outperformed younger boys at age 11. A strong positive correlation was observed between relative age and balance at 11 and 13 years, and a strong negative correlation observed at 12 years of age, meaning that relatively older boys displayed better balance performance than younger boys at ages 11 and 13 years, whilst relatively younger boys performed more strongly at 12 years. This suggests that the nature of the association of relative age with speed and balance may vary relative to whole age and biological maturity status. By inference, further research is needed.

The mechanism for greater sprint performance or reduced balance performance with greater relative age is unknown and further research would be required to establish this. This observation of superior speed with greater relative age, however, aligns with previous research in a non-athletic sample of 8–15-year-old male Japanese schoolchildren (Nakata et al., 2017). One explanation may be that an older relative age may lead to an increased time growing in the age group tested, with studies previously demonstrating relatively older individuals to be significantly taller (Carling et al., 2009). Limb length is associated with greater speed in adolescents (Oliver, Lloyd and Rumpf, 2013) and, therefore, relatively older individuals in this cohort may be taller and may have longer legs, hence may run faster. In contrast, research across elite sport appears to show no association between relative age and maximal speed (Fragoso, Massuca and Ferreira, 2015; Huertas et al., 2019; Patel et al., 2019). Fitness testing in an athletic sample occurs within a very homogenous pre-selected group of elite athletes, many of which are likely to be fast and, most likely, already selected for their athleticism, amongst other attributes. This could explain the difference in the association between speed and relative age observed in non-athletic samples, as in the current study, compared to athletic samples.

The inverse association between relative age and balance performance is worth noting. In contrast to the suggestion that an increased limb length may be an advantage for speed performance in relatively older individuals, when considering balance performance, the heightened COM that occurs due to the increase in limb length (Quatman et al., 2005) may negate limb length advantages. COM height has been shown to negatively impact postural sway, an underlying component of balance performance (Ojie, Saatchi and Saatchi., 2020) as well as muscular control about the knee joint which likely negatively influences proprioceptive control and balance performance (Quatman et al., 2005). That said, given that the magnitude of this association is comparatively small and that there are no studies to compare this with, this finding should be interpreted with a degree of caution. Future studies should seek to explore this finding further and identify potential factors or mechanisms that might contribute towards such an association if it truly exists.

Upon controlling for whole age, maturity status was positively associated with strength and momentum and inversely associated with balance. The inverse association observed between maturation and balance performance is of particular interest. Whereas balance performance appeared to increase slightly with age, likely to be due to increases in limb length (Holden et al., 2016), when age was controlled for, later maturing boys appeared to outperform their earlier maturing counterparts. On average, early maturers experience an accelerated growth spurt compared to late maturers (Malina, Bouchard and Bar-Or, 2004). This more rapid growth likely negatively influences motor coordination and balance (Ryan et al., 2018) whereby early maturing boys are learning to coordinate their rapidly growing new limbs and, in combination with an increase in COM that occurs with growth, this may negatively affect balance performance. A recent study in elite, male soccer players of ages 9-

14 years found similar results in a different test of balance, observing later maturing boys to outperform earlier maturing boys (Rommers et al., 2019). In contrast, a recent study by Lesinski et al., (Lesinski et al., 2020) demonstrated that the performance of elite athletic adolescents in the Y-balance test did not significantly change with maturity status. Although there were differences in study design (Khamis-Roche vs Maturity offset maturity status assessment), and participants (elite vs normal) across the studies, the limited research conducted in this area provides an area for consideration and future research. Furthermore, pre-PHV and post-PHV individuals have been shown to perform better than circa-PHV individuals in various balance tests, suggesting the growth spurt may disrupt balance performance (Hammami et al., 2016). In relation to this study, it could be that a greater number of the early maturing boys are going through their growth spurt, resulting in impaired performance.

An interaction between relative age and maturity status was found to predict upper body strength. Closer inspection of this interaction revealed that older relative age resulted in superior performance for late, but not early, maturing boys. This finding suggests that differences in relative age may have less impact on the upper body strength of males who are advanced in maturational status. Peak gains in strength tend to occur in the latter stages of puberty as a consequence of underlying changes in many neural, biomechanical and muscular factors, resulting primarily from large hormonal rises of testosterone, growth hormone and insulin-like growth factor (Beunen and Malina, 2008). For example, neural system developments include improvements in motor unit recruitment, firing frequency, synchronisation and neural myelination, whilst increased muscle cross-sectional area, improved pennation angle and enhanced tendon properties all contribute to enhanced force application with maturation (Malina, Bouchard and Bar-Or, 2004). Thus, in this sample, being relatively older may go a little way in negating the reduced performance associated with delayed maturation and strength, observed both in the current study, and previous studies (Malina, Bouchard and Bar-Or, 2004).

4.5.1 Practical Implications

The findings presented in this study have useful implications within general, paediatric environments, such as school sport and community clubs. The tests involve easy-to-implement field-based protocols and whilst some do require equipment, if budget allowed, schools and clubs could use these tests and the benchmarks developed to provide a means of monitoring their children's fitness in an engaging manner. This should be carried out with education at the forefront (Silverman, Keating and Phillips, 2008), coupling fitness assessment with sports science and the important athletic qualities underpinning sports performance.

Most studies investigating maturity- and relative age-associated variation in athletic tests of fitness are performed in elite, homogenous, pre-selected populations of athletes, many of which are often dominated by early maturing and/or relatively older males (Malina, 2011). Further, few of these studies have considered the simultaneous or interactive effects of relative age and maturation upon fitness performance. The results from this study, therefore, have practical implications for individuals working with youth populations. A failure to control for, or consider, each variable could lead to attenuated or inflated associations between fitness, relative age and/or maturation. Coupled with this, Till and Baker (Till and Baker, 2020) recently highlighted the complexity that relative age and maturational factors add to fitness comparisons as part of talent identification within sports. In line with this reasoning, Gillison and colleagues (Gillison et al., 2017) recently showed the importance of adjusting for biological age when assessing age-related weight status in children. More specifically, categorisation of weight status against biologically age-matched reference charts resulted in the re-classification of 23% of boys into a lower weight class. Adjustments for variation in relative age and/or maturation could also be performed for fitness testing in youth. That is, performance could be adjusted for variance in relative age and/or maturity to obtain more developmentally aligned evaluations of fitness. Such a strategy could add value in schools where teachers aim to engage all students in sport and physical activity and, therefore, a more accurate representation of fitness may benefit children on an individual level.

More developmentally aligned measures of performance may also benefit the young individuals themselves. Increased awareness of the athletic benefits associated with advanced maturity in males may reduce complacency amongst early maturers, ensuring they do not develop a false sense of their athletic competence and they continue working hard to develop technical, tactical, cognitive, and physical skills. Similarly, more developmentally aligned measures may reassure later maturing males that they are physically capable and may help explain why they are not performing as well as their more mature yet chronologically age-matched peers. This could improve the confidence and self-esteem of late maturers (Simmons and Blyth, 1987). Such an approach should ideally be accompanied by an educational programme for individuals, parents, teachers and coaches, increasing awareness and knowledge of the impact of growth and maturation in physical domains.

The present study also highlights the importance of considering relative age and biological maturation in sport and physical development, in particular for understanding adolescent fitness for the processes of talent identification and evaluation, and for the monitoring and evaluations of strength and conditioning programmes. A lack of development measures for assessing physical fitness was highlighted as a concern in the BASES Expert Statement on Trainability During Childhood and Adolescence (Barker et al., 2014). Comparison to normative, biological age-adjusted data will give practitioners a better understanding of the individuals strengths and weaknesses, and a better determination of the success of a training or physical education programme, establishing whether it has helped develop an individual above and beyond his normal development.

The results of the current study also highlight the importance of considering developmental differences in studies or programmes monitoring health-related fitness in youths. Performances in tests of muscular and motor fitness are included in many health fitness batteries for youth (e.g., Fitnessgram (Welk et al., 2011) and ALPHA-FIT (Ruiz et al., 2011)). Differences in maturation and, potentially, relative age may contribute to performance on such tests and, therefore, need to be considered and/or controlled for.

4.5.2 Limitations

There are several limitations to this study. Firstly, this study examines the relationship between relative age, maturity status and physical fitness of a cross-sectional sample of male adolescents in English schools. To gain a deeper understanding of the effect of relative age and maturity status on adolescent fitness, longitudinal tracking could be studied in future research. Secondly, self-reported parental heights were used as part of the method to estimate biological maturity status, and the Epstein height prediction equation and reference values to establish the z-scores were developed in the United States (Epstein et al., 1995).

It is worth highlighting the small increases in maturity z-scores observed in participants (see Table 4.1). One would expect values close to 0, however there appears to be a systematic bias towards higher z-scores at older ages, and z-scores of 0.23, 0.21 and 0.36 are observed in 13-, 14- and 15-year-olds, respectively. This increase is not observed to as large an extent in biological age values of participants. The expression of maturity status as a z-score uses a reference sample from a US cohort in the Berkeley Guidance Study (Bayer and Bayley, 1959), whereas biological age values are determined from a more recent UK reference dataset (Freeman et al., 1995). Thus, the older, US reference data results in slightly inflated z-scores at older ages in males and this is not seen when maturity status is expressed as biological age, suggesting biological age may be a better value to use for maturity estimations.

There are also some limitations concerning the testing protocols carried out. Acceleration was determined from an average velocity across 8m to 12m to provide an accurate measure of momentum, similar to the protocol used by Howard et al., (Howard et al., 2016). Whilst this provides an accurate measure of acceleration across 10m, direct comparison to studies using a linear 10m sprint are not possible. Similarly, many studies that assess balance performance using the Y-Balance test commonly adjust scores for leg length, with leg length being shown to be positively correlated to Y-Balance performance (Gribble and Hertel, 2003). However, due to time constraints during the present study's testing sessions, leg length was unable to be measured. When comparing young individuals, it is often useful to control for body mass to provide an insight into performance mechanisms without the influence of mass (Meylan et al., 2014). Strength and power performances can be expressed using ratio scaling (per unit of body mass) however this does not produce a size-free index. Allometric scaling is a more accurate method to scale for body mass, whereby exponents specific to the performance test and cohort are applied (Welsman and Armstrong, 2008). The current study focuses, however, on absolute performance of the individuals to better understand changes with age. However, to gain further insight into performance allometric scaling could have been used. With the association between aerobic performance and success in some sports (Harrison et al., 2015), it would have been useful to have assessed aerobic performance. However, this was not possible, again, due to time constraints.

4.5.3 Conclusion

In conclusion, this study has shown that relative age and biological maturity are independent constructs, acting on male adolescent fitness performance differently.

They therefore both need to be considered when working with youth. There is an association between upper body strength, momentum and balance performance and maturation. An association between relative age and maximal speed and balance exists, however, only after whole age differences are controlled for. This study also observed a strong association between age and all the tests of fitness employed.

The findings presented in this study provide value to those working with adolescents, both in school and elite sport; highlighting the need to consider relative age and biological maturation when working with youth. It is recommended for future research that longitudinal data be collected to better assess the association between relative age and maturity status with physical fitness in the paediatric population. This study has also highlighted the necessity to create developmentally adjusted strategies, such as using trajectories of age standards, to better understand how an individual is performing in tests of physical fitness. Further studies could also explore the association of relative age and maturation in health parameters such as cardiovascular fitness, rather than the fitness tests as considered in this study.

CHAPTER FIVE

THE AGE ASSOCIATED VARIANCE AND MAIN AND INTERACTIVE EFFECTS OF RELATIVE AGE AND MATURATION UPON THE PERFORMANCE OF FEMALE ADOLESCENTS IN TESTS OF ATHLETIC FITNESS

5.1 ABSTRACT

PURPOSE: To consider the main and interactive effects of relative age and biological maturation upon the performance of female school children on athletic tests of physical fitness. **METHODS:** British female school children aged 11 to 15 years old (N=418) performed standardised tests of linear speed, initial sprint momentum, agility, upper body strength, lower body and total body power, and a lower quadrant Y-balance test. Relative age and biological maturity (percentage of predicted adult stature attained at measurement) of the participants were assessed concurrently. **RESULTS:** Univariate analyses of variance revealed significant differences across all fitness variables by chronological age ($p < 0.01$), with the mean values for all tests showing a general trend towards improving. Pearson product moment correlations observed no association between relative age and maturity status. A series of multiple linear regression analysis were used to estimate the main and interactive effects of whole age, relative age and maturation upon physical fitness. The percentage of variance explained by the models ranged from 9% (lower body power) to 62% (momentum). Maturation was positively associated with momentum, strength, and agility ($p < 0.05$), yet inversely associated with maximal speed and lower body and total body power ($p < 0.05$). That is, earlier maturation was associated with improved momentum, strength, and agility, but reduced speed and power performance. Relative age was positively associated with upper body strength ($p < 0.05$). That is, an older relative age was associated with increased upper body strength. **CONCLUSION:** Relative age and biological maturity are independent constructs, acting on female adolescent fitness performance differently. Practitioners should consider developmental differences among adolescent females when evaluating and monitoring fitness.

5.2 INTRODUCTION

The development and assessment of physical fitness are complex processes during the adolescent period as they take place on an ever-changing base of growth, maturation and behavioural development, unique to an individual (Malina, Bouchard and Bar-Or, 2004). Females, in particular, can have a challenging relationship with their physical self during the adolescent period. Females' perceptions of their physical fitness or competence often decreases with age (Cumming et al., 2011). Society also often holds this view of girls' fitness, sports competence and physical attractiveness decreasing during adolescence (Cumming et al., 2011). Physical self-concept is a key determinant of physical activity participation, with a positive perception of one's self predicting a greater involvement in moderate-to-vigorous levels of physical activity (Sabiston and Crocker, 2008), whilst body dissatisfaction is associated with lower physical activity levels (Neumark-Sztainer et al., 2006). Accordingly, female engagement in physical activity reduces to a greater extent than males during adolescence (Finne et al., 2011). This highlights the need to better understand and educate both the female adolescents themselves, and those working with them, on the changes that take place during this period of life to help increase enjoyment and engagement in sport and activity.

Additionally, from a sport perspective, the increase in professionalism of many female sports over recent years has heightened the need to better understand female athletic development (Fink, 2015). Aligned with this, improved physical development, training and testing practices are required to assist with this increase in professionalism (Datson et al., 2014). Certain sports such as tennis (Myburgh et al., 2016) and rugby league (Jones et al., 2016) place a greater emphasis on athletic size, strength and power, whilst aesthetic sports such as gymnastics and ballet typically place greater importance on having a smaller frame and greater flexibility and balance (Baxter-Jones, Thompson and Malina, 2002). Establishing how a non-athletic female cohort performs in tests of athletic performance, whilst considering both biological maturity status and relative age, would provide important information for both school/non-elite sport and elite sport, providing comparative data from a non-athletic normative population and increasing understanding on how maturation and relative age may impact adolescent fitness. This will enhance the monitoring of individuals' strengths and weaknesses against physical priorities, track their athletic development and evaluate the adaptation from fitness interventions/strength and conditioning programmes. Elite sports teams will routinely monitor their athletes (Pion et al., 2014), this is not so commonplace however in school sport. For elite athletes, understanding how individuals compare against the performance of both their athletic peers and the normal population could play an important part in their fitness monitoring.

Within schools, sports and youth athletic development programmes, children are traditionally grouped relative to their chronological age (Cumming et al., 2017). For example, within the Football Association's (FA) Regional Talent Centres (female football youth academies) players train and compete in two-year age bands (i.e. under-10s, under 12s, etc.) (Emmonds et al., 2018). In such talent identification and development systems, athletes are compared relative to their chronological age-matched peers. However, females of the same age can vary markedly in both biological maturation and relative age (Baxter-Jones, Thompson and Malina, 2002). These are two non-modifiable but independent constructs that can influence fitness performance in female adolescents. The differences in biological maturation and relative age may mask or enhance assessments of athletic aptitude and fitness in young females, especially during puberty and the periods of peak growth and peak weight velocity (Malina et al., 2015). These are crucial periods during which maturity-associated variance in size and functionality can greatly impact female fitness (Malina, Bouchard and Bar-Or, 2004). Such effects make it challenging for practitioners to understand true fitness performance, evaluate strengths and weaknesses, predict future athletic potential, and assess training gains above and beyond those associated with the normal processes of growth and maturation (Lloyd and Oliver, 2012).

Biological maturation refers to the process of progression towards an adult/mature state. Biological maturation is referred to with regard to its timing, tempo and status and can be considered across many biological systems, such as skeletal, endocrinal, dental, sexual and somatic. The occurrence of these three factors is heavily influenced by genetic predisposition (Baxter-Jones, Thompson and Malina, 2002). Timing refers to the period where a specific maturation event occurs and females, on average, reach pubertal milestones 2 years earlier than males. These maturational events will include the age at menarche, the age at the beginning of breast development, the age of pubic hair appearance and the age of peak height velocity. The tempo refers to the rate at which maturational events may occur and status describes the stage of maturation attained (e.g. pre-, circum-, or post-pubertal) (Baxter-Jones, Thompson and Malina, 2002).

Maturational timing has been shown to impact the athletic performance of female adolescent athletes (Volver, Viru and Viru, 2010), although this impact is less clear than it is in male sports (Malina et al., 2015). From the onset of puberty, early maturing females will be taller and heavier than their later maturing counterparts, with a period of peak height velocity occurring between 11-12 years and a period of peak weight velocity occurring 6-9 months later (Malina, Bouchard and Bar-Or, 2004). The increase in body mass during puberty is predominantly that of fat mass, with girls achieving much lower gains in lean muscle mass than boys (Tønnessen et al., 2015). Body Mass Index (BMI) is positively associated with sexual maturity in girls (Beunen et al., 1997), with overweight and obese girls tending to be advanced in maturation, whilst having a more linear physique is associated with delayed maturation (McNeill and Livson, 1963). Early maturing girls, therefore, generally have a higher body mass and fat mass, and are more likely to have an endomorph somatotype, than later maturing girls, who often have a more ectomorph somatotype Beunen et al., 1997).

Differences in physique and body composition can influence physical performance, with the increased fat mass and endomorphic physique of advanced maturation negatively affecting performance in some fitness tests, especially around puberty (Beunen et al., 1997). However, in general, maturity-associated variation in fitness performance is not consistent and varies according to the task and across age. Longitudinal data in normal adolescent populations shows early maturing girls tend to be slightly stronger than later maturing girls until the age of around 13 years, whilst later maturing girls tend to outperform early maturing girls in the shuttle run speed and agility test, flexibility tests and upper body muscular endurance tests (Little, Day and Steinke 1997; Malina, Bouchard and Bar-Or, 2004). Performances in tests of power have shown little variation with maturation, however, when expressed relative to body mass, later maturing females tend to perform slightly better than early maturing females (Little, Day and Steinke, 1997). Recent research has looked more extensively at the association between maturation and fitness in elite female athletes (Myburgh et al., 2016; Emmonds et al., 2018; Ramos et al., 2020). Whilst absolute strength, speed, agility and power may increase with increasing maturation (Emmonds et al., 2018), a reduction in performance of certain physical qualities relative to body mass, such as strength (Emmonds, Morris et al. 2017) and power (Emmonds et al., 2018), has been observed in female elite athletes.

As well as maturational timing influencing athletic performance, it also impacts selection into sports. Somatic characteristics are considered to be important determinants of success in gymnastics (Claessens, 1999) and result in an apparent selection bias towards gymnasts delayed in their age at menarche (Bacciotti et al., 2017). In contrast, the enhanced physical and functional characteristics, such as greater size and strength, observed with earlier maturation can offer a competitive advantage in sports where height and/or physical dominance is of increased importance, such as tennis (Myburgh et al., 2016) and swimming (Erlandson et al., 2008).

Relative age refers to the difference in chronological age between individuals born in the same selection year and is determined by date of birth and the sports' cut-off dates (Veldhuizen et al., 2015). This can lead to the situation where, in a single year age band, a child who is born earlier within the selection year is almost 12 months older than a child born at the end of the selection year. As described in previous chapters, the phenomenon whereby girls born earlier in the selection year are overrepresented in a sport compared to those born later in the selection year is known as the relative age effect (RAE) (Musch and Grondin, 2001). It is proposed that a greater relative age provides an advantage to athletes because of the increased experience and time spent playing that sport (Hill et al., 2019) and potentially a greater physical, neural, motor and/or psychosocial maturity (Helsen et al., 2000; Wattie, Cobley and Baker, 2008). However, whilst a RAE is well established in many male sports, there is less robust support and equivalent findings in female samples. A significant RAE has been identified in football (Romann and Fuchslocher, 2013), ice hockey (Weir et al., 2010), handball (Schorer et al., 2009) and swimming (Costa et al., 2013), however, other studies have observed no RAE across female sports (Till et al., 2010; Nakata and Sakamoto, 2012). The inconclusive findings could reflect the nature of competition level across female sports, with some leagues or levels of sport not competitive enough to drive a RAE. Should participation numbers be too low, a RAE may not appear, and this is more likely the case in many female sports when compared with male sports.

A consideration for age range may be required when examining the presence of a RAE; some sports demonstrate a RAE in younger but not older female age groups (Till et al., 2010). This variation in RAE with age may be supported by an association between relative age and fitness. A recent study in Japanese schoolchildren observed a significant relationship between relative age and tests of physical fitness in younger girls aged 7-10 years but showed no relationship between relative age and fitness in older girls ages 11-15 years (Nakata et al., 2017). Although the impact of relative age on athletic fitness is an under-researched area, conflicting evidence has emerged from the few studies in the area. Contrary to the study in Japanese schoolchildren, another recent study identified no relationship between relative age and performance in an endurance fitness test in female school children (Veldhuizen et al., 2015). Further research is required to understand if there is an association between relative age and physical fitness performance. In male athletes, no robust association has been observed and it is, therefore, unlikely that the RAE phenomenon can be attributed entirely to increased size and physicality; it is more likely to involve playing experience differences, developmental and social factors (Helsen et al., 2000; Wattie, Cobley and Baker, 2008). This may also be the case in female athletes where an association may be even less obvious due to the blunted fitness response in female adolescents compared to males (Malina, Bouchard and Bar-Or, 2004).

Contrary to lay opinion, and that of some scholars, older relative age does not imply more advanced maturation. Relative age and biological maturation are two independent constructs that exist and operate independently of one another (Cumming et al., 2017). As previously noted, relative age and maturation are a result of different factors (i.e., date of birth and selection dates vs. genotype and environmental interactions). Accordingly, it is entirely possible to be the oldest athlete within an age group year but also be the least mature athlete, and vice-versa. There is also much greater scope for variance in maturation than relative age. Whereas relative age is typically limited to a maximum of a one-year difference, children of the same age have been shown to vary by as much as five to six years in terms of their skeletal age (Johnson, 2015).

For practitioners working with young females, it is, therefore, crucial to consider these adolescent developmental processes when monitoring and assessing physical fitness. Although the contribution of physical fitness to athletic performance in males is better documented, our understanding of this relationship in females is less comprehensive. Further, the knowledge and understanding of this subject area gained from studies in male athletes may not directly transfer to female cohorts due to inherent developmental difference that exists between the sexes (Emmonds, Heyward and Jones, 2019). Whilst little is known about how biological maturation and relative age interact and influence fitness in female adolescents, little is also known about how a non-athletic female cohort performs in tests of athletic performance. To better understand athletic performance in both athletic and non-athletic settings and, importantly, how growth-, maturity- and age-related factors contribute to fitness performance, comparison to a normative population is needed (Barker et al., 2014). There is, however, a lack of contemporary data on the assessment of non-athletic populations in athletic fitness tests with consideration for maturation and relative age. The majority of testing batteries appear to focus on general health-related qualities with a lack of consideration for these developmental porcesses (Welk et al., 2011; Smolianov, Zakus and Gallo, 2014; Liu, Keating and Shangguan, 2017).

The purpose of this study, therefore, was to examine the main and interactive effects of relative age and biological maturation upon athletic tests of fitness in a non-athletic sample of female schoolchildren aged between 11-15 years. In line with existing research, it is hypothesised performance on all tests of fitness will increase with chronological age, although there is a likelihood of a plateau in performance at the older age groups. Consistent with previous literature, it was predicted that more advanced maturation would be associated with superior performance on tests of strength, speed, agility and power. Although no previous research exists which examines the relationship between maturation and momentum performance in females, given the close relationship between momentum and body mass (Howard et al., 2016), it was hypothesised performance in this test would also improve with advanced maturity. Similarly, little research exists that examines balance performance in female adolescents. However, due to an increased centre of mass that occurs with increased growth during adolescence, and the negative impact on balance this can lead to (Quatman et al., 2005; Ojie, Saatchi and Saatchi., 2020) it was hypothesised that performance in the balance test would not improve with advanced maturity. In line with previous research, concerning relative age effects across female sports, it was predicted that an older relative age would be associated with superior performance in all tests of fitness. Further, it was predicted that variance in performance in the fitness tests may be further associated with the interaction between relative age and maturation. That is, advanced or delayed maturation may mitigate or enhance the association between relative age and performance.

5.3 METHODOLOGY

For a detailed description of the study methodology see Chapter Three.

5.3.1 Participants

The sample included 418 females, aged 11 to 15 years, enrolled in a school located in the South-West of England in the 2014-15 and 2015-16 school years. Participants conducted the testing in their academic year groups. However, for analysis of data, participants were grouped into whole age cohorts according to their decimal age. For example, an individual that was 12.3 years of age would be evaluated within the 12-year age category.

5.3.2 Ethics and Consent

This study was approved by the Research Ethics Approval Committee at the host University. Informed written consent was obtained via the school's head teacher acting *loco parentis,* and a parental opt-out option was given to every individual. Self-assent was obtained for the participant. The schoolteachers were informed about the procedures and aims of the study prior to completion, and only those participants that indicated a willingness to take part were included.

5.3.3 Maturity Status

The percentage of predicated adult height attained at the time of testing was used as the indicator of maturity status. Height (stretch-method, (Tanner, 1962)) and weight (Seca scales 813 Robusta) of each girl were measured. Decimal age, height, and weight of the individual and mid-parent height were used to predict mature, adult height for each participant using equations developed on the Fels Longitudinal Study sample in south-central Ohio (Khamis and Roche, 1994). Parental heights were self-reported prior to the testing session and were adjusted for overestimation (Epstein et al., 1995). Where this information was not possible, the participant could participate in the testing session, but her results were not used in the analysis. The current height of each participant was expressed as a percentage of predicted mature/adult height; by inference, the girl closer to mature height (higher percentage) is advanced in maturity status compared to the girl who is further removed (lower percentage). The percentage of predicted mature stature was also converted to a z-score to provide a means to classify participants by maturity status. Z-scores above +1 and below -1 are commonly used, respectively, to classify youth as early and late maturing; a z-score between +1 and -1 classifies youth as average or on-time (Cumming et al., 2009).

5.3.4 Biological Age

An estimate of biological age was calculated by comparing the percentage of peak adult stature to age- and sex-specific reference standards generated from the UK 1990 growth reference data (Freeman et al., 1995). Consistent with the method employed by Gillison and colleagues (Gillison et al., 2017), reference standards for percentages of adult height attained at 0.1 yearly intervals were established. Percentages were based on mean values for stature attained at each age interval, as well as the mean value for stature at and above 18 years of age (% PAS). For example, a girl of chronological age 12.5 years who was measured at 90% of her predicted PAS would have achieved a %PAS equivalent to the mean %PAS attained by a girl 11.6 years of age. Consequently, she would be given a biological age of 11.6 years.

5.3.5 Relative Age

Relative age was calculated for each girl as the difference between birth date and the end date of the academic year (August 31st), divided by the number of days within the year (Cumming et al., 2018). It was expressed as a decimal value between 0 and 0.99, with the lowest and highest representing the youngest and oldest individuals, respectively.

5.3.6 Fitness Tests

The fitness test battery adopted in the study was based on consideration of tests commonly used in athletic testing protocols to assess the most important fitness qualities for youth athletic development and performance in physical activity and sport. The battery included; a handgrip strength (dynamometer) as an estimate of upper body strength; a 30m linear sprint with 8m, 12m, 20m and 30m splits to determine 10m acceleration, 20m and 30m maximal speed and initial sprint momentum; the 505 agility test as an indicator of agility performance; the vertical countermovement jump (CMJ) with and without arms to determine total body and lower body power, respectively; the lower quadrant Y-balance test as an indicator of balance. For a detailed description of the testing protocols used please refer to Chapter Three. The majority of the tests have demonstrated validity and reliability in youth populations (Lloyd et al., 2009; España-Romero et al., 2010; Filipa et al., 2010; Rumpf et al., 2011; Stewart, Turner and Miller, 2014).

5.3.7 Statistical Analysis

All data were analysed using Statistical Package for the Social Sciences (SPSS) for Windows Version 23; minimal statistical significance was set at ($p < 0.05$). Descriptive statistics were calculated for all the variables. A series of univariate analyses of variance (ANOVA) were conducted to investigate the differences between chronological age groups and the various physical fitness attributes. Partial eta squared were conducted to examine the direction and magnitude of variance between each fitness attribute and age group. The criteria for effect size, as described by (Cohen, J., 1988) were set at: small = < 0.01; moderate= < 0.06; large = < 0.14. Post Hoc analysis of pairwise comparisons was conducted, with significance set at $p < 0.05$ to examine the difference between fitness variables and age groups.

Correlations were calculated to evaluate relationships (magnitude and direction) among the variables of interest. The criteria for magnitude of correlation, as described by (Cohen, 1988) were set at: small = 0.1; moderate = 0.3; large = 0.5. Finally, a series of stepwise multiple linear regression analyses, controlling for whole age cohort, were performed to investigate the main and interactive effects of relative age and maturity status upon each physical fitness variable. To reduce the risk of co-linearity among predictor variables, the relative age x maturity status interaction was derived from centred scores (relative age – mean relative age) x (z-score – mean z-score) and then included in the third and final stage of the model.

5.4 RESULTS

5.4.1 Descriptive Statistics

Descriptive statistics for chronological age, height, weight, relative age, biological age, percentage of predicted adult stature and maturity z score are summarised by age group in Table 5.1. Mean values for height, weight, biological age and % PAS increased with age group. The mean values for maturity z–scores approximated or fell just below zero in all age groups. Descriptive statistics for fitness variables are presented in Table 5.2. The mean performances in all tests of fitness generally increased sequentially across the age groups. However, 10m speed and lower body power performance did not increase from age 13 years to 14 years, whilst momentum, 10m speed, 20m speed and agility performance did not increase from 14 to 15 years.

Table 5.1. Descriptive statistics (mean ± standard deviation) for chronological age, body size, relative age, and estimated maturity status by age groups for female schoolchildren

	11 Years (n = 29)	12 Years (n = 69)	13 Years (n = 97)	14 Years (n = 133)	15 Years (n = 90)
Variables	M (SD)	M (SD)	M (SD)	M (SD)	M (SD)
Chronological Age	11.6 (0.30)	12.5 (0.30)	13.5 (0.29)	14.5 (0.27)	15.4 (0.24)
Height (cm)	148.1 (7.43)	155.9 (7.65)	162.3 (7.34)	163.7 (6.74)	164.9 (7.42)
Weight (kg)	44.8 (13.24)	47.7 (11.02)	54.6 (10.97)	56.8 (9.04)	57.8 (10.46)
Relative Age	.60 (0.3)	.51 (0.29)	.56 (0.69)	.50 (0.71)	.31 (0.76)
Biological Age	11.77 (1.40)	12.73 (1.2)	13.96 (1.11)	14.59 (0.84)	15.00 (0.62)
Predicted Adult Stature, %	90.55 (4.26)	93.72 (3.13)	96.98 (1.80)	98.36 (0.96)	99.00 (0.44)
Maturity Z-Score	-.26 (1.24)	-.27 (1.07)	-.16 (0.98)	-.39 (0.88)	-.86 (0.70)

Table 5.2. Descriptive statistics (mean ± standard deviation) for fitness tests by age groups for female schoolchildren

Variables	11 Years (n = 36) M (SD)	12 Years (n = 85) M (SD)	13 Years (n = 116) M (SD)	14 Years (n = 164) M (SD)	15 Years (n =113) M (SD)
Lower Body Power (cm)	20.3 (5.2)	22.7 (4.5)	22.5 (5.5)	23.7[a] (4.8)	25.3 (3.9)
Total Body Power (cm)	22.6 (5.6)	25.5 (4.9)	26.3 (6.0)	27.3[a] (5.6)	28.8 (5.0)
10m Speed (s)	2.2 (0.2)	2.1 (0.2)	2.1 [a] (0.2)	2.0 (1.2)	2.0[a] (0.1)
20m Speed (s)	4.1 (0.4)	3.9 (0.3)	3.7 [a] (0.4)	3.6 (0.3)	3.6[a] (0.2)
30m Speed (s)	6.0 (0.6)	5.6 (0.5)	5.4 [a] (0.6)	5.2 (0.5)	5.1[a] (0.4)
Agility (s)	3.4 (0.3)	3.2 (0.3)	3.1 [a] (0.3)	3.0 (0.3)	3.0[a] (0.2)
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	201.8 [a](56.7)	223.9 [a](52.4)	263.8 [b](54.2)	288.2 (50.3)	286.2[a] (45.8)
Upper Body Strength (kg)	18.9 (5.2)	21.5 (4.3)	26.4 (6.2)	28.4[b] (5.6)	29.4 (5.5)
Balance (cm)	194.5 (24.1)	213.9 (25.7)	218.1 (26.3)	221.4[c] (22.4)	240[b] (28.2)
	[a] = n = 35	[a] = n = 84	[a] = n = 111 [b] = n = 110	[a] = n = 169 [b] = n = 170 [c] = n = 168	[a] = n = 111 [b] = n = 104

5.4.2 Univariate Analyses of Variance

A series of univariate analyses of variance (ANOVA) were conducted to investigate age-related differences in fitness attributes. Significant differences were observed across all fitness variables by chronological age ($p < .01$). Across all the tests, the largest difference was observed between the youngest age group, 11 years, and the older ages of 14 to 15 years. Specific details pertaining to each analysis are as follows:

Acceleration Speed

A significant main effect for age was observed for acceleration as measured by 10m speed, $F(4,501)=26.6$, $p < .001$, $\eta^2 = .18$. More specifically, mean values for acceleration showed some trends towards decreasing with age, that is, the participants' capacity to accelerate showed a trend towards improving with age. Age explained approximately 18% of the variance in acceleration demonstrating a large difference in acceleration across age group. Pairwise comparisons revealed significant differences in acceleration across several age groups. Specifically, the greatest difference across consecutive age groups was observed between 13 and 14 years (0.09). No significant difference was observed between ages 14 to 15 years (See Table 5.3)

Maximal Speed

A significant main effect for age was observed for maximal speed, both the 20m and 30m sprints, $F(4,501)=32.09$, $p < .001$, $\eta^2 = .20$ and $F(4,501)=35.1$, $p < .001$, $\eta^2 = .22$ respectively. Mean values for maximal speed decreased with age, that is, the participants' capacity to sprint at maximal speed improved with age. Age explained 20% and 22% of the variance in 20m and 30m speed respectively demonstrating a large difference in maximal speed across age groups. Pairwise comparisons revealed significant differences in speed across several age groups (see Table 5.3). Specifically, the greatest consecutive age difference in both 20m and 30m maximal speed was observed between 11 and 12 years (0.20 and 0.40 respectively) (see Table 5.3).

Agility

A significant main effect for age was observed for agility, $F(4, 499) = 18.4$, $p < .001$, $\eta^2 = 0.13$. Mean values for agility decreased with age but did not significantly change from 14 to 15 years old meaning agility performance improved with age until the age of 14. Age groups explained approximately 13% of the variance in agility demonstrating a large effect. Pairwise comparisons revealed significant differences in agility across several, but not all, age groups, specifically, the greatest single age difference occurred between ages 11 and 12 years (See Table 5.3).

Power

A significant main effect for age was observed for total body power, $F(4, 509) = 10.4$, $p < .001$, $\eta^2 = 0.08$ as well as for lower body power $F(4, 509) = 9.6$, $p < .001$, $\eta^2 = 0.07$. Mean values for power generally increased, with age explaining 8% and 7% of the variance in total body and lower body power respectively. Accordingly, the magnitude of the differences in power across age groups can be considered large. Pairwise comparisons revealed significant differences in power across several age groups, specifically, the greatest consecutive age difference was observed between 11 and 12 years of age for both total body and lower body power. The smallest differences were observed across ages 12 to 14 years (See Table 5.3).

Upper Body Strength

A significant main effect for age was observed for upper body strength, $F(4, 513) = 47.1$, $p < .001$, $\eta^2 = 0.27$. Mean values for upper body strength generally increased across the age groups and age explained 27% of the variance in upper body strength. In terms of magnitude, the age-related differences in upper body strength can be considered to be very large. Pairwise comparisons revealed significant differences in upper body strength across several age groups (See Table 5.3), specifically, the greatest single age difference was observed between ages 12 and 13 years (4.83).

Balance

A significant main effect for age was observed for absolute balance, $F(4, 499) = 25.1$, $p < .001$, $\eta^2 = 0.17$. Mean values for balance increased with age and age explained 17% of the variance in balance demonstrating a large difference across age group. Pairwise comparisons revealed significant differences in balance across several age groups (See Table 5.3). More specifically, the greatest single age differences occurred between ages 11 to 12 years (19.41) (See Table 5.3).

Momentum

A significant main effect for age was observed for momentum, $F(4, 477) = 38.50$, $p < .001$, $\eta^2 = 0.24$. Mean values for momentum increased with age although no increase was observed from 14- to 15-years, suggesting momentum performance improved until age 14 years, when performance then began to stagnate. Age explained 24% of the variance in momentum, demonstrating a large difference in momentum across age group. Pairwise comparisons revealed significant differences in momentum across several age groups (See Table 5.3), specifically, the greatest single age difference was observed between ages 12 and 13 years (39.93).

Table 5.3. Differences in mean values for each of physical test variable across multiple age groups.

	11 v 12	11 v 13	11 v 14	11 v 15	12 v 13	12 v 14	12 v 15	13 v 14	13 v 15	14 v 15
Lower Body Power (cm)	**2.44[a]**	2.28[a]	3.46[c]	4.96[c]	.17	1.01	2.52[c]	1.18[a]	2.69[c]	1.50[b]
Total Body Power (cm)	**2.91[b]**	3.73[c]	4.66[c]	6.09[c]	.82	1.75[a]	3.17[c]	.93	2.35[c]	1.43[a]
10m Speed (s)	.08[b]	.16[c]	.25[c]	.22[c]	.07[a]	.16[c]	.13[c]	**.09[c]**	.06[b]	.03
20m Speed (s)	**.20[b]**	.36[c]	.49[c]	.48[c]	.16[c]	.29[c]	.28[c]	.14[c]	.12[b]	.02
30m Speed (s)	**.40[c]**	.62[c]	.86[c]	.89[c]	.22[b]	.45[c]	.49[c]	.24[c]	.27[c]	.03
Agility (s)	**.15[b]**	.26[c]	.36[c]	.38[c]	.10[b]	.20[c]	.23[c]	.10[b]	.12[b]	.02
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	22.09[a]	62.01[c]	85.99[c]	84.68[c]	**39.93[c]**	63.90[c]	62.60[c]	23.98[c]	22.67[b]	1.31
Upper Body Strength (kg)	2.68[a]	7.51[c]	9.51[c]	10.54[c]	**4.83[c]**	6.83[c]	7.85[c]	2.00[b]	3.02[c]	1.03
Balance (cm)	**19.41[c]**	23.59[c]	26.85[c]	44.57[c]	4.18	7.44[a]	25.16[c]	3.26	20.98[c]	17.72[c]

[a] $p < 0.05$ level
[b] $p < 0.01$ level
[c] $p < 0.001$ level
Text in bold represents value showing largest difference across consecutive age groups.

5.4.3 Correlations

Correlations are summarised in Table 5.4. Whole age was associated with superior performance on all tests of physical fitness. Of note, lower body power (moderate association), total body power (moderate association), 20m and 30m speed (small association) were negatively and significantly associated with maturation, whereas agility (small association), momentum (large association) and upper body strength (moderate association) were positively and significantly associated with maturation. Relative age was positively and significantly associated with upper body strength, albeit the association was small.

5.4.4 Regression Analysis

Results of the linear regression analyses (step 3) for each fitness variable are summarised in Table 5.5. All models are statistically significant, and percentages of explained variance range from 9% (lower body power) to 62% (momentum). Upon controlling for whole age, maturity status served as a statistically significant and positive predictor of momentum and upper body strength, displaying large and moderate associations, respectively. Maturity status was a statistically significant yet inverse predictor of lower body and total body power, displaying small associations. That is, earlier maturation was associated with reduced power performance but better strength and momentum performance. Relative age served as a statistically significant and positive predictor of total body power (very small), 20m speed (small), 30m speed (small), agility (small), momentum (small) and strength (small). That is, an older relative age was associated with a faster sprint, power, agility, momentum, and strength performance. The interaction between relative age and maturity status showed no association with any of the fitness variables.

Table 5.4. Summary of correlations between age, relative age, maturity status, z-score and fitness tests in the total sample

Variables	Whole Age	Relative Age	Maturity 'z'	Lower Body Power (cm)	Total Body Power (cm)	10m Speed (s)	20m Speed (s)	30m Speed (s)	Momentum (kg·m^{-1}·s^{-1})	Agility (s)	Upper Body Strength (kg)	Balance (cm)
Whole Age	-											
Relative Age	-.14[c]	-										
Maturity 'z'	-.16[c]	.04	-									
Lower Body Power (cm)	.25[c]	.03	-.19[c]	-								
Total Body Power (cm)	.27[c]	.06	-.18[c]	.90[c]	-							
10m Speed (s)	-.38[c]	-.02	.04	-.60[c]	-.62[c]	-						
20m Speed (s)	-.42[c]	-.05	.08[a]	-.69[c]	-.72[c]	.89[c]	-					
30m Speed (s)	-.44[c]	-.04	.10[a]	-.71[c]	-.73[c]	.87[c]	.95[c]	-				
Momentum (kg·m^{-1}·s^{-1})	.46[c]	.04	.52[c]	.10[a]	.13[a]	-.44[c]	-.38[c]	-.38[c]	-			
Agility (s)	-.35[c]	-.07	-.12[a]	-.63[c]	-.64c	.67[c]	.75[c]	.75[c]	-.28[c]	-		
Upper Body Strength (kg)	.50[c]	.08[a]	.22[c]	.41[c]	.44[c]	-.44[c]	-.51[c]	-.53[c]	.66[c]	-.46[c]	-	
Balance (cm)	.38[c]	.03	-.04	.47[c]	.49[c]	-.41[c]	-.44[c]	-.47[c]	.33[c]	-.45[c]	.46[c]	-

[a] $p < 0.05$ level (1-tailed)
[b] $p < 0.01$ level (1-tailed)
[c] $p < 0.001$ level (1-tailed)

Table 5.5. Standardised β coefficients and standard errors from the final model hierarchical regression analyses for variables predicting fitness performances of girls 11-15 years

	Lower Body Power (cm)	Total Body Power (cm)	10m Speed (s)	20m Speed (s)	30m Speed (s)	Agility (s)	Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	Upper Body Strength (kg)	Balance (cm)
Variable	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)	B (SE)
Age	.25[c] (.18)	.26[c] (.20)	-.37[c] (.01)	-.42[c] (.01)	-.44[c] (.02)	-.34[c] (.01)	.46[c] (2.0)	.50[c] (.21)	.45[c] (1.06)
Relative Age	.07 (.77)	.11[a] (.88)	-.08 (.03)	-.12[b] (.05)	-.11[b] (.08)	-.13[b] (.05)	.12[c] (6.1)	.15[c] (.83)	.02 (4.74)
Maturity z-score	-.16[c] (.24)	-.14[c] (.28)	-.03 (.01)	0.01 (0.02)	.02 (.03)	.06 (.02)	.64[c] (1.88)	.31[c] (.26)	.05 (1.41)
Relative Age x Maturity z-score	-.02 (.89)	-.02 (1.01)	-.02 (.03)	.05 (.06)	.02 (.09)	.01 (.05)	.03 (6.84)	-.02 (.96)	.03 (4.77)
R^2	.09	.10	.15	.19	.21	.14	.62	.36	.21
F Final (df)	12.4[c] (509)	13.8 [c] (509)	21.5[c] (501)	28.8[c] (501)	32.8[c] (501)	19.6[c] (499)	193.1[c] (481)	72.2[c] (513)	23.1[c] (494)

Note: Relative Age and Maturity were centred at their means

[a] $p < 0.05$ level (1-tailed)
[b] $p < 0.01$ level (1-tailed)
[c] $p < 0.001$ level (1-tailed)

5.5 DISCUSSION

The purpose of this study was to investigate the main and interactive effects of relative age and biological maturation, and additionally evaluate age-associated variance, of a normal female adolescent sample in the performance in several physical fitness tests. In line with previous research, a trend towards improved fitness across age groups was observed with a plateau in performance across some tests in some age groups also noted (Viru et al., 1999; Malina, Bouchard and Bar-Or, 2004). Accordingly, age was treated as a covariate in block one of the models. The key findings from the study were that biological maturation was significantly associated with several fitness variables, namely, advanced biological maturation was associated with superior performance in tests of upper body strength and momentum whereas delayed maturation was associated with better performance in tests of power and maximal speed (20m and 30m sprint). Relative age showed a significant but small association with upper body strength. Of interest, relative age was unrelated to maturity status in this female sample. Meaning, being relatively older in this study did not imply more advanced maturity for one's age. This supports the notion that relative age and maturity status are separate constructs that exist and operate independently (Cumming et al., 2017).

The independent nature of relative age and biological maturity is illustrated in their respective correlations with physical fitness. Advanced biological maturation was associated with superior performance on tests of upper body strength and momentum. That is, early maturing females performed better than their later maturing counterparts in these tests. Advanced maturation was also associated with superior agility performance; however, this significant association was removed when other variables were included within the regression analysis. Research has consistently shown early maturation to be associated with greater strength (Malina, Bouchard and Bar-Or, 2004; Myburgh, et al., 2016). Maturation of the neuromuscular system underpins the improvements in strength during adolescence (Lloyd and Oliver, 2012), with the increase in muscle mass that occurs during this period increasing the body's force generating capabilities and thus strength performance. The more mature neuromuscular system and increased mass of early maturing females probably explains the improved strength and momentum performance of early maturing females in the present study. Momentum, important in sports such as rugby (Barr et al., 2014) and American football (Jalilvand et al., 2019), is the product of mass and velocity. Whilst earlier maturation was associated with reduced maximal velocity performance in the present study this may have been negated and, in fact, super-compensated for, by the increased mass of the early maturing girls, resulting in superior momentum performance. To my knowledge no other studies have assessed momentum performance in adolescent females, however, this finding is consistent with studies in male adolescents (Howard et al., 2016). Caution should however be taken when comparing the results with that of a male population given the inherent sex differences.

In the present study, in tests where a greater body mass may be detrimental, such as when having to move this mass against inertia through space during a sprint or jump, performance is negatively impacted. Specifically, delayed maturation was associated with being both faster across 20m and 30m, and jumping higher in both CMJ tests, however, this association with speed was removed upon input of other variables into the regression analysis. Recent research considering maturational status and sprint or jump performance in non-athletic adolescent females is scarce, however, the few studies that have looked at it have observed little association. Little and colleagues (Little, Day and Steinke, 1997) showed small differences in tests of both lower body and upper body power across varying maturity groups in a normal female cohort. However, upon controlling for body mass, later-maturing females performed slightly better than early or on time maturers, as is observed in the current study (Little, Day and Steinke, 1997). In elite tennis players, Myburgh and colleagues (Myburgh. et al.,

2016) observed inconsistent trends between power performance and maturational status. These inconsistencies were likely due to variation in the test used, with advanced maturation associated with superior performance in tests of overhead power but not in jumping lower body power tests.

As noted, delayed maturation was associated with superior maximal sprint performance in the current study. This result is also observed in the study by Myburgh et al., who also observed no significant association between sprint performance and maturity status (Myburgh et al., 2016). A tendency for early maturing females to be slower than average or late maturing females has been previously observed in non-elite cohorts (Little, Day and Steinke, 1997). It is well documented that the large neuromuscular spurt that occurs in adolescent males is blunted in females (Lloyd and Oliver, 2012). The ability to produce force and then apply and direct force into the ground is key for successful sprinting and jumping performance (Morin, Edouard and Samozino, 2011; Jidovtseff et al., 2014). As a result of a blunted neuromuscular spurt in females, the muscular-tendon properties that influence the force and velocity generating capabilities of the neuromuscular system are unlikely to have developed to a great enough level to cope with the increase in body mass that is often evident in early maturers and thus may limit speed and power improvements (Quatman et al., 2006). This is likely further emphasised in non-athletic females due to a general lack of strength and conditioning training. The net result is that an increase in body mass, without an improvement in the ability to effectively apply and orientate force to move this mass, may negatively impact speed and power performance, as observed in the present study. This result was not observed in the male cohort, as discussed in Chapter Four, and further supports the gender difference in the neuromuscular spurt during adolescence. This notion is supported by Emmonds et al., (Emmonds et al., 2018) whereby it was observed that despite peak force increasing with biological age, relative force did not, and consequently CMJ performance did not increase with increasing maturity. The authors also attributed this to an increase in body mass in adolescent females, however, as is a limitation of the present study, body composition was not assessed. In the present study body composition assessment would have added depth to the understanding of results, however it was not possible to assess this during testing sessions. Therefore, given the inconclusiveness of previous research in this area, further research is needed to enhance understanding of how speed and power performance changes with female adolescent maturation in females.

Being relatively older was associated with a better upper body strength performance. This was consistent across both the correlational analysis and regression analysis of the data. There exists little research assessing the influence of relative age on female adolescent fitness performance, however, a recent study in Japanese schoolchildren observed an opposing association between relative age and strength (Nakata et al., 2017). This study did, however, observe an association between relative age and upper body strength in 14-year-old girls, but not in 12-, 13-, or 15-year olds. Differences in the sporting cultural upbringing in Japan compared to England may reflect the differences in results across the two studies. In support of findings in the current study, Nakata et al., observed no association between relative age and tests of speed and power (Nakata et al., 2017).

Upon controlling for differences in whole age, relative age was positively associated with several other fitness qualities, namely, total body power, 20m speed, 30m speed, agility and momentum. That is, an older relative age was associated with a faster sprint, and better power, agility, and momentum performance when whole age was controlled for. This is described as a "net suppression effect", that is, the appearance of an association after controlling for another variable. A net suppression effect indicates that the nature and magnitude of association among variables can change when additional factors are controlled for. Specifically, a net suppression effect describes the observation of an association between variables, as a result of controlling for another variable. This would, therefore, suggest it is possible that the nature of the associations between relative age and fitness vary as a function of age. Closer examination of this association supports this and suggests these associations may be different at different ages when whole age and biological maturity are controlled for. Interestingly, a moderate positive correlation was observed between relative age and 20m speed, 30m speed and agility in the 15-year-olds, meaning relatively younger girls were faster and more agile than relatively older girls at age 15. This was also observed in the 14-year-olds; however, the results were not significant in this age group. In contrast, a small to moderate negative correlation was observed in the 13-year-olds, and non-significant correlations at 11-years and 12-years of age were also observed. This means that relatively older girls were faster than the relatively younger girls at 11-13 years. Therefore, in the younger age groups relatively older girls appear to be faster than relatively younger girls, however at ages 14 and 15 this reverses, and the relatively younger girls appear to have a faster maximal speed across 20m and 30m. Also, a moderate positive correlation was observed between relative age and momentum performance at 13 years, meaning that relatively older girls displayed better momentum performance than relatively younger girls at this age. This suggests the nature of the association between relative age, speed, agility and momentum may vary relative to whole age and biological maturity; however, further research is required to understand this.

The evaluation of athletic fitness variance with age has been more extensively studied than the contribution of relative age and biological maturation to female adolescent fitness performance. The observed increase in athletic fitness with age is consistent with the existing literature on physical fitness in young females (Little, Day and Steinke, 1997; Viru et al., 1999; Malina, Bouchard and Bar-Or, 2004). Whilst performance generally increases with age in the current study, there is a tendency for performance in some tests to plateau in the older age groups (See Table 5.2). The descriptive results show that acceleration speed and lower body power performance do not increase from 13 years to 14 years of age whilst momentum, acceleration, 20m maximal speed and agility performance do not improve from 14 to 15 years of age. This supports existing research which shows a plateau in fitness occurring towards the end of puberty in females generally around 14-15 years of age (Bouchard and Bar-Or, 2004). In contrast, assessment of boys' fitness performance with age, as discussed in Chapter Four, demonstrated a more continued trend towards improving with age (Table 4.2). These observed gender differences support existing research (Malina, Bouchard and Bar-Or, 2004).

The results from the ANOVA's pairwise comparisons (Table 5.3) provide additional support to the observation of a plateau in female fitness with age, with performance in only the balance and power tests showing significant difference from 14 years of age to 15 years. This blunting of fitness performance through adolescence likely results from naturally occurring adolescent physiological processes such as increased deposition of fat mass and a blunted neuromuscular spurt which can result in females displaying a less consistent trend towards improved performance than males (Lloyd and Oliver, 2012). This blunted neuromuscular spurt is a result of sexual maturation and the absence of a large increase in testosterone levels that is seen in pubertal boys. Sexual maturation in adolescence drives various sex differences in muscle size, muscle fibre type and tendon architecture for example, all of which lead to a performance improvement of a smaller magnitude in some physical qualities in females compared to males (Malina, Bouchard and Bar-Or, 2004).

Whilst a plateau in fitness performance across various tests was observed in the current study, no regression in physical fitness performance across any of the age groups or in any of the tests occurred. This observation was encouraging yet also paradoxical as girls' perception of their physical fitness or ability often subsides or decreases with age (Cumming et al., 2011). That is, girls may improve or maintain their fitness levels, yet they perceive themselves as being less competent in these domains. Society also often holds this view of girls' fitness, sports competence and physical attractiveness decreasing during adolescence (Cumming et al., 2011). It is well known that boys will outperform girls in most tests of fitness from the pubertal period (Malina, Bouchard and Bar-Or, 2004) and this could lead to conclusions that girls' fitness is not improving. Whilst the general improvements in fitness observed in the current study are unlikely to be as dramatic as those observed in an equivalent boys' cohort, as described in Chapter Four, this female population do improve in performance and do not regress.

Studies have shown that changes in physical appearance are considered more important to teenage girls than changes in functional capacity and sports competence (Sherar et al., 2010) and physical attractiveness may be the most salient source of self-esteem and self-worth in adolescent girls (Page and Fox, 1997). Physical self-concept is a key determinant of physical activity participation with a positive perception of one's self predicting a greater involvement in moderate-to-vigorous levels of physical activity (Sabiston and Crocker, 2008), whilst body dissatisfaction is associated with lower physical activity levels (Neumark-Sztainer et al., 2006). The Mediated Effects Model of Psychological Adaptation to Puberty (Petersen and Taylor, 1980) supports this and describes that the beliefs and attitudes an individual has towards physical activity are largely connected to the perception one has of their own self and can also be influenced by external factors such as cultural and social ideals. The drop in girls' participation rates in physical activity during the adolescent period may therefore be enhanced by sociocultural messages centred around body image influencing girls' perception of the pubertal changes (Finne et al., 2011). To counter negative perceptions of a fitness decline in females it is important to educate girls about the changes that occur during puberty. While the fitness gap between girls and boys may be becoming greater, girls may still become fitter. Fitness testing could act as a useful educational tool in helping girls' perception of their fitness ability.

The findings in this thesis support the well documented evidence that adolescent boys demonstrate greater physical fitness performance than adolescent females (Malina, Bouchard and Bar-Or, 2004). In all tests of fitness, except balance, and across all ages, the boys outperformed the girls. These gender differences were greatest across all fitness tests (except balance) from ages 13 and 14 years onwards. It is well understood that, whilst males display better fitness performance than females in childhood, gender differences in fitness are more obvious from puberty (Malina, Bouchard and Bar-Or, 2004) which is likely where the greatest gender differences are observed in this thesis.

The observation that females performed better in the balance test than males of the same age cohort across all ages except at age 14 is interesting and supports existing research (Cratty, 1979; Mickle, Munro and Steele, 2011). As discussed previously, COM height influences postural sway (Ojie, Saatchi and Saatchi., 2020) and makes muscular control of lower limb joints more difficult (Quatman et al., 2005), both of which likely negatively influence balance performance. Skeletal growth during childhood and adolesence leads to a rise in COM (Quatman et al., 2005). At all ages, except for age 12 years where average height was approximately the same, the average height of the male participants was greater than the females. This greater height of the males results in a heightened COM which may have negative consequences on balance performance. Additionally, 'athletic awkwardness' has been more robustly discussed in the research as a phenomenom to occur more consistently in males than females (Ryan et al., 2018). Athletic awkwardness, that is, reduced motor control and coordination, may also negatively influence balance performance in the boys (Quatman-Yates et al., 2012; Ryan et al., 2018). Additionally, the earlier maturation of fermales visual, vestibular and proprioceptive systems compared to males may also contribute to a superiour performance systems (Cratty, 1979; Mickle, Munro and Steele, 2011).

5.5.1 Practical Implications

The results from this study have practical implications for individuals working with female adolescents. Very few studies have assessed the performance of general female adolescent populations across tests of athletic performance and of the few that have researched this area, none have considered the simultaneous or interactive effects of maturation and relative age upon physical performance. The present study highlights the importance to consider both relative age and maturity status when training, assessing or evaluating female adolescent fitness. Furthermore, it highlights the need to consider maturation and relative age as separate constructs rather than in the often observed interchangeable manner. A failure to control for, or consider, each variable could lead to attenuated or inflated associations between fitness, relative age and/or maturation. This will benefit teachers and coaches working with adolescent females to provide a more individual and holistic approach to fitness development.

More developmentally aligned measures of performance may also benefit the young athletes themselves. During adolescence, young females face many challenges and changes, for example, dealing with emotional changes resulting from puberty, societal pressures and changes in body size and composition, and these factors can result in an increase in females dropping out of physical activity and sport during this period (Dumith et al., 2011). Increasing awareness and knowledge of the impact of growth and maturation in physical domains through education programmes to athletes, parents and coaches would be beneficial to helping to tackle these issues.

Additionally, with an increase in professionalism in female sports there can be an increased pressure to select the best athletes for immediate success. In youth sport this may result in the biased selection of the bigger, stronger or older girls and thus may increase the likelihood for maturity selection biases or relative age effects to appear within sport. Increasing our understanding of how relative age and maturation impacts athletic performance is, therefore, increasing in importance and the present study adds value in this area. Coupled with this, Till and Baker (Till and Baker, 2020) recently highlighted the complexity that relative age and maturational factors add to fitness comparisons as part of talent identification within sports. In line with this reasoning, Gillison et al., (Gillison et al., 2017) recently showed the importance of adjusting for biological age when assessing age-related weight status in children. More specifically, categorisation of weight status against biologically age-matched reference charts resulted in the re-classification of 43% of girls into a lower weight class. Adjustments for variation in relative age and/or maturation could also be performed for fitness testing. That is, performance could be adjusted for variance in relative age and/or maturity to obtain more developmentally sensitive evaluations of fitness. Such a strategy could have relevance for the processes of talent identification, and for the monitoring and evaluations of strength and conditioning programmes. A lack of developmental measures for assessing physical fitness was highlighted as a concern in the BASES Expert Statement on Trainability During Childhood and Adolescence (Barker et al., 2014). Comparison to normative, biological age-adjusted data will give practitioners a better understanding of the athlete's strengths, weaknesses and a better determination of the success of a training programme, establishing whether it has helped develop an individual above and beyond normal development.

The present study also highlights the potential to consider differences in maturation and, potentially, relative age in other testing batteries, such as those monitoring the health-related fitness of youth. Many of the studies monitoring national health and fitness in the paediatric population incorporate tests of muscular and motor fitness, e.g., Fitnessgram (Welk et al., 2011) and ALPHA-FIT (Ruiz et al., 2011). Considering developmental differences across test performance would enhance the insight gained from these health-focused studies.

5.5.2 Limitations

There are several limitations to this study, many of which are consistent with those discussed in Chapter Four. Firstly, this study examines the relationship between relative age, maturity status and physical fitness of a cross-sectional sample of female adolescents in English schools. To gain a deeper understanding of the effect of relative age and maturity status on adolescent fitness, longitudinal tracking of fitness should be sought in future research. Secondly, self-reported parental heights were used as part of the Khamis-Roche method to estimate biological maturity status, a method which uses Epstein height prediction equations and reference values that were developed in the United States. This presents a limitation when involving British participants, as used in the present study. There are also some limitations with the testing protocols carried out. Acceleration was determined from an average velocity across 8m to 12m to provide a more accurate measure of momentum performance, similar to the protocol used by Howard et al., (Howard et al., 2016). However, whilst this provides an accurate measure of acceleration across 10m, direct comparison with studies using a direct 10m sprint are not possible. Similarly, many studies that assess balance performance using the Y-Balance test commonly adjust scores for leg length, with leg length being shown to be positively correlated to Y-Balance performance (Gribble and Hertel, 2003). However, due to time constraints during the present study's testing sessions, leg length was unable to be measured.

A further limitation of the study is that the cohort was, on the whole, slightly delayed in maturation. This bias was particularly evident at the older age group of 15-year-olds. Females advanced in maturation in this cohort may be more likely to be going through puberty and their menstrual cycle. It is common for girls to have concerns over their menstrual cycle during adolescence, whilst early maturing females are also more likely to have reduced confidence and lower self-esteem (Davison et al., 2007).

This may result in a tendency for early maturing girls to opt out of the fitness testing for fear of embarrassment or body concerns, resulting in an increased number of later-maturing girls in the cohort. Further research into the maturity-associated relationship with female participation levels in school PE lessons would be interesting and may provide further understanding of this area.

A particular consideration for fitness assessment in this female cohort relates to the validity and reliability of the testing protocols used. Although the testing protocols used in this study have been shown to be reliable, valid and possible within adolescent populations (Plisky et al., 2006; Castro-Piñero et al., 2010; Stewart, Turner and Miller, 2014; Fernandez-Santos et al., 2015; Paul and Nassis, 2015), these populations predominantly consist of male samples. Given that most of the research in this field has been established from considering the fitness tests required to assess the physical demands of male sports, the tests may bias towards male attributes or biomechanics. It is unknown whether they are the most appropriate tests to assess speed, momentum, agility, power and balance in females. Whilst this is out of the scope of the present study it needs consideration.

5.5.3 Conclusion

In conclusion, this study has shown that relative age and biological maturity are independent constructs, acting on female adolescent fitness performance differently. They therefore both need to be considered when working with young females. An association between upper body strength, momentum, maximal speed and power and maturation exists. There is also an association between relative age and upper body strength, whilst an association between relative age and total body power, maximal speed, agility and momentum also exists, however, only after whole age differences are controlled for. Further studies could explore the association of relative age and maturation in health parameters such as cardiovascular fitness, rather than athletic tests, as considered in this study. This study has also enhanced understanding of the performance of normal female adolescents in contemporary tests of physical fitness that are widely used within fitness testing batteries and in athletic development programmes and elite sport. It is recommended for future research that longitudinal data be collected to better assess the association between relative age and maturity status with physical fitness in the paediatric population. It has also highlighted the necessity for trajectories of age-based standards with consideration for maturation and/or relative age to be produced to better understand how an individual is performing in tests of physical fitness.

CHAPTER SIX

THE ESTABLISHMENT OF AGE-BASED FITNESS PERFORMANCE TRAJECTORIES TO EVALUATE THE IMPACT OF BIOLOGICAL MATURATION RELATIVE TO CHRONOLOGICAL AGE IN MALE ADOLESCENT SCHOOLCHILDREN

6.1 ABSTRACT

PURPOSE: To establish age-based fitness performance trajectories of adolescent boys across a range of athletic fitness tests. Further to this, investigate the degree to which biological maturity status impacts performance relative to the trajectories. **METHODS:** British male school children aged 11 to 15 years old (N=180) performed standardised tests of initial sprint momentum, upper body strength, and a lower quadrant Y balance test. Biological maturation was determined using the Khamis-Roche method and maturity status and biological age were calculated for each participant. **RESULTS:** Individual performance scores were plotted onto age-based trajectories for both chronological and biological age. Wilcoxon Signed Rank tests demonstrated superior mean percentile scores for early maturing boys for CA rather than BA and superior mean percentile scores for late maturers evaluated for BA rather than CA across the tests of momentum, strength, and balance. Kruksal Wallace H tests demonstrated significant difference in the BA-CA differential scores for strength, momentum, and balance ($p < .001$). **CONCLUSION:** Physical performance trajectories with consideration for maturation provide a novel approach for assessing physical fitness relative to BA and CA in adolescent males. Early maturing boys demonstrate superior performance on tests of momentum, upper body strength and balance when evaluated relative to CA rather than BA. In contrast, later maturing boys perform better when evaluated relative to BA rather than CA. Fitness performance may, therefore, be enhanced, and/or, masked as a result of individual differences in biological maturation. This highlights the importance of considering individual differences when evaluating the physical fitness performance of adolescents.

6.2 INTRODUCTION

Physical fitness describes a set of attributes that people have or achieve in relation to their ability to perform physical activity (Riddoch and Boreham, 1995). The physical fitness of an individual can therefore be both improved and reduced over a period of time. Fitness develops in a non-linear fashion throughout childhood and adolescence (Malina, Bouchard and Bar-Or, 2004). Changes in an individual's functional and physical qualities occur as a result of the biological processes of growth and maturation brought about by hormonal changes and the refinement of movement patterns through physical activity behaviours, training and instruction (Malina, Bouchard and Bar-Or, 2004); for example, maturational changes of the neural and muscular systems, such as enhanced motor unit recruitment, increased firing frequency and enhanced muscle cross-sectional area, contribute to performance improvement in qualities such as strength and power. Furthermore, neuromuscular changes as well as skeletal and somatic maturation result in changes in height, limb length and body mass and can lead to the natural development of speed during childhood and adolescence (Lloyd and Oliver, 2012). Although the process of maturation significantly contributes towards developmental gains in fitness, it is important to note that improvements in physical fitness can also be developed through training. Resistance training, for example, in youth has been shown to improve strength, power, and speed (Behm et al., 2017).

Individual variation in the timing and tempo of maturational events, such as puberty and peak height velocity, impacts the physical and functional development of children, presenting a challenge for practitioners engaged in the processes of physical development (Malina, Bouchard and Bar-Or, 2004; Bergeron et al., 2015). Variation in the timing of maturity, and maturation status, can mask or enhance functional capacities in youth making it difficult to assess an individual's true ability or future potential (Baxter-Jones, Eisenmann and Sherar, 2005). Differences in the timing of maturation also makes it challenging for teachers and coaches to accurately evaluate and monitor a child's strengths, weaknesses and/or differentiate any fitness gains that occur above and beyond those changes associated with the process of growth and maturity (Cumming, 2018). The confounding effects of maturation, therefore, should be controlled for when considering paediatric fitness (Baxter-Jones, Eisenmann and Sherar, 2005).

As noted in the previous chapters, boys that mature in advance of their peers are, on average, taller and heavier from late childhood than their on-time or later maturing counterparts. It is not until the onset of puberty, however, that early maturing boys present a marked advantage in functional capacity (Malina, Bouchard and Bar-Or, 2004). Of note, these differences in functional capacity generally coincide with the emergence of maturity-associated selection biases in sport (Malina et al., 2015). The greater gains in height, weight and lean mass also lead to an enhanced athletic profile. This often results in early maturing boys performing better in tests of strength, power and speed when compared to their on-time, or later maturing counterparts (Malina, Bouchard and Bar-Or, 2004; Malina et al., 2005). This is particularly evident around 11-14 years of age, upon the onset of puberty (Malina et al., 2015).

The individual differences afforded by growth and maturation present a challenge for schoolteachers and practitioners in community-based sports programmes where they want to engage all children in sport and activity and promote a positive association with fitness. Peer acceptance and social status amongst peer networks are important social constructs for adolescents and perceived popularity represents an important factor in the social status in adolescents (Rubin, Bukowski and Parker., 1998; Corsaro and Eder., 1990). Those individuals perceived as being popular are viewed by their peers as being more attractive, more influential and more athletic (Badad, 2001; Lease, Kennedy and Axelrod., 2002; Lease, Musgrove and Axelrod., 2002). In general, early maturing boys display greater self-esteem, confidence, popularity and physical attractiveness compared to late maturing boys (Jones., 1958; Dubas, Graber and Petersen., 1991) and in combination with the physical advantages afforded by earlier maturation, support the benefit in creating developmentally aligned sporting environments in schools.

The physical and functional advantages associated with advanced maturation in boys' results in an overrepresentation of early maturing males in some sports such as football (Whiteley, Johnson and Farooq, 2017) and rugby league (Till et al., 2010). It has also recently been shown that biological age can influence coaches' evaluation of sports' performance. Hill et al., (Hill et al., 2020) demonstrated that young male soccer players advanced in maturation were more likely to be given a higher performance grade and a more positive coaches' evaluation across some age groups. This suggests the adolescent profile, when considered only by chronological age, can lead to a misguided prediction of adult success (Ford et al., 2012). In support of this, the physical and functional advantages associated with earlier maturation are often attenuated and sometimes removed in adulthood where late maturing boys catch up and may even surpass performance in some tests of fitness (Lefevre et al., 1990). This highlights that, due to variance in biological maturation, the assessment of physical fitness during adolescence may not accurately represent current, and/or, future physical capabilities of the child.

Given the preceding discussion, there is a clear need to better the understanding of the role of growth and maturation in relation to the development of fitness and create fitness assessment strategies and standards that are more developmentally aligned (Lloyd et al., 2014). Youth fitness testing, both in elite and non-elite sport, usually compares absolute values in relation to age-specific standards or in relation to the performances of peers within the same age group (Lloyd et al., 2014). Whilst it could be argued that such strategies are useful in terms of describing the individual's fitness relative to those that they will compete against in their age group cohorts, such strategies are limited in their ability to assess the individual's true ability or their potential for success at the adult level. For example, if an early maturing 14-year-old individual can jump higher in a countermovement jump test than a less mature, age-matched peer, this will also be replicated in PE or on the basketball court, so it could be argued that the testing is fair. However, until maturity status is considered, it is unclear to what degree the early maturing boy is in fact benefitting from advantages associated with earlier maturation and whether or not they would perform as well if compared against individuals of a similar maturation status.

To address the aforementioned concern, researchers have proposed the development and implementation of fitness standards that consider, and/or, adjust for individual differences in maturation status, and/or, biological age (Golle et al., 2015; Cumming et al., 2017; Till et al., 2018). As part of the Elite Player Performance Plan, the Premier League implemented parallel growth and maturation screening programmes for all players registered with Premier League and category one academies in England and Wales (https://www.goalreports.com/EPLPlan.pdf). The data collected from these projects allowed for the generation of age- and maturation-specific standards with the Premier League's Player Management Application, a Data Performance system that is used to assess and monitor the development of registered academy players. These features enabled the consideration of player fitness relative to both age- and maturity-specific standards, affording the opportunity to better determine and assess players' strength and weakness.

Age-standards, based upon cross-sectional assessments of fitness, provide a useful starting point from which to consider an individual's current fitness relative to their development at a given time point (Malina, Bouchard and Bar-Or, 2004). They do not, however, allow the teacher or coach to assess and monitor changes in fitness over a given time period. The creation of age-based performance trajectories for fitness, whilst tracking against biological age, would allow for greater understanding of physical performance (Till et al., 2018). National and international age-specific and sex-specific fitness benchmarks, or centiles, have been created for the performance of youth populations in the US in various tests of physical fitness (Laurson et al., 2017). This has enhanced the knowledge of a nation's fitness against normative values and for comparison of fitness between nations. Percentile curves for the physical fitness of both children and adolescents have also been developed around the world, for example, in Europe (De Miguel-Etayo et al., 2014; Vanhelst et al., 2017), Australia (Catley and Tomkinson, 2013) and Africa (Olds et al., 2006).

To date, only a small number of studies have attempted to create performance trajectories or percentile curves with consideration for biological maturation for the purpose of better assessing and monitoring athletic fitness in youth. Studies by Myburgh et al., (Myburgh et al., 2020) and Ulbricht et al., (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013), for example, demonstrated a significant difference in fitness percentiles obtained for junior tennis players when evaluated relative to their biological and chronological age. Specifically, Myburgh et al., (Myburgh et al., 2020) demonstrated that early maturing males performed significantly worse in an acceleration sprint test when they were evaluated relative to their biological age rather than chronological age. Similarly, Ulbricht et al., (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013) demonstrated that a later maturing tennis player performed poorly in an upper body power test when considered relative to chronological age. However, when analysed relative to biological age these individuals performed well, obtaining significantly greater percentile scores. Adopting a similar approach, Votteler and Höner (Votteler and Höner, 2014) created developmental trajectories to better understand the general performance of young, elite German footballers across a range of football-specific motor skills and technical tests. In this case, the researchers evaluated the influence of relative age, rather than biological age, on performance. In terms of absolute performance on a compositive measure of soccer aptitude, relatively younger players performed more poorly than their older age group peers.

In relation to the developmental curve, however, the relatively younger players performed well above the expected values for their age; whereas the performances of the relatively older players typically fell below those expected for their age. This observation is consistent with the underdog hypothesis which posits that, to be retained within competitive sports programmes, relatively young, and/or, later maturing athletes must possess abilities or qualities well above those expected for their age, and/or, stage of maturity (Gibbs, Jarvis and Dufur, 2012).

Though limited, the studies that have considered the use of developmental standards for fitness, and/or, performance, present encouraging evidence that such strategies can provide more developmentally aligned assessments of athletes' fitness when young. These studies have, however, based their performance trajectories on the performance of groups of select and highly talented youth (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Votteler and Höner, 2014; Myburgh et al., 2020). As such, these standards are naturally skewed towards, and representative of, a very highly skilled set of junior athletes and, thus, may not apply to the general population. To date, no studies have created physical fitness centiles, with consideration for biological age for the general, adolescent population. The development of normative age-based standards derived from the general population would allow for more informed and individualised decision making in the development and management of adolescent fitness. Such standards may also be more appropriate when evaluating young individuals across a range of sports, such as in athletic development programmes. From an applied perspective, such standards would allow practitioners to more objectively compare an individual's physical profile relative to normal, biological age standards, furthering understanding of performance. This will also provide a better base from which to programme fitness training, allowing for more targeted interventions on an individual's physical weaknesses (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013).

In light of the preceding discussion, the aim of this study is to establish physical performance age-based trajectories of adolescent boys, aged 11-15 years, across a range of athletic fitness tests. Further to this, the degree to which biological maturity status impacts physical fitness relative to the performance trajectories will be evaluated. The fitness tests of upper body strength, momentum, and balance have been chosen for evaluation. These tests were chosen due to their close association with biological maturity (see Chapter Four). It is hypothesised that boys advanced in maturity will present lower (worse) percentile scores for strength and momentum tests when scores are expressed relative to biological maturity status than to chronological age. It is also therefore hypothesised that the opposite would be observed for later maturing individuals where they will present higher (better) percentile scores for strength and momentum tests when scores are expressed relative to biological maturity status than to chronological age. Concerning balance performance, the results observed in Chapter Four demonstrated an inverse relationship between maturity and balance. Therefore, in this study it is hypothesised that boys advanced in maturity will present higher (better) percentile scores when expressed relative to biological maturity status than to chronological age. In contrast, it is hypothesised that the later maturing males will present lower (worse) percentile scores when expressed relative to biological maturity status than to chronological age.

6.3 METHODOLOGY

6.3.1 Participants

The physical fitness testing of male schoolchildren aged 11 to 15 years in the South-West of England provided the data from which the creation of developmental curves for fitness were derived. A total of 180 male schoolchildren were assessed during the academic years of 2014-15 and 2015-16. The mean age of participants was 13.9 years (±1.22). Participants were assessed once, providing a cross-sectional data sample. Participant's performance scores were plotted independently for both chronological age and biological age. This allowed an individual's percentile score for each test to be compared across chronological and biological age. Only participants that satisfied all inclusion criteria of date of birth (to establish chronological age), maturity information and test completion were included in the analysis.

6.3.2 Ethics and Consent

This study was approved by the Research Ethics Approval Committee at the host University. Informed written consent was obtained via the school's head teacher acting *loco parentis* and a parental opt out option was given to every individual. Self-assent was obtained for the participant. The schoolteachers were informed about the procedures and aims of the study prior to completion and only those participants that indicated a willingness to take part were included.

6.3.3 Physical Fitness and Anthropometric Measurements

All fitness testing was carried out during the participants' normal physical education lesson. For a detailed description of height and weight measurement please refer to Chapter Three. The fitness tests employed were; hand grip dynamometer to assess upper body strength; a linear sprint to assess momentum; and a Y-Balance test to assess balance performance. For a detailed description of fitness testing protocols and assessment measurements please refer to Chapter Three.

6.3.4 Maturity Measurements

Decimal age, height, and weight of the individual, and mid-parent height, were used to predict mature, adult height for each participant using equations developed on the Fels Longitudinal Study sample in south-central Ohio (Khamis and Roche, 1994). Parental heights were self-reported prior to the testing session and were adjusted for overestimation (Epstein et al., 1995). The current height of each participant was expressed as a percentage of his predicted mature/adult height; by inference, the boy closer to mature height (higher percentage) is advanced in maturity status compared to the boy who is further removed (lower percentage). To translate biological maturation status into an index of biological age, methods described by Gillison and colleagues were used (Gillison et al., 2017). That is, percentage of adult height achieved at the time of assessment was compared to age-specific and sex-specific reference standards derived from the UK 1990 growth reference data to obtain a biological age for each participant (Freeman et al., 1995; Gillison et al., 2017). Reference standards for percentage of adult stature were calculated at 0.1 yearly intervals relative to the UK reference data. An individual's biological age was determined from the individual's percentage of attained adult height compared to the mean adult height attained at each age relative to the mean stature at/above 18 years of age. For example, a boy with a chronological age of 12.8 who has reached 85.0% of his peak adult height at the time of measurement presents a value for percentage of adult height that is equivalent to the mean value for a boy that is 12.4 years. Thus, this individual would be assigned a biological age of 12.4 years. Biological age was expressed at 0.1 yearly intervals.

Maturity status was determined as BA minus CA. Participants were grouped as being advanced in maturity if the difference between BA and CA was > 0.5 year, delayed if the difference was > -0.5 year, and on-time if the difference fell between -0.4999 year and 0.4999 year (Drenowatz et al., 2013). Using the example above, the boy would have been classified as on-time (BA 12.4 – CA 12.8 = -0.4). For the analysis, maturity bandings of ±0.5 yearly intervals were chosen rather than the traditional ±1.0 years because it was believed that this would better differentiate between early and late maturing individuals. The traditional method of -1 to +1 does not differentiate between individuals who differ markedly in maturity but are classified as the same maturity status group (e.g., a z-score of +0.99 and a z score of -0.99) (Hill et al., 2019).

6.3.5 Performance Trajectories of Age-Based Standards

As noted in Chapter Four, biological maturation in males was found to be closely associated with upper body strength, momentum and balance performance. Consistent with methods described by Myburgh and colleagues (Myburgh et al., 2020), selected quantiles (10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th}) were calculated by chronological age using the R Package Quantreg (Koenker, 2005). Smoothness of fit was controlled for via total variation penalization. This non-parametric method establishes both medians and percentiles, it is robust to outliers and makes no assumptions on the underlying distribution of data. These trajectories permitted the evaluations of an individual's fitness performance, in percentiles, as a function of their chronological and biological age.

6.3.6 Statistical Analysis

A series of Wilcoxon Signed Rank Tests were employed to examine the degree to which the participants fitness performance centiles scores differed relative to their BA and CA, in early, on-time, and late maturing individuals. These analyses were performed for upper body strength, momentum, and balance performance, and independently for early, on-time, and late maturing males.

Percentile discrepancy scores were calculated for BA and CA percentile values by subtracting the CA percentile from the BA percentile. For example, if a participant's upper body strength score was in the 37^{th} percentile for CA and the 65^{th} percentile for BA, the percentile discrepancy score would be 28%. Subsequently, a series of Kruksal-Wallis tests were then employed to evaluate the difference in percentile discrepancy scores for strength, momentum, and balance scores across each of the maturity groups (i.e., early, on-time, late). Statistical significance for all analyses was set a $p < 0.05$. Effect sizes for nonparametric data (z-score divided by the square root of total sample number) were calculated to indicate the magnitude of difference across each variable. A value of ≤ 0.10 was considered to be a small effect, 0.30 a moderate effect, and ≥ 0.50 a large effect (Cohen, 1992).

6.4 RESULTS

Descriptive statistics were calculated and summarised as per Chapter Four.

To illustrate the distribution of fitness performance across the participants, performance values for each fitness test (upper body strength, momentum, and balance) were plotted for CA onto the respective trajectories. These analyses can be seen in figures 6.1-6.3. The trajectories support the summaries described in Chapter Four in that all aspects of fitness performance generally increased with age. The plotting of values into the trajectories established percentile scores for both BA and CA for each participant. For all three tests, the greater the percentile score, the better the test performance.

To illustrate the practical application of these trajectories, the specific centiles scores (BA and CA) for an individual have been included. Figure 6.1 displays the developmental curve for upper body strength performance, in which the green dot represents an individual's position on the curve according to his CA (14 years) where he is in the 39th centile, whereas the red dot represents the same boy's position on the curve according to his BA (13 years) where he is in the 82nd centile. As a late maturing boy, it is not surprising that this individual score was markedly higher on this test when evaluated relative to his biological rather than his chronological age. Figure 6.2 displays the developmental curve for momentum performance, in which the red dot represents an individual's position on the curve according to his CA (12 years) where he is in the 88th centile, whereas the green dot represents the same boy's position on the curve according to his BA (14 years) showing he is in the 34th centile. This participant is an early maturing boy and so, perhaps unsurprisingly, this individual score was higher on this momentum test when evaluated relative to his chronological rather than biological age. Figure 6.3 displays the developmental curve for balance performance. The red dot displays a single participant's centile score of 81% where his CA is 12.5 years, whilst the green dot displays the same participant's centile score of 62% for his BA of 15 years. This boy is an early maturing boy and so it is, again, unsurprising that his performance score is higher when evaluated relative to his chronological rather than biological age.

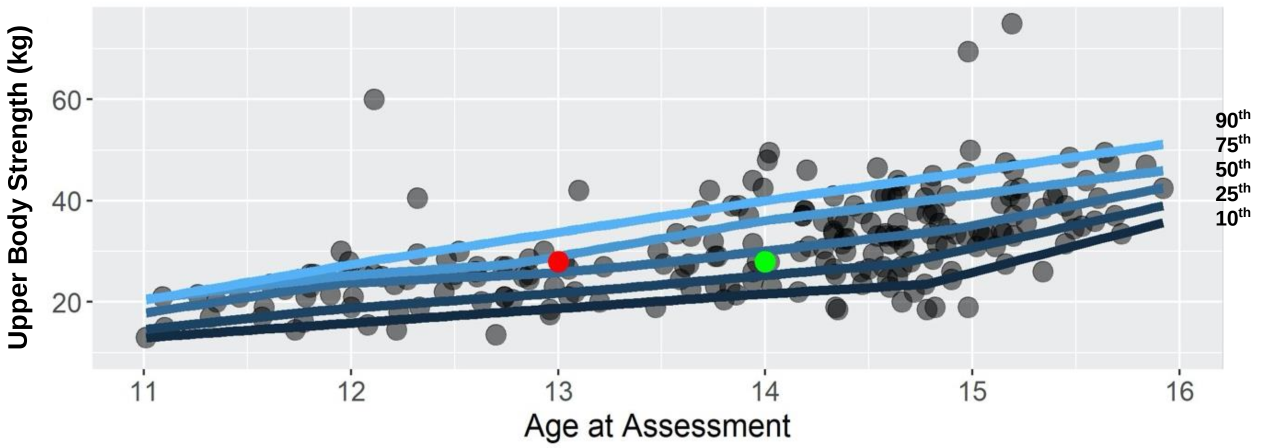


Figure 6.1 Performance trajectory displaying upper body strength distribution of male school children according to biological and chronological age. Each dot represents a single participant. The green dot represents an individual's performance score relative to his CA, whilst the red dot represents the same individual's performance score relative to his BA.

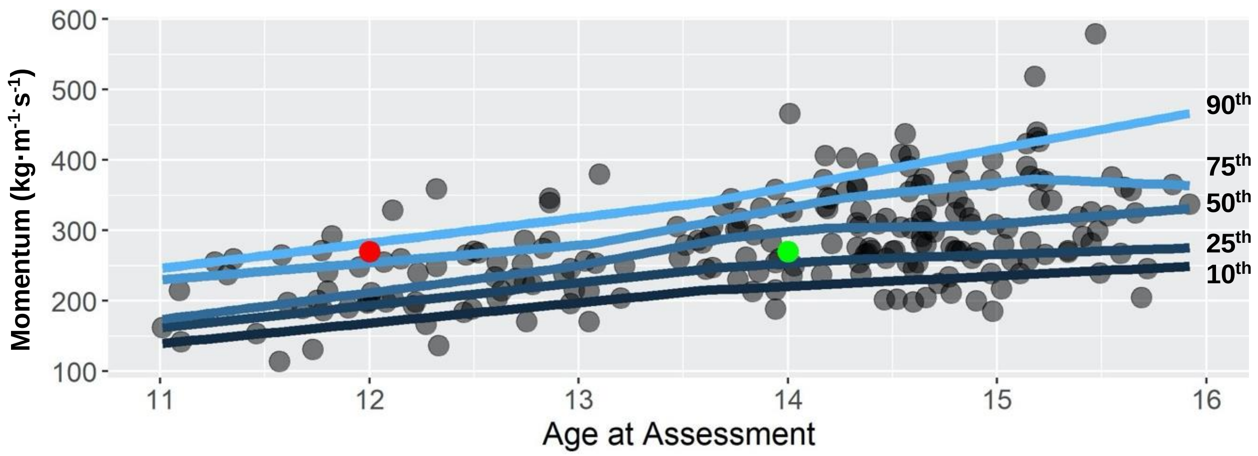


Figure 6.2 Performance trajectory displaying momentum distribution of male school children according to biological and chronological age. Each dot represents a single participant. The red dot represents an individual's performance score relative to his CA, whilst the green dot represents the same individual's performance score relative to his BA.

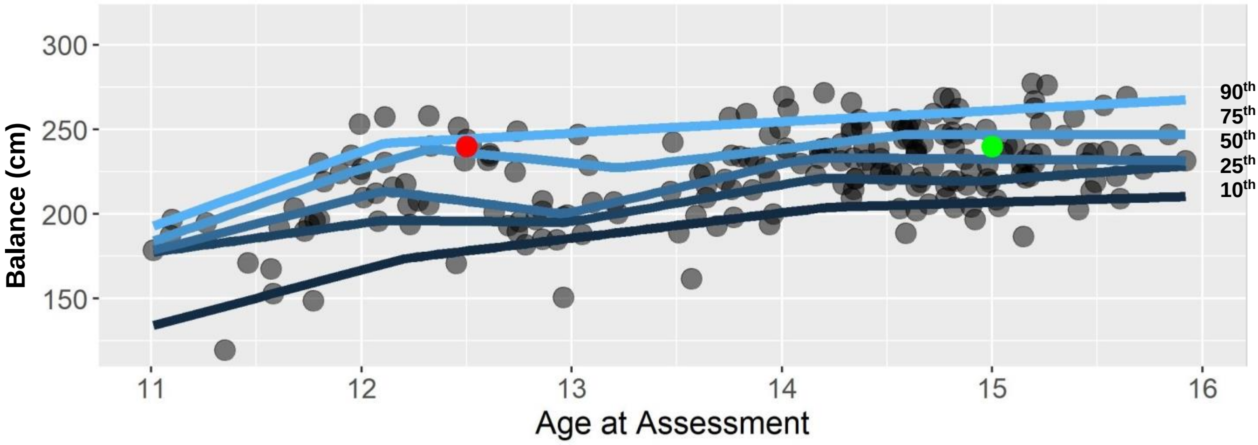


Figure 6.3 Performance trajectory displaying balance distribution of male school children according to biological and chronological age. Each dot represents a single participant. The red dot represents an individual's performance score relative to his CA, whilst the green dot represents the same individual's performance score relative to his BA.

To determine the extent to which fitness scores on the trajectories varied relative to BA and CA, a series of Wilcoxon Signed Rank tests were conducted. Separate analyses were performed for each test of fitness. Similarly, individual analyses were conducted for participants categorised as early, on-time and late maturing.

The results of the Wilcoxon Signed Rank Tests for upper body strength are presented in Figure 6.4. In late maturing males ($n = 29$), the mean percentile value obtained for upper body strength performance for BA was significantly greater (Mean = 55%) than the equivalent value for CA (Mean = 39%), $z = -4.27$, $p < .001$. Of those 29 individuals identified as late maturing, 23 presented upper body strength centile scores for BA that were higher than the equivalent values for CA, whilst only 5 were worse and 1 was unchanged. In individuals categorised as on-time ($n = 110$), the mean percentile value for upper body strength expressed relative to BA (52%) did not differ significantly from the equivalent value for CA (51%), $z = -1.43$, $p = .15$. Whereas 51 of the individuals categorised as on-time presented BA centile scores for upper body strength that were higher than their equivalent value for CA, 19 presented values that were unchanged and another 40 presented values that were lower. In early maturing boys (n = 41), the mean percentile obtained for strength performance for BA was significantly worse (Mean = 44%) than the equivalent value for CA (Mean = 63%), z-score = -5.15, p < .001. Of those 41 individuals identified as early maturing, 35 displayed upper body strength centile scores for CA that were higher than the equivalent values for BA, whilst 3 were worse and 3 remained unchanged.

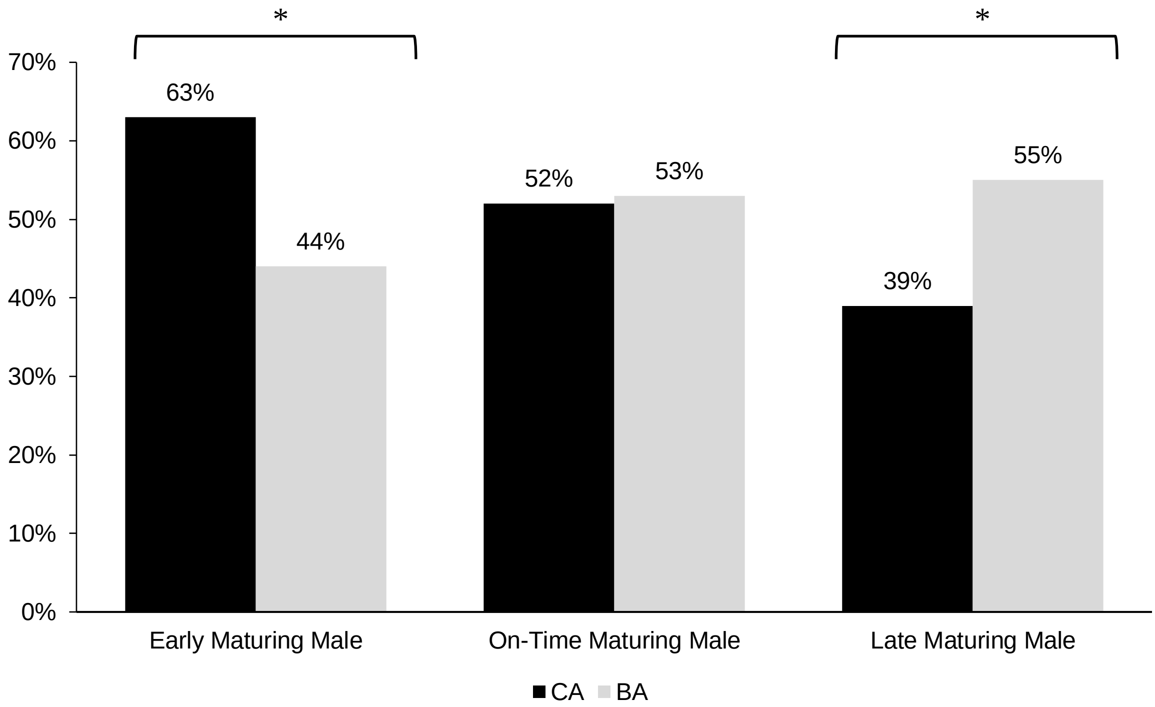


Figure 6.4 Mean percentile values relative to biological and chronological age displaying upper body strength performance of different maturity categories in 11-15-year-old male schoolchildren

The results of the Wilcoxon Signed Rank Tests for momentum are presented in Figure 6.5. In late maturing males (n = 27), the mean percentile value obtained for momentum performance for BA was significantly greater (Mean = 43%) than the equivalent value for CA (Mean = 32%), z = -4.22, p < .001. Of those 27 individuals identified as late maturing, 23 presented momentum centile scores for BA that were higher than the equivalent values for CA, whilst only 3 were worse and 1 was unchanged. In individuals categorised as on-time (n = 108), the mean percentile value for momentum expressed relative to BA (47%) did not differ significantly from the equivalent value for CA (47%), z-score = -0.79, p = .429. Whereas 48 of the individuals categorised as on-time presented BA centile scores for momentum that were higher than their equivalent value for CA, 20 presented values that were unchanged and another 40 presented values that were lower. In early maturing boys (n = 39), the mean percentile obtained for momentum performance for BA was significantly worse (Mean = 63%) than the equivalent value for CA (Mean = 73%), z-score = -3.94, p < .001. Of those 39 individuals identified as early maturing, 32 displayed momentum centile scores for CA that were higher than the equivalent values for BA, whilst 6 were worse and 1 remained unchanged.

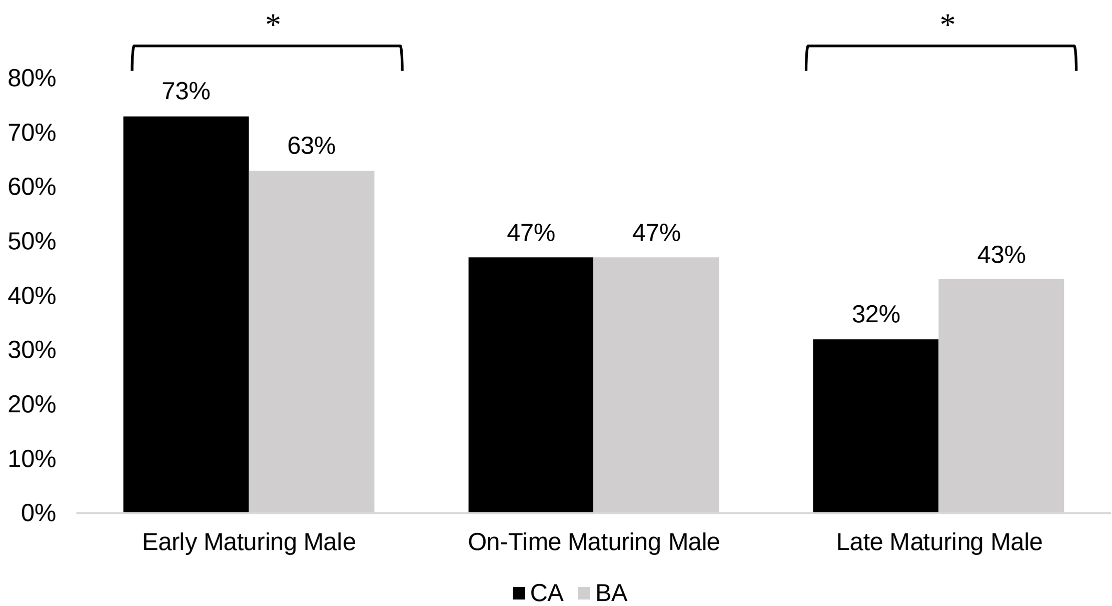


Figure 6.5 Mean percentile values relative to biological and chronological age displaying momentum performance of different maturity categories in 11-15-year-old male schoolchildren

The results of the Wilcoxon Signed Rank Tests for balance performance are presented in Figure 6.6. In late maturing males (n = 28), the mean percentile value obtained for balance performance for BA was significantly greater (Mean = 58%) than the equivalent value for CA (Mean = 44%), z = -3.16, $p < .01$. Of those 28 individuals identified as late maturing, 19 presented balance centile scores for BA that were higher than the equivalent values for CA, whilst 8 were worse and 1 was unchanged. In individuals categorised as on-time (n = 108), the mean percentile value for balance expressed relative to BA (52%) did not differ significantly from the equivalent value for CA (52%), z-score = -0.38, p = .704. Whereas 43 of the individuals categorised as on-time presented BA centile scores for balance that were higher than their equivalent value for CA, 21 presented values that were unchanged and another 44 presented values that were lower. In early maturing boys (n = 37), the mean percentile obtained for balance performance for BA was significantly worse (Mean = 47%) than the equivalent value for CA (Mean = 55%), z-score = -3.30, $p < .001$. Of those 37 early maturers, 27 displayed balance centile scores for CA that were higher than the equivalent values for BA, whilst 8 were worse and 2 remained unchanged.

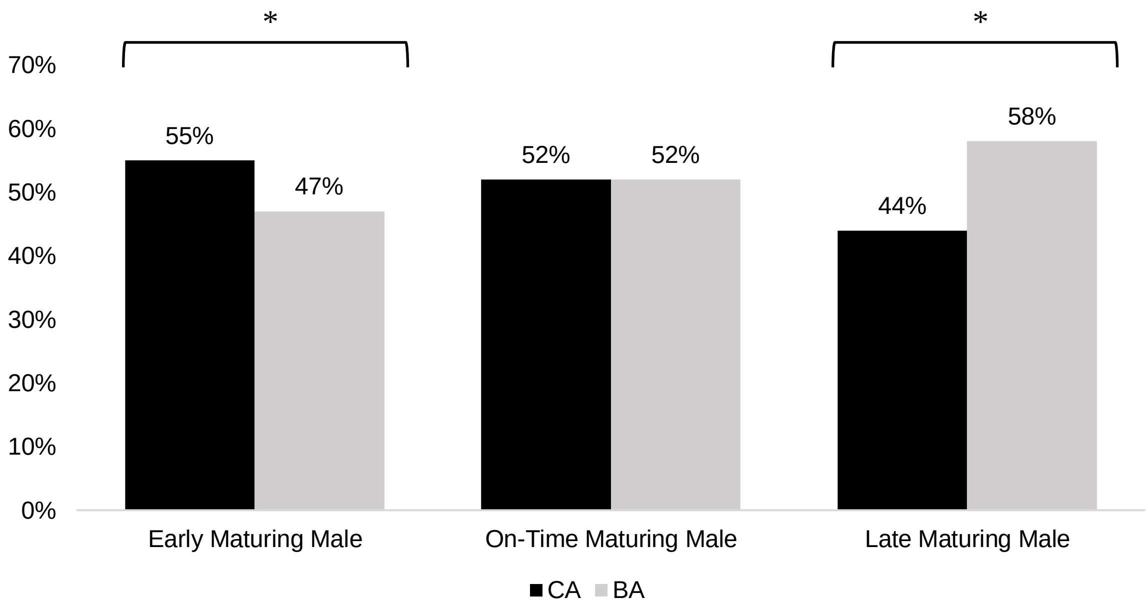


Figure 6.6 Mean percentile values relative to biological and chronological age displaying balance performance of different maturity categories in 11-15-year-old male schoolchildren

A series of Kruskal Wallace H Tests were used to determine the degree to which the fitness performances discrepancy scores (BA centile – CA centile) varied across three independent maturity groups (i.e., early, on-time, late). Results are displayed in Figure 6.7. A statistically significant difference in the BA-CA differential score was observed for upper body strength across the three maturity groups, H (2) = 76.67, $p < .001$, with a mean rank upper body strength result of 143.86 for late-maturing boys, 96.66 for on-time maturing boys and 36.22 for early maturing boys.

A statistically significant difference in the BA-CA discrepancy score for momentum was also observed across the three maturity groups, H (2) = 54.99, $p < .001$, with a mean rank result of 134.29 for late maturing boys, 93.31 for on-time maturing boys and 43.48 for early maturing boys. A statistically significant difference across maturity groups for balance performance was similarly observed, H (2) = 29.34, $p < .001$. A mean rank balance result of 122.30 for late maturing boys, 88.83 for on-time maturing boys and 54.93 for early maturing boys was observed.

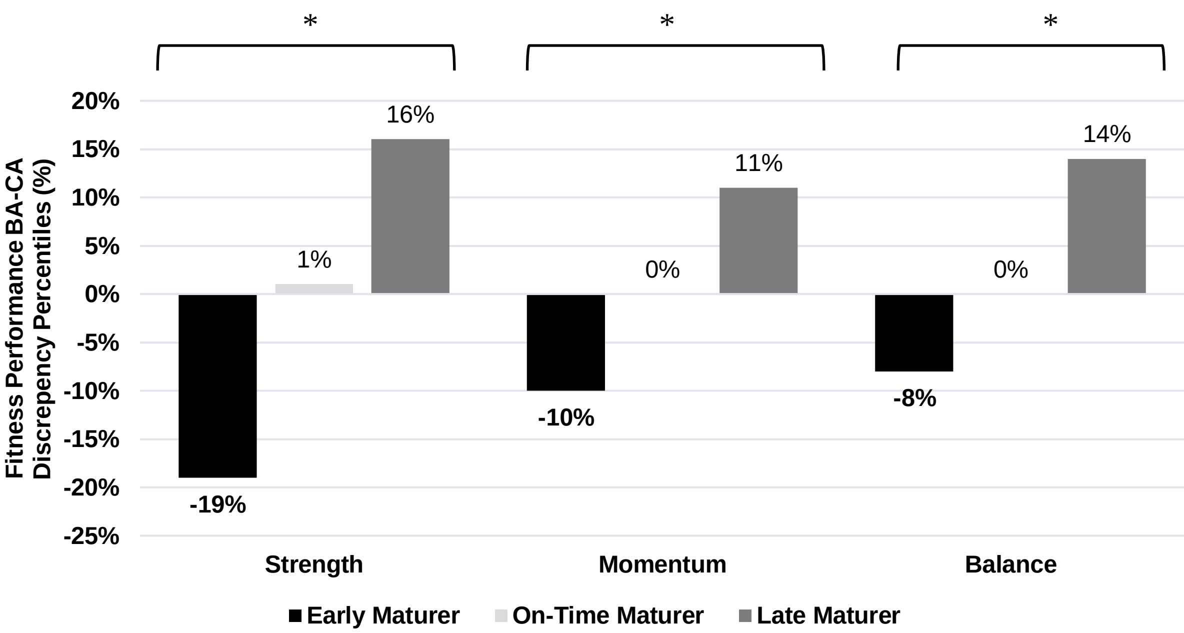


Figure 6.7 Discrepancies in upper body strength, momentum and balance performance percentiles by chronological and biological age in early, on-time, and late maturing male school children aged 11 to 15 years

6.5 DISCUSSION

The purpose of the current study was to investigate the extent to which assessments of biological maturation and fitness to create performance trajectories of age-based standards could provide more developmentally aligned evaluations of performance in a cohort of male adolescents from the general population. Given the well documented associations between physical fitness, athleticism, and maturation in adolescent males (Malina, Bouchard and Bar-Or, 2004), it was not surprising that for early and late maturing boys the evaluations of performance varied relative to BA and CA. A consistent observation across all tests of physical fitness was that physical performance was poorer for early maturing boys when they were evaluated on the basis of their biological, rather than chronological, age. Conversely, the opposite was true for late maturing boys who presented superior performance when judged relative to their BA rather than CA. For those boys identified as maturing ‘on time’ the performance scores were generally equivalent when evaluated on the basis of biological and chronological age. These observations have important implications for those involved in the development of fitness and engagement in physical activity in young males. Additionally, for those working in sport, these findings have valuable use for the identification, confirmation, and development of talented athletes. Specifically, evaluations of athletic aptitude, and/or, potential are likely to be enhanced, and/or, mitigated as a result of individual differences in biological maturation. Accordingly, the regular assessment, monitoring and consideration of growth and maturation is essential if one is to accurately evaluate any of these attributes in adolescent males.

The performance trajectories established in this study were derived from the performances of 180 individuals from the general population. The trajectory of the fitness curves established in the current study are consistent with those derived from longitudinal studies of general fitness in youth (Lefevre et al., 1990). They are also consistent with age-associated differences in the fitness results reported in Chapter Four, in that fitness generally improved with age. This age-associated improvement happened to a greater extent in strength and momentum performance compared balance. Whilst balance performance did improve with age, the fitness curve for CA was flatter than it was for strength and momentum. From an applied perspective, the performance trajectories allow the evaluation of upper body strength, momentum, and balance performance over time. Particularly important is the consideration of both BA and CA, allowing any observed changes in fitness to be quantified relative to both chronological and biological age. This may be of particular benefit in terms of allowing practitioners to differentiate those gains in fitness associated with the normal processes of growth and maturation, from those associated with the implementation of training programmes (Till et al., 2018).

Whilst the performance trajectories derived from athletic tests of fitness created in the present study are the first to use data derived from the general population, their trajectories are generally consistent with those developmental curves derived from samples of elite, junior athletes (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Votteler and Höner, 2014; Myburgh et al., 2020). In elite, junior, late maturing tennis players it was demonstrated that athletic performance was significantly better when considered relative to biological age rather than chronological age, whilst the opposite held true for early maturing tennis players (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Myburgh et al., 2020). The magnitude of these discrepancies was, however, notably smaller in the current study when compared to results established by Myburgh and colleagues (Myburgh et al., 2020). This may, or may not be, surprising. One would expect elite samples, by their selective nature, to be more homogenous. That is, within an elite sample, one would expect all athletes, regardless of their maturity timing, to possess high levels of physical fitness. Although different fitness tests were performed, in the study by Myburgh and colleagues (Myburgh et al., 2020), physical performance percentile scores of a 5m sprint test were much greater for both BA and CA than fitness scores observed in the current study, suggesting the elite boys performed much better than the normal boys. The better performance score of the elite males is expected. However, the discrepancy scores between BA and CA were much greater for the elite males compared to the normal males in this study. For example, the mean percentile score for elite, late maturing boys performing a 5m sprint test, where a lower percentile score is better, was 8% when evaluated by BA and it worsened to 39% when evaluated by CA, reflecting a 31% difference. In contrast, mean percentile values for normal, late maturing boys performing a strength test in the present study were 55% when evaluated by BA and 39% according to CA, reflecting a 16% difference after adjusting for maturity. This suggests that in the elite sample, physical performance is very good and, when adjustments are made for BA this had a bigger impact than in the non-elite boys. One could argue that elite samples are more likely to include athletes with exceptional abilities or those at the extremes of the maturity continuum, increasing the discrepancies between the most and least mature athletes. Accordingly, the need to account for maturational status when considering the physical fitness of adolescents may be greater in more elite samples.

The performance trajectories and results for upper body strength were of interest. Consistent with previous longitudinal studies, upper body strength generally increased linearly with age with a slight period of acceleration at approximately 14 years of age (Catley and Tomkinson, 2013; Laurson et al., 2017). With respect to the discrepancies between performance relative to BA and CA, 79% of late maturing boys reported superior performances when assessed for biological age, with a mean improvement in percentile values, from CA to BA, of 16%. Conversely, upper body strength scores were superior for early maturing boys when evaluated relative to CA compared to BA. Mean percentile scores were 19% greater in the early maturing males when evaluated with CA compared to BA. Concerning the on-time maturing boys, no significant difference in performance was observed relative to BA and CA with mean percentile scores falling close to the mean for both (52% and 51% respectively). This suggests that adjusting for BA makes little difference for the many boys who are 'on time'. As expected, the mean BA-CA discrepancy values differed statistically across early, on-time and late maturing males. The magnitude of the difference between the upper body strength discrepancy scores across early, on-time, and late maturing males was large, supporting the contention that strength is one of the 'strongest' and most consistent correlates of maturation in adolescent males (Lefevre et al., 1990; Malina, Bouchard and Bar-Or, 2004).

Greater momentum is a physical quality desired for success in a number of collision sports, including rugby and American football (Barr et al., 2014; Jalilvand et al., 2019) and it has been shown to distinguish between elite and non-elite levels (Baker and Newton, 2008). Although limited to a few studies, results from the present study support existing research showing momentum performance to improve with age (Barr et al., 2014; Till et al., 2015). The performance trajectory displays this linear improvement in momentum performance with age with an accelerated increase around 13 years until age 15, when the curve begins to flatten. With respect to the discrepancies between performance relative to BA and CA, 85% of late maturing boys reported superior performances when assessed for biological age, with a mean improvement in percentile values, from CA to BA, of 11%. Conversely, momentum scores were superior for early maturing boys when evaluated relative to CA compared to BA and mean percentile scores were 10% greater in the early maturing males when evaluated with CA compared to BA. Concerning early maturing boys, 82% displayed superior momentum performances when assessed for CA rather than BA. As with strength performance, no significant difference in performance by BA and CA was observed for the on-time maturing boys, with mean percentile scores falling close to the mean for both (47% for both BA and CA). As expected, the mean BA-CA discrepancy values differed statistically across early, on-time and late maturing males. The magnitude of the difference between the momentum discrepancy scores across early, on-time, and late maturing males was large, highlighting that momentum is strongly correlated with maturation in adolescent males. It also emphasises the importance of considering maturation when assessing momentum, particularly in individuals competing in collision sports where this attribute may have important implications for performance and player safety (Fuller et al., 2010).

The development of balance and the impact of the variance in biological maturation on balance performance during adolescence is an under researched area. Balance is central to many fundamental and sport-specific movements skills, and, thus, has relevance to athletic performance (Hammami et al., 2016) and injury risk (Gribble, Hertel and Plisky, 2012). The influence of maturity status on balance performance in the present study was consistent with that for upper body strength and momentum. That is, the later maturing boys benefited from BA adjustments, whereas the early maturing boys did not. With respect to the discrepancies between performance relative to BA and CA, 68% of late maturing boys reported superior performances when assessed for biological age, with a mean improvement in percentile values, from CA to BA, of 14%. Conversely, balance scores were superior for early maturing boys when evaluated relative to CA compared to BA. Mean percentile scores were 8% greater in the early maturing males when evaluated with CA compared to BA. With regard to early maturing boys, 73% displayed superior momentum performances when assessed for CA rather than BA. No significant difference in performance by BA and CA was observed for the on-time maturing boys with mean percentile scores falling close to the mean for both (52% for both BA and CA).

As expected, the mean BA-CA discrepancy values for balance performance differed statistically across early, on-time and late maturing males. The magnitude of the difference between the balance discrepancy scores across early, on-time and late maturing males was large, highlighting that balance is strongly associated with maturation in adolescent males. The mean BA-CA discrepancy scores were, however, not as large for balance as they were for strength or momentum performance (H = 76.67, 54.99, 29.34, for strength, momentum, and balance respectively). 79%, 85% and 68% of the later maturing boys performed better when evaluated by BA compared to CA for upper body strength, momentum, and balance performance, respectively. Similarly, 85%, 82% and 73% of the early maturing boys performed better when evaluated by CA compared to BA for upper body strength, momentum, and balance performance, respectively. This suggests that, whilst it is important for all tests of athletic fitness, it is more, important for practitioners to account for maturity differences when considering strength and momentum performance in youth populations, when compared to balance performance. This supports recent research which demonstrated maturity had a smaller association with performance in the Y-balance test than performance in the hand grip upper body strength test in elite, athletic adolescent boys (Lesinski et al., 2020).

The results observed in the current study for balance performance were of particular interest and differ from those determined in Chapter Four. The regression analysis carried out in Chapter Four showed no relationship between maturity status and balance performance until whole age was controlled for, after which an inverse relationship was observed. That is, later maturing boys performed better than their earlier maturing counterparts in the previous study. Whereas in the current study, late maturing males benefited most from adjustments for maturity. In the current study, whole age is not considered as a control variable as it is in Chapter Four which may explain the reason for the contrasting results observed across studies. In addition, the indicator of maturity used in each study was slightly different (z-scores to establish maturity status were calculated from BA-CA in the present study, and from % PAS in Study Four) and relative age was also included in the regression analyses in Chapter Four. Additionally, when it comes to adolescent balance performance, maturity timing (i.e., early, on-time, or late) may not be as important a contributor to performance as maturity status (i.e., pre-, mid-, and post-PHV). Balance performance may be disrupted during periods of rapid growth (Viel, Vaugoyeau and Assaiante, 2009) and this may occur for an individual regardless of whether he is an early or late maturer. Therefore, a different approach may be needed when considering balance compared to other physical qualities such as speed and strength. Adjustment for maturity status, rather than timing, may be more critical to accurately monitor adolescent balance performance.

It is worth noting that the strength performance of both late, and on-time maturing boys, when adjusted for BA, are close to the 50^{th} percentile. Thus, although many late and on-time maturing boys may present fitness scores that are comparatively poor for their age group, they are, from a developmental perspective, performing at a level that is expected for their stage of development. Interestingly, the performance percentile of early maturing boys dropped below the mean to 44% when evaluated by biological age, suggesting the opposite effect. That is, when adjusting for maturation, these individuals are performing below expectations. These observations highlight the effect biological maturity can have in masking or enhancing physical fitness performance. From an applied perspective, strength and conditioning coaches need to consider these differences. As a result of their physical advantages, early maturing boys may become complacent believing they are inherently stronger than their peers and, thus, do not require additional training or conditioning. Such effects could be detrimental to the long-term development of early maturing athletes. In later adolescence and adulthood, once earlier biological maturation is no longer an advantage, true physical capability will manifest itself in performance and later maturing boys may catch up and even overtake the physical fitness of early maturing boys (Lefevre et al., 1990). Late maturing boys should also not be overlooked or dismissed for not possessing comparatively strong levels of fitness and should be encouraged to gauge their fitness relative to their stage of development.

6.5.1 Practical Implications

The advantages associated with earlier maturation are reflected in the present study through a superior momentum, upper body strength, and balance performance of earlier maturing 11-to-15-year-olds when scores are shown relative to their CA rather than BA. Upon evaluating performance of early maturing boys relative to biological maturity status, strength, momentum, and balance scores decrease by 19%, 10% and 8% respectively. In contrast, later maturing boys performed better when scores were considered relative to BA rather than CA. These results suggest that, should a teacher or practitioner consider a boy's athletic performance only in relation to their CA, performance could be misinterpreted.

A failure to consider the impact of biological maturation on fitness performance may contribute towards the increased confidence and self-esteem demonstrated by early maturers and, in contrast, contribute to the lower self-esteem of late maturers (Jones., 1958; Dubas, Graber and Petersen., 1991). To increase the engagement, motivation and confidence of late maturing individuals participating in sport and physical activity, the physical fitness environment should account for variance in maturation. As described above, this will allow late maturing boys to demonstrate their true physical capabilities and perform on a 'more even playing field' with early maturing boys. Observations in this study show that when the fitness of late maturing boys is considered relative to BA, results are closer to, or even greater than, the mean. Given that physical activity levels drop during adolescence (Allison et al., 2007), the strategy proposed in the present study of fitness evaluation relative to BA, may reinforce positive associations adolescents have with fitness which may subsequently encourage them to continue participating in sport and activity.

Early maturers are more likely to receive better coaching, enhanced sports science and medical support, greater competition opportunities and better training facilities than late matruers (Vaeyens et al., 2006; Meylan et al., 2010; Whiteley, Johnson and Farooq, 2017). In addition, maturity status appears to influence coaches' perception of talent, with football coaches grading and evaluating early maturing males better than their peers (Hill et al., 2020). This suggests maturity-associated biases go beyond fitness onto the field of play. The present study highlights the importance of considering biological maturation in youth sport, whether through individually developed physical development programmes (Ryan et al., 2018), the bio-banding of adolescents as part of a training/competition programme (Cumming et al., 2017) or to help reduce the selection biases towards early maturing boys (Malina et al., 2015).

The results presented in the current study are, to my knowledge, the first to create performance trajectories and consider both chronological and biological age for normal male school children in performance of athletic fitness tests. The data is cross-sectional in nature, however, by establishing performance trajectories, it allows the tracking and monitoring of fitness over time. Till and Baker (Till and Baker, 2020) recently highlighted the challenges of using cross-sectional data collection at 'one-off' moments to accurately assess talented, young athletes. The strategy presented in this study allows better evaluation of both current performance and future potential by accounting for the impact of biological maturation and is therefore more useful for fitness evaluation, development of physical fitness and talent identification, than one-off testing protocols. The plotting of individual performance scores on trajectories of age-based standards elicits a method of establishing measurable differences between the CA percentile and the BA percentile, which subsequently helps to understand if the individual is on track, ahead of, or behind their peers (Myburgh et al., 2020). i.e., an athlete may achieve a momentum score within the top 10th centile with their CA, however, their result according to their BA could mean they sit much lower in comparison to those within the same age group and of similar biological maturity.

These findings have important implications for teachers, strength and conditioning coaches and athlete development practitioners. Practitioners can cross reference the performance of their own children against the performance trajectories to determine if a change in performance is due to natural development or a training stimulus. This information would improve training practises by aligning individual programmes to stage of maturation rather than CA, thus accounting for individual development, strengths, and weaknesses. The International Olympic Committee consensus statement on youth athletic development highlighted the importance of considering the individual to optimise development (Bergeron et al., 2015). This strategy has been successfully implemented at Arsenal Football Club, where academy players are grouped and trained according to their own individual needs, including consideration for stages of growth and maturation (Ryan et al., 2018).

Very little is understood about changes in balance and momentum performance during adolescence. The creation of performance trajectories for these physical qualities provides novel research to enhance understanding of both the performance changes during adolescence and the influence of maturity status. As previously mentioned, momentum is an important physical quality for successful performance in collision sports, such as rugby (Barr et al., 2014). Consideration for the influence of maturity status on momentum performance and understanding how this may transfer into an adolescent players' rugby performance should aid rugby coaches and scouts when assessing and evaluating rugby performance.

Assessment of balance performance often has a role in injuries; evaluation of injury, to assess changes following an injury and to assess improvement after an intervention for an injury (Gribble, Hertel and Plisky, 2012). Therefore, the normative trajectories established in this study can provide useful information for return to play strategies following an injury. Practitioners could apply the Y-Balance test as part of a physical screening process to determine athletic capability and obtain pre-injury, baseline, and post-injury return to play percentiles (Gribble, Hertel and Plisky, 2012). The plotting of individual performance on trajectories to establish the performance percentile will enhance understanding of whether the individual is ahead or behind where he should be for both his chronological and biological age. Further research on the associations between maturation and balance in boys is warranted. In particular, researchers should consider not just the impact of maturity timing but also the impact of maturity status (Malina et al., 2015). For example, decrements in balance performance may be more likely to be observed during rapid periods of development, such as the growth curve, and may provide greater insight as to the nature of adolescent awkwardness (Viel, Vaugoyeau and Assaiante, 2009).

6.5.2 Limitations

As with previous chapters, limitations of the current study should be noted. The current study uses the non-invasive, easy to administer, Khamis-Roche method of biological maturation assessment and employs athletic tests of fitness in a general adolescent population (Khamis and Roche, 1994). These trajectories of age-based standards, however, may not generalise to other samples, other tests of fitness or other indices of maturation. Should teachers or practitioners choose to establish maturity status of their own adolescent cohort, they too could create performance trajectories for their own tests, specific to their own environment.

Although the trajectories allow the tracking of the fitness qualities from ages 11 to 15 through the cross-sectional collection of lots of individual scores at a given time, more accurate and applicable data could have been gathered from longitudinal tracking of individuals over time. Longitudinally tracking individuals from late childhood through adolescence would further enhance understanding of the direction and magnitude of trends in adolescent athletic fitness performance. In addition, future studies could also consider a greater number of physical fitness tests and could include a larger age range to test across. The creation of the performance trajectories only spans the age of participants tested; therefore, because there is no comparable CA performance data, younger and late maturing participants as well as older, early maturing participants, are unable to be included in the analysis. To capture the full breadth of the adolescent developmental period, performance data could be collected at younger and older ages. The trajectories created were based on fitness performance according to CA. Thus, potential confounding effects of anthropometrical measures such as height and weight, as well as differences in biological maturation, were not accounted for. Future studies creating trajectories should look to consider maturity differences within age groups.

6.5.3 Conclusion

In conclusion, the current study provides an approach to tracking the development of physical fitness through adolescence that can be applied within school and elite sport. Further to this, it has evaluated the degree to which biological maturity status impacts physical fitness relative to performance trajectories of age-based standards and is the first study to do so in tests of athletic fitness in normal male adolescents. This study demonstrated that boys who matured in advance of their age-matched peers were more likely to perform better in tests of momentum, upper body strength and balance when considered according to CA compared to BA. In contrast, late maturing boys performed better when considered relative to BA rather than CA. Whilst the impact of biological maturation on physical fitness is widely known (Malina, Bouchard and Bar-Or, 2004), the present study has provided a means of quantifying this impact. This is useful for teachers, coaches and practitioners working with young people to underpin better training programmes and to better understand physical potential for talent identification and development programmes.

CHAPTER SEVEN

THE ESTABLISHMENT OF DEVELOPMENTAL FITNESS CURVES TO EVALUATE THE IMPACT OF BIOLOGICAL MATURATION RELATIVE TO CHRONOLOGICAL AGE IN FEMALE ADOLESCENT SCHOOLCHILDREN

7.1 ABSTRACT

PURPOSE: To establish age-based fitness performance trajectories of adolescent girls across a range of athletic fitness tests. Further to this, investigate the extent to which biological maturity status impacts fitness relative to these trajectories. **METHODS:** British female school children aged 11 to 15 years old (N = 397) performed standardised tests of initial sprint momentum, upper body strength and a 30m maximal speed test. Biological maturation was determined using the Khamis-Roche method and maturity status and biological age were calculated for each participant. **RESULTS:** Individual performance scores were plotted onto performance trajectories for both chronological and biological age. Wilcoxon Signed Rank tests demonstrated superior mean percentile scores for early maturing girls for CA rather than BA and superior mean percentile scores for later maturers evaluated for BA rather than CA across all three fitness tests. Kruksal Wallace H tests demonstrated significant difference in the BA-CA differential scores of early, on-time and late maturing girls for tests of strength, momentum and maximal speed ($p < .001$). **CONCLUSION:** A novel and developmentally adjusted approach to assessing fitness through adolescence is demonstrated, identifying evaluations of performance varied relative to BA and CA. Early maturing girls are more likely to perform better in tests of momentum, upper body strength and speed when considered according to CA compared to BA. In contrast, later maturing girls are more likely to perform better when evaluated by BA rather than CA. Fitness performance may, therefore, be enhanced and/or reduced as a result of individual differences in biological maturation. This highlights the importance to consider individuals differences when evaluating the physical fitness performance of adolescents.

7.2 INTRODUCTION

Adolescence is a dynamic stage of development in females, marked by distinct changes in an individual's biological, psychological, behavioural and social development. During adolescence, events such as puberty and the adolescent growth spurt all contribute to shape the individual into their adult form (Malina, Bouchard and Bar-Or, 2004). These biological events are all underpinned by the process of growth and maturation. Biological maturation describes this progress towards the adult, mature state and occurs across multiple biological systems, such as the skeletal, endocrine, sexual, and somatic systems (Malina, Bouchard and Bar-Or, 2004). Growth and maturity-associated changes result in the development of physical fitness during childhood and adolescence, and speed, strength, agility and power all improve in females during this period (Beunen and Thomis, 2000; Croix, 2007; Papaiakovou et al., 2009; Vänttinen et al., 2011).

Individual variance in timing and tempo of growth and maturation of females has been shown to influence size, physique, and fitness. As such, when considering paediatric fitness in adolescent females there is a need to consider these individual differences (Malina, Bouchard and Bar-Or, 2004). Differences in the timing and tempo of maturation present a significant challenge for practitioners working with female athletes. As a result of an earlier onset of puberty, girls advanced in maturation are generally taller, heavier, and stronger than their on-time and later maturing peers (Malina, Bouchard and Bar-Or, 2004). In contrast, later maturing females tend to perform slightly better than early maturers on tests of speed and power (Little, Day and Steinke, 1997). The physical and anthropometrical advantages associated with earlier maturation can result in an increased likelihood of selection into sports where height and/or physical dominance is a competitive advantage, such as swimming (Erlandson et al., 2008) and tennis (Myburgh et al., 2016). In contrast, late maturers are more likely to be selected into sports such as artistic gymnastics (Malina et al.,

2013) and figure skating (Malina et al., 2015), possibly due to their smaller stature and physique. This suggests that, despite the association between maturation and fitness not being as obvious in females as it is in males, it appears to be influencing coaches' selection and talent identification of athletes.

Despite steady improvements in physical fitness through adolescence, adolescent girls tend to perceive themselves as less physically fit and less competent in sport (Cumming et al., 2011). This apparent paradox is important to consider as girls perception of the maturity-associated changes in their body and fitness during this period is the mechanism often used to explain the increased dropout among girls from both sport and physical activity (Cumming et al., 2020). Girls who mature in advance of their peers tend to hold the lowest perceptions of physical self-concept and it is perhaps not surprising that these individuals are also less likely to engage in sport and remain active through adolescence (Cumming et al., 2020). To address this issue, it is important that educators, coaches, and practitioners working with adolescent girls better understand the processes of growth and maturation and their impact upon physical fitness and activity during adolescence (Barker et al., 2014). It is equally important they develop strategies to counter misperceptions regarding fitness to help adolescent girls realise that their fitness is improving during this stage of development and that it should not serve as a barrier to participation in physical activity and sport.

In light of the previous discussion, there is a clear need to create more developmentally aligned methods for assessing and monitoring physical fitness in adolescent females. More specifically, there is a pressing need to develop methods that can account for individual differences in maturation when interpreting fitness data in youth (Till et al., 2018). Several new strategies aimed at accommodating variance in biological maturation have been proposed. For example, the bio-banding of individuals for specific competitions and/or training sessions involves grouping youth athletes according to biological maturity status rather than chronological age (Malina et al., 2019). The creation of performance trajectories to better assess and monitor youth fitness has also been proposed. To date, however, only a few studies have attempted to create these, and they have either evaluated performance in elite female cohorts (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Myburgh et al., 2020), male cohorts (Votteler and Höner, 2014), or used methods of maturity assessment that are less reliable, i.e., Mirwald Maturity Offset method to calculate maturity status (Till et al., 2018). A number of these studies have, however, successfully shown the benefits of using performance curves for the monitoring of adolescent fitness. Studies by Myburgh et al., (Myburgh et al., 2020) and Ulbricht et al., (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013), demonstrated a significant difference in fitness percentiles obtained for junior tennis players when evaluated relative to their biological and chronological age. Specifically, they observed that elite, early maturing tennis players displayed significantly better athletic performance when observed relative to chronological rather than biological age, whilst the opposite could be seen for late maturing elite females (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Myburgh et al., 2020). Age-associated fitness standards have previously been created in the general adolescent population; however, the focus of these fitness assessments has been on establishing health-based evaluations rather than assessing athletic fitness required for athletic development. In addition, maturity status has not been assessed within these standards (Morrow Jr, Going and Welk, 2011; Ortega et al., 2011; Dobosz, Mayorga-Vega and Viciana, 2015). To date, no studies have created age-based trajectories of performance in athletic tests of fitness, accounting for biological maturation, in the general population.

Developmental fitness standards derived from the general population would afford several advantages. First, such standards could be used within the general population and applied across a broader range of sports and activities, many of which may not have available data from which to derive fitness standards. Second, these standards would allow practitioners to better identify those changes in physical fitness that might arise above or beyond the changes associated with normal growth and maturation in youth. This would have particular benefit for those attempting to evaluate the benefits of physical training and/or conditioning programmes (Ryan et al., 2018). The development of normative performance standards from the general population would also allow the interpretation of individual data in relation to both normal chronological and biological age performance percentiles (Till et al., 2018). This will enhance practitioners understanding of individual performance, including providing a more objective understanding of true physical weaknesses compared to biological age, improving the training interventions given to individuals. Were these strategies to be incorporated into talent identification processes, interpretation of individuals current physical performance against normative standards would provide a more accurate representation of current performance and future athletic potential.

In light of the preceding discussion, the aim of this study is to establish age-based performance trajectories for the physical fitness of adolescent girls, aged 11-15 years, across a range of fitness tests. Further to this, the degree to which biological maturity status impacts physical fitness relative to the performance trajectories will be evaluated. The fitness tests of upper body strength, momentum and 30m maximal speed have been chosen for evaluation. These tests were chosen due to their close association with biological maturity (see Chapter Five). It is hypothesised that girls advanced in maturity will present worse percentile scores for each test, when scores are expressed relative to biological maturity status than to chronological age. It is also therefore hypothesised that the opposite would be observed for later maturing individuals, where they will present better percentile scores for each test when scores are expressed relative to biological maturity status than to chronological age.

7.3 METHODOLOGY

7.3.1 Participants

The physical fitness testing of female schoolchildren aged 11 to 15 years in the South-West of England provided the data from which the creation of developmental curves for fitness were derived. A total of 397 female schoolchildren were assessed during the academic years of 2014-15 and 2015-16. The mean age of participants was 13.96 years (±1.18). Participants were assessed once, providing a cross-sectional data sample. Each individual's performance score was plotted independently for both chronological age and biological age. This allowed an individual's percentile score for each test to be compared across chronological and biological age. Only participants that satisfied all inclusion criteria of date of birth (to establish chronological age), maturity information and test completion were included in the analysis.

7.3.2 Ethics and Consent

This study was approved by the Research Ethics Approval Committee at the host University. Informed written consent was obtained via the school's head teacher acting as *loco parentis* and a parental opt out option was given to every individual. Self-assent was obtained for the participant. The schoolteachers were informed about the procedures and aims of the study prior to completion and only those participants that indicated a willingness to take part were included.

7.3.3 Physical Fitness and Anthropometric Measurements

All fitness testing was carried out during the participants normal physical education lesson. For a detailed description of height and weight measurement please refer to

Chapter Three. The fitness tests performed were; hand grip dynamometer for upper body strength; a linear sprint for momentum and 30m maximal speed evaluation. For a detailed description of fitness testing protocols and assessment measurements please refer to Chapter Three.

7.3.4 Maturity Measurements

Percentage of adult height for each participant was calculated by methods described in Chapter Five and Seven. To translate biological maturation status into an index of biological age, methods described by Gillison and colleagues were used (Gillison et al., 2017). That is, percentage of adult height achieved at the time of assessment was compared to age-specific and sex-specific reference standards derived from the UK 1990 growth reference data to obtain a biological age for each participant (Freeman et al., 1995; Gillison et al., 2017). Reference standards for percentage of adult stature were calculated at 0.1 yearly intervals relative to the UK reference data. Consistent with the methods described in Chapter Six, a participant's biological age was determined from the individual's percentage of attained adult height compared to the mean adult height attained at each age relative to the mean stature at/above 18 years of age. Maturity timing was determined as BA minus CA. Participants were grouped as being advanced in maturity if the difference between BA and CA was > 0.5 year, delayed if the difference was > -0.5 year, and on-time if the difference fell between -0.4999 year and 0.4999 year (Drenowatz et al., 2013). For the analysis, maturity bandings of ±0.5 yearly intervals were chosen rather than the traditional ±1.0 years because it was believed that this would better differentiate between early and late maturing individuals. The traditional method of -1 to +1 does not differentiate between individuals who differ markedly in maturity but are classified as the same maturity status group (e.g., a z-score of +0.99 and a z score of -0.99) (Hil et al., 2019).

7.3.5 Performance Trajectories of Age-Based Standards

As noted in Chapter Five, biological maturation in females was found to be closely associated with upper body strength, momentum, and 30m sprint performance. Accordingly, performance trajectories were generated for these tests of physical fitness. Consistent with methods described by Myburgh and colleagues (Myburgh et al., 2020), selected quantiles (10th, 25th, 50th, 75th, and 90th) were calculated by chronological age using the R Package Quantreg (Koenker, 2005). Smoothness of fit was controlled for via total variation penalization. This non-parametric method establishes both medians and percentiles, it is robust to outliers and makes no assumptions on the underlying distribution of data. These trajectories permitted the evaluations of an individual's fitness performance, in percentiles, as a function of their chronological and biological age.

7.3.6 Statistical Analysis

A series of Wilcoxon Signed Rank Tests were employed to examine the degree to which the participants fitness performance centiles scores differed relative to their BA and CA, in early, on-time and late maturing individuals. These analyses were performed for upper body strength, momentum, and maximal speed performance, and independently for early, on time and late maturing females.

Percentile discrepancy scores were calculated for BA and CA percentile values by subtracting the CA percentile from the BA percentile. For example, if a participant's momentum scores were in the 39th percentile for CA and the 69th percentile for BA, the percentile discrepancy score would be 30%. Subsequently, a series of Kruksal-Wallis tests were then employed to evaluate the difference in percentile discrepancy scores for strength, momentum, and speed scores across each of the maturity groups (i.e., early, on-time, late). Statistical significance for all analyses was set a $p < 0.05$.

Effect sizes for nonparametric data (z-score divided by the square root of total sample number (BA + CA for each maturity group)) were calculated to indicate the magnitude of difference across each variable. A value of ≤ 0.10 was considered to be a small effect, 0.30 a moderate effect, and ≥ 0.50 a large effect (Cohen, 1992).

7.4 RESULTS

Descriptive statistics were calculated and summarised as per Chapter Five.

To illustrate the distribution of fitness performance across the participants, performance values for each fitness test (upper body strength, momentum, and maximal speed) were plotted for CA onto the respective performance trajectories. These analyses can be seen in Figures 7.1-7.5. The plotting of values into the trajectories established percentile scores for both BA and CA for each participant. For both the upper body strength and momentum tests, the greater the percentile score, the better the test performance. For the speed test, the lower the percentile score, the better the test performance. The trajectories support the summaries described in previous chapters in that all aspects of fitness performance generally increased with age, with a plateau in performance observed during the age range tested.

To illustrate the practical application of these trajectories, the specific centiles scores (BA & CA) for an individual have been included (Figures 7.1-7.5). Figure 7.1 displays the trajectory for upper body strength performance, where the red dot represents an individual's position on the trajectory according to her CA (13 years) where she is in the 34th centile, whereas the green dot represents the same girl's position on the trajectory according to her BA (12 years) where she is in the 54th centile. As a late maturing girl, it is perhaps not surprising that this individual score was markedly higher on this test when evaluated relative to her biological rather than her chronological age.

Figure 7.2 and Figure 7.3 display the same performance trajectory for momentum performance. Figure 7.2 highlights the performance of an early maturing, older girl. The red dot represents her position on the curve according to her CA (14.3 years) where she is in the 73rd centile, whereas the green dot represents the same girl's position on the curve according to her BA (15 years) showing she is in the 83rd centile.

Despite being an early maturer, her score was higher on this momentum test when evaluated relative to her biological rather than chronological age, suggesting she demonstrated a superior score when displayed relative to her biological age compared to her chronological age. In contrast, Figure 7.3 highlights the momentum performance of a younger girl. Again, the red dot represents her position on the curve according to her CA (12.4 years) where she is in the 32nd centile, whereas the green dot represents the same girl's position on the curve according to her BA (13 years) showing she is in the 19th centile. This girl is also an early maturing female, however at this younger age this individuals score is superior when evaluated relative to her chronological rather than biological age.

Figure 7.4 and Figure 7.5 both display the performance trajectory for 30m maximal speed performance, where the lower the percentile the better. Figure 7.4 highlights the performance of a late maturing younger girl. The red dot displays her centile score of 56% where her chronological age is 12.5 years, whilst the green dot displays her centile score of 24% for her biological age of 11.2 years. As said, this girl is a late maturing girl and so it is perhaps unsurprising that her performance score is better when evaluated relative to her biological rather than chronological age. Figure 7.5 displays the same 30m maximal speed performance curve, however this time highlights the performance of an older adolescent. The red dot displays this girl's centile score of 63% where her CA is 14.6 years, whilst the green dot displays the same girl's centile score of 65% for her BA of 15.6 years, demonstrating that she is an early maturing girl. At older adolescence, maturity status has a reduced impact on maximal speed performance.

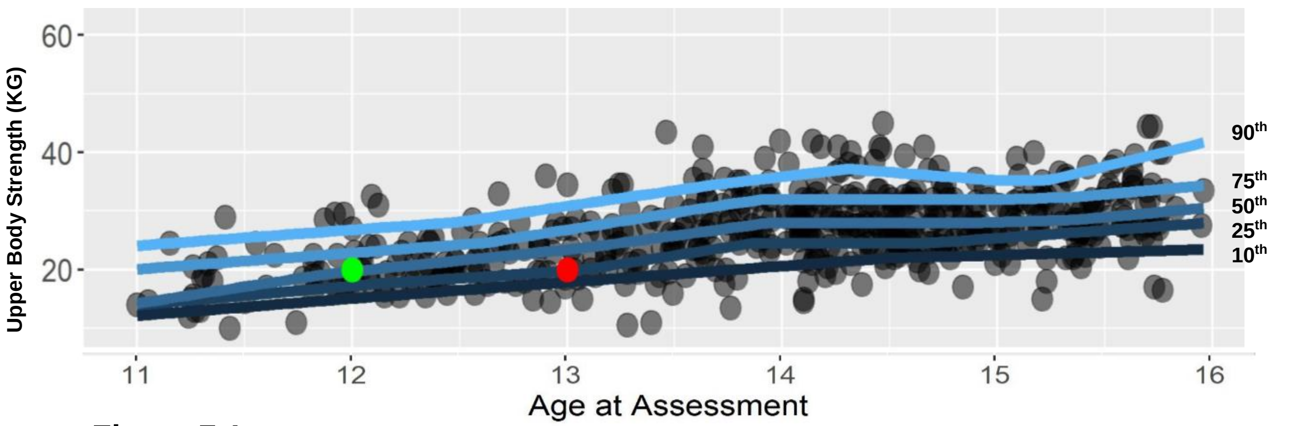


Figure 7.1

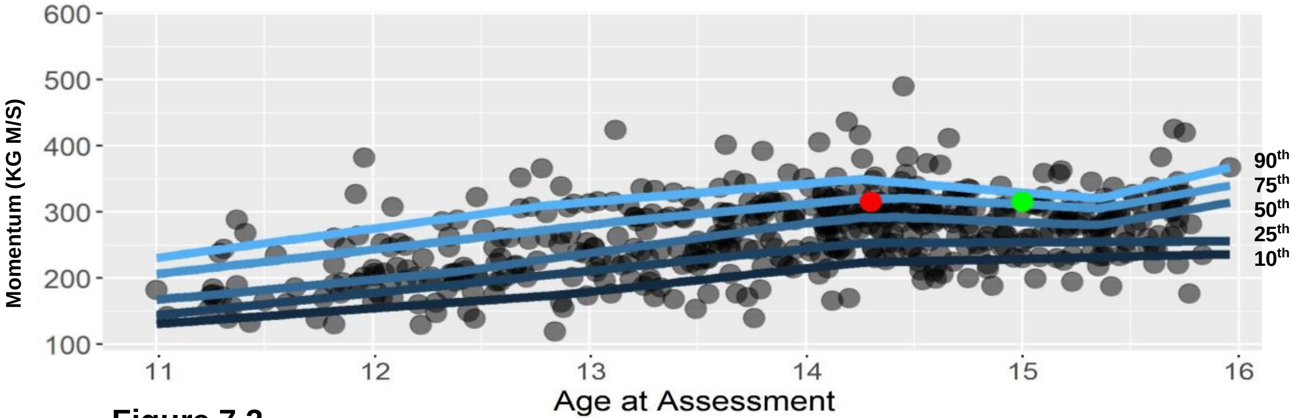


Figure 7.2

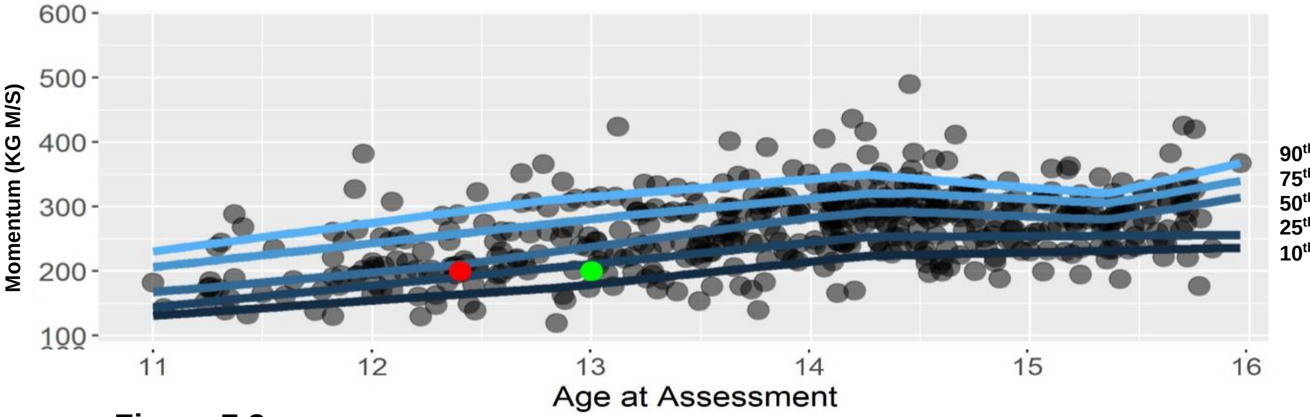


Figure 7.3

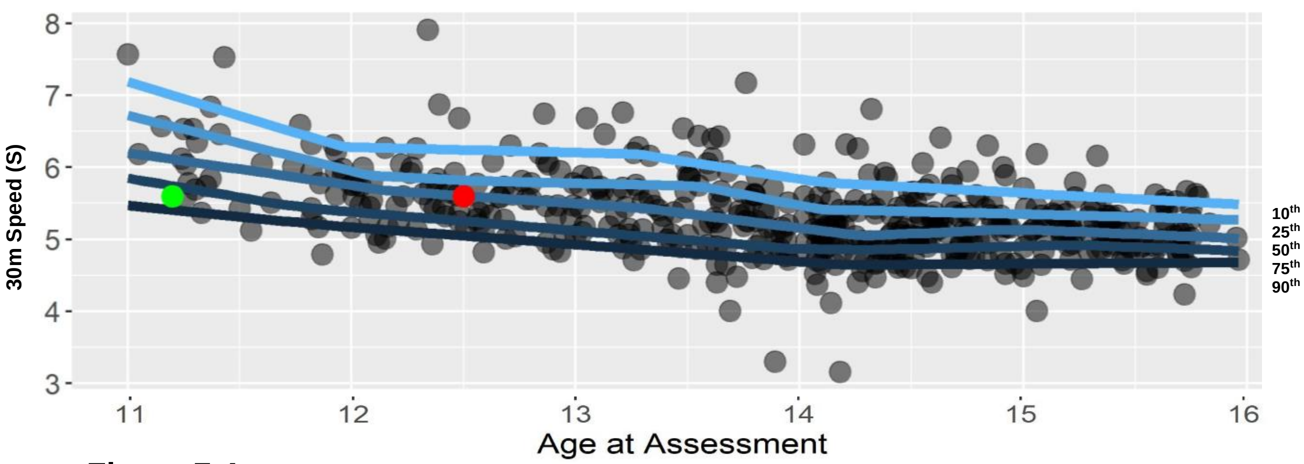


Figure 7.4

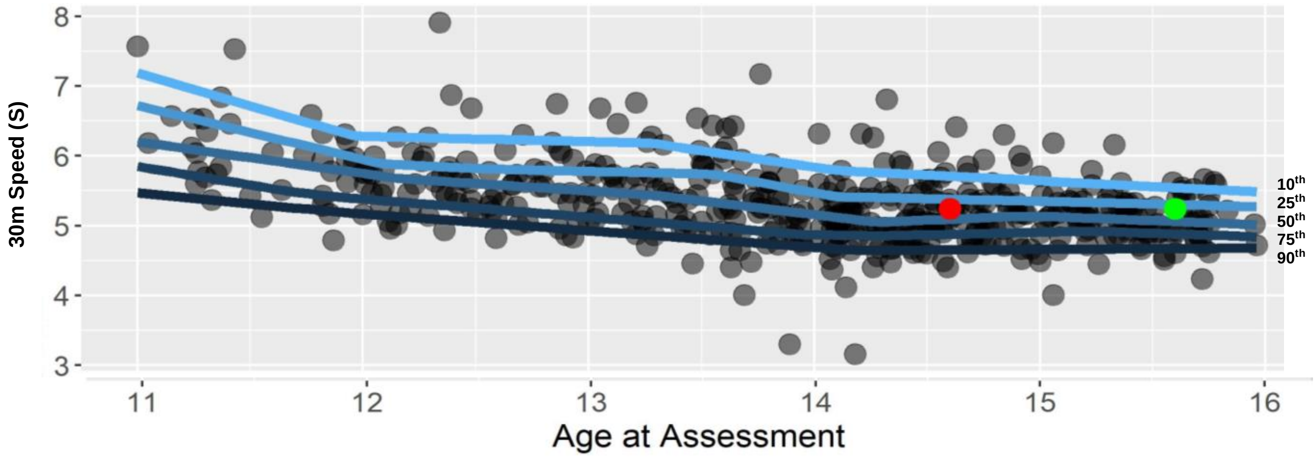


Figure 7.5

Figure 7.1, 7.2, 7.3, 7.4, and 7.5 Performance trajectories displaying physical fitness distribution of female school children according to BA and CA. Figure 7.1 displays the trajectory for upper body strength, Figures 7.2 and 7.3 display the momentum performance trajectory and Figures 7.4 and 7.5 displays trajectories for 30m maximal speed performance. Each dot represents a single participant. The red dots represent an individual's performance score relative to CA, whilst the green dots represent the same individual's performance score relative to BA.

To determine the extent to which fitness scores on the performance trajectory varied relative to BA and CA, a series of Wilcoxon Signed Rank tests were conducted. Separate analyses were performed for each test of fitness. Similarly, individual analyses were conducted for participants categorised as early, on time and late maturing.

The results of the Wilcoxon Signed Rank Tests for upper body strength are presented in Figure 7.6. In late maturing females (n = 94), the mean percentile value obtained for upper body strength performance for BA was significantly greater (Mean = 49%) than the equivalent value for CA (Mean = 40%), $z = -7.28$, $r = 0.53$, $p < .001$. Of those

94 individuals identified as late maturing, 76 presented upper body strength centile scores for BA that were higher than the equivalent values for CA, whilst only 13 were worse, and 5 were unchanged. In individuals categorised as on time (n = 220), the mean percentile value for upper body strength expressed relative to BA (53%) did not differ significantly from the equivalent value for CA (53%), z = -0.50, r = 0.02, p = .62. Whereas 90 of the individuals categorised as on-time presented BA centile scores for upper body strength that were higher than their equivalent value for CA, 47 presented values that were unchanged, and another 83 presented values that were lower. In early maturing girls (n = 83), the mean percentile obtained for strength performance for BA was significantly worse (Mean = 51%) than the equivalent value for CA (Mean = 66%), z-score = -7.10, r = 0.55, p < .001. Of those 83 individuals identified as early maturing, 68 displayed upper body strength centile scores for CA that were higher than the equivalent values for BA, whilst 11 were worse and 4 remained unchanged.

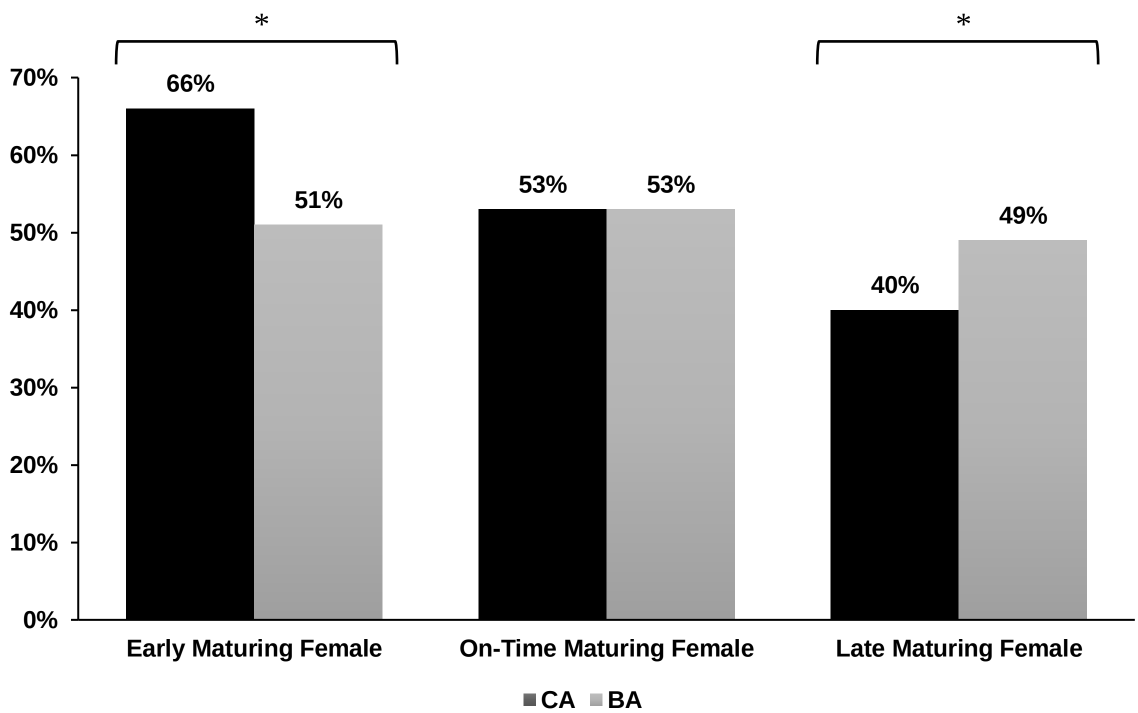


Figure 7.6 Mean percentile values relative to BA and CA displaying upper body strength performance of different maturity categories in 11-15-year-old female schoolchildren

The results of the Wilcoxon Signed Rank Tests for momentum are presented in Figure 7.7. In late maturing females (n = 84), the mean percentile value obtained for momentum performance for BA was significantly greater (Mean = 35%) than the equivalent value for CA (Mean = 29%), z = -4.33, r = 0.33, p < .001. Of those 84 individuals identified as late maturing, 55 presented momentum centile scores for BA that were higher than the equivalent values for CA, whilst 25 were worse, and only 4 were unchanged. In individuals categorised as on time (n = 217), the mean percentile value for momentum expressed relative to BA (49%) did not differ significantly from the equivalent value for CA (49%), z-score = -0.56, r = 0.03, p = .576. Whereas 82 of the individuals categorised as on-time presented BA centile scores for momentum that were higher than their equivalent value for CA, 39 presented values that were unchanged, and another 96 presented values that were lower. In early maturing girls (n = 81), the mean percentile obtained for momentum performance for BA was significantly worse (Mean = 65%) than the equivalent value for CA (Mean = 77%), z-score = -6.58, r = 0.47, p < .001. Of those 81 individuals identified as early maturing, 64 displayed momentum centile scores for CA that were higher than the equivalent values for BA, whilst 13 were worse and 4 remained unchanged.

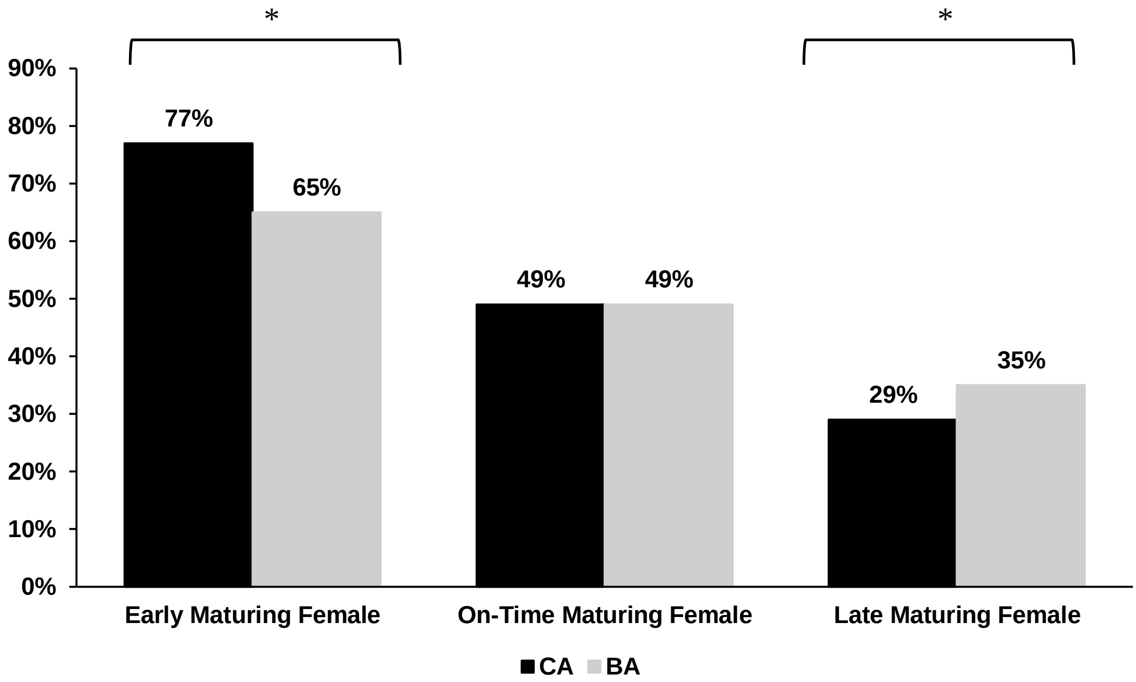


Figure 7.7 Mean percentile values relative to BA and CA displaying momentum performance of different maturity categories in 11-15-year-old female schoolchildren

The results of the Wilcoxon Signed Rank Tests for maximal speed performance are presented in Figure 7.8. In this test, a lower percentile score is superior. In late maturing females (n = 27), the mean percentile value obtained for speed performance for BA was significantly greater (Mean = 44%) than the equivalent value for CA (Mean = 60%), z = -4.38, r = 0.60, p < .001. Of those 27 individuals identified as late maturing, 25 presented balance centile scores for BA that were better than the equivalent values for CA, whilst only 1 was worse, and 1 was unchanged. In individuals categorised as on time (n = 73), the mean percentile value for maximal speed expressed relative to BA (55%) did not differ significantly from the equivalent value for CA (54%), z-score = -0.18, r = 0.02, p = .86. Whereas 29 of the individuals categorised as on-time presented BA centile scores for maximal speed that were higher than their equivalent value for CA, 27 presented values that were unchanged, and another 17 presented values that were lower. In early maturing girls (n = 54), the mean percentile obtained for speed performance for BA was significantly worse

(Mean = 71%) than the equivalent value for CA (Mean = 58%), z-score = -5.99, r = 0.58, p < .001. Of those 54 individuals identified as early maturing, 46 displayed balance centile scores for CA that were better than the equivalent values for BA, whilst 4 were worse and 4 remained unchanged.

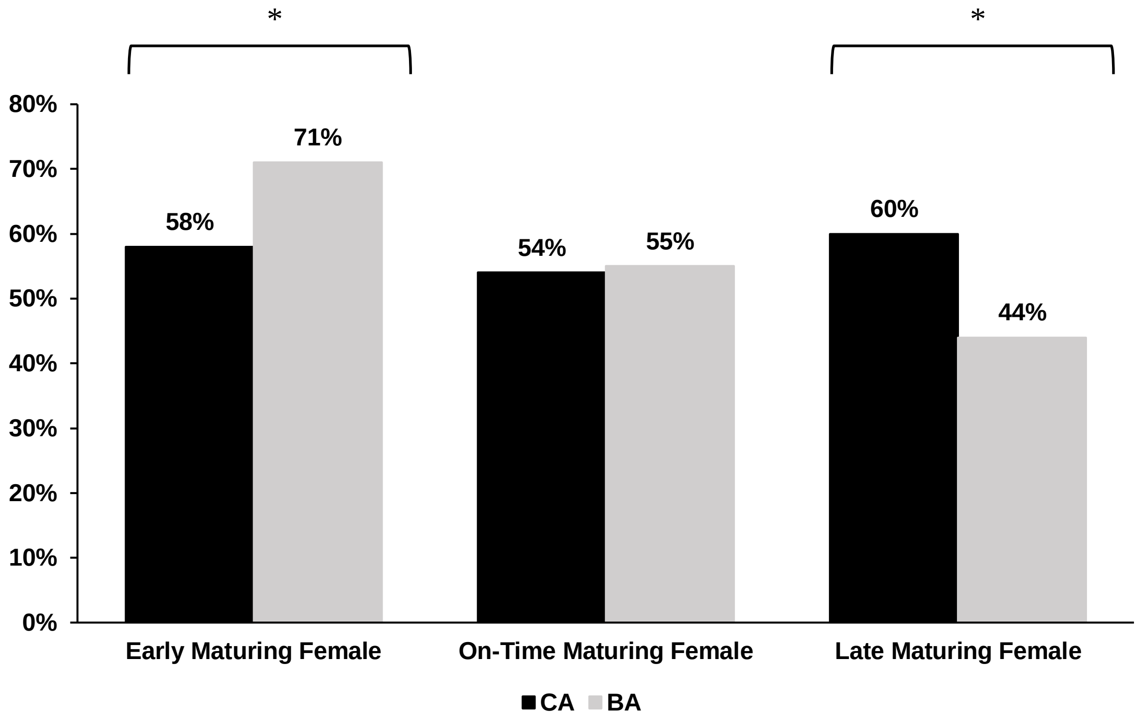


Figure 7.8 Mean percentile values relative to BA and CA displaying maximal speed performance of different maturity categories in 11-15-year-old female schoolchildren

A series of Kruskal Wallace H Tests were used to determine the degree to which the fitness performances discrepancy scores (BA centile – CA centile), varied across the three independent maturity groups (i.e., early, on-time, late). Results are displayed in Figure 7.9. A statistically significant difference in the BA-CA differential score was observed for upper body strength across the three maturity groups, H (2) = 156.67, p < .001, with a mean rank upper body strength result of 300.38 for late maturing girls, 198.84 for on-time maturing girls and 84.62 for early maturing girls.

A statistically significant difference in the BA-CA discrepancy score for momentum was observed across the three maturity groups, H (2) = 87.56, p < .001, with a mean rank result of 257.30 for late maturing girls, 204.33 for on-time maturing girls and 100.01 for early maturing girls.

A statistically significant difference across maturity groups for maximal speed performance was observed, H (2) = 81.46, p < .001. A mean rank speed result of 23.30 for late maturing girls, 69.53 for on-time maturing girls, and 115.38 for early maturing girls was observed.

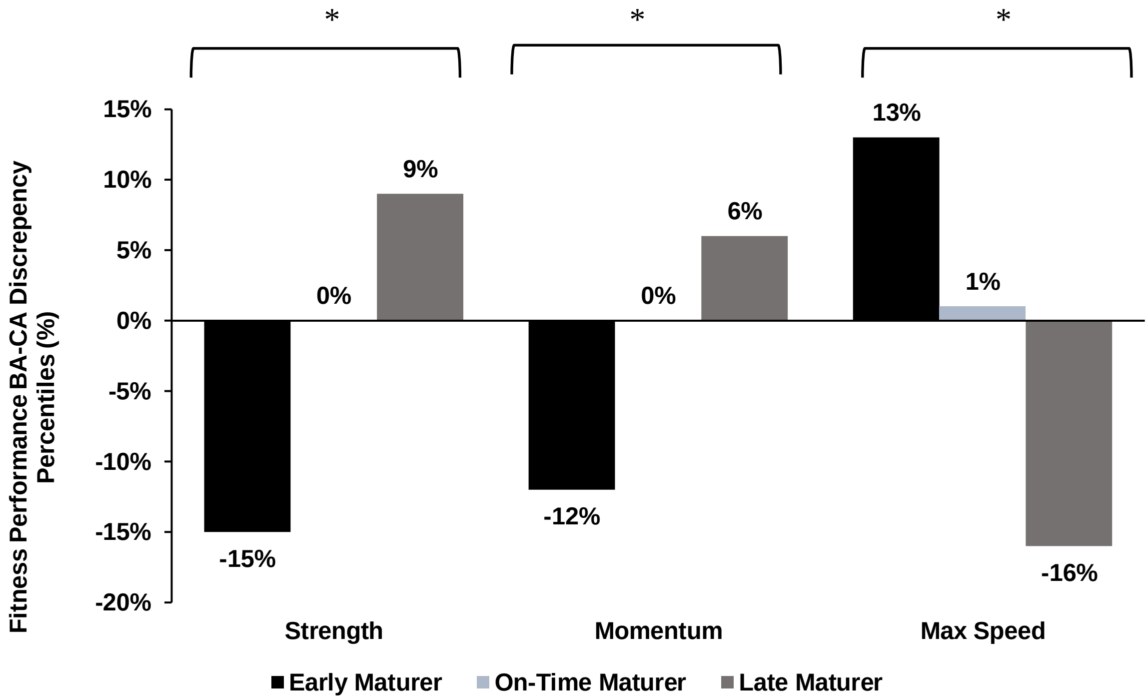


Figure 7.9 Discrepancies in upper body strength, momentum, and maximal speed performance percentiles by chronological and biological age in early, on-time and late maturing female school children aged 11 to 15 years.

7.5 DISCUSSION

The purpose of this study was to investigate the use of performance trajectories of age-based standards, with consideration for both biological and chronological age, as a more developmentally aligned method of assessment of fitness performance in a cohort of female adolescents. The evaluation of fitness performance varied relative to BA and CA for both early and late maturing girls for all tests. Across each fitness test, in general, performance was superior for late maturing females when they were evaluated relative to their BA, rather than their CA. Conversely, the opposite effect was observed for early maturing females, who displayed poorer performances when evaluated relative to BA, compared to CA. For those girls identified as maturing 'on-time' the performance scores were generally equivalent when evaluated on the basis of biological and chronological age. The impact of maturity status did, however, appear to change with age in the cohort tested, particularly for the momentum and maximal speed fitness tests. As illustrated in Figures 7.4 and 7.5, maturity status had less of an impact on maximal speed performance in older participants than it did in their younger peers. A similar pattern was observed for momentum. Figures 7.2 and 7.3 depict two different girls' momentum performances, both are early maturing but one older and one younger girl and illustrated that momentum performance is superior in the older girl when expressed relative to BA but is superior in the younger girl when expressed relative to CA. This supports current evidence that maturity status has a less obvious relationship with adolescent physical fitness than observed in males (Cumming et al., 2017).

These observations have important implications for those involved in the engagement, development and assessment of fitness in female adolescents. Individual differences in biological maturation likely enhance and/or mitigate fitness performance and this may change during the adolescent period (Malina, Bouchard and Bar-Or, 2004). Accordingly, the regular assessment and utilisation of individual growth and maturation data needs to be integrated into evaluations of athletic aptitude and/or potential if complete and accurate understanding is desired.

The trajectories of performances established from each of the fitness tests are consistent with those derived from longitudinal studies of general fitness in young females (Malina, Bouchard and Bar-Or, 2004). They are also consistent with age associated differences in the fitness results reported in Chapter Five, in that fitness generally improved with age at the start of the age range tested, and then began to plateau at older ages. The trajectories created in this study track fitness changes with age in fitness tests used in modern, elite sporting environments. Momentum performance, for example, is critical to assess in rugby players (Barr et al., 2014). However, to date no other studies have considered momentum performance in young females. Practically, these performance trajectories allow teachers and practitioners to compare their individuals with the curves presented in this study and better understand individual strengths, weaknesses and assess whether fitness improvements are above and beyond those expected for normal development due to effective training.

Strength is an important physical quality that underpins all other areas of athletic fitness (Lloyd and Oliver, 2012). Consistent with previous research (Beunen and Thomis, 2000), the age-based trajectory for strength displays an accelerated increase in performance until around 14 years of age, where the trajectory then begins to flatten. With respect to the discrepancies between performance relative to BA and CA, 81% of late maturing girls reported superior performances when assessed for biological age, with a mean improvement in percentile values, from CA to BA, of 9%. Conversely, upper body strength scores were superior for early maturing girls when evaluated relative to CA compared to BA. Mean percentile scores were 14% greater in the early maturing females when evaluated with CA compared to BA. Concerning the on-time maturing girls, no significant difference in performance was observed relative to BA and CA with mean percentile scores falling close to the mean for both (53% for both CA and BA). This suggests that adjusting for BA makes little difference for the many girls who are ‘on time’. As expected, the mean BA-CA discrepancy values differed statistically across early, on-time and late maturing females. The magnitude of the difference between the upper body strength discrepancy scores across early, on-time, and late maturing females was large, supporting the contention that strength is one of the most consistent correlates of maturation in adolescent females (Beunen and Thomis, 2000; Malina et al., 2011).

To date, no studies have considered momentum performance in female adolescents. Momentum is the product of speed and mass and given the increases in mass during adolescence, and the importance of momentum in certain sports (Baker and Newton, 2008), momentum performance is an interesting attribute to research in females. The performance trajectory shows an improvement in performance up until approximately 14.5 years, where a dip in performance then occurs to 15.5 years. This lack of improvement at older ages may be due to the increase in body mass, and in particular fat mass, that occurs during adolescence (Malina, Bouchard and Bar-Or, 2004). In addition, as observed from the strength performance trajectory, a cessation of strength improvements also occurs around this age, which in combination with an increase in mass, likely leads to a reduction in momentum performance at older adolescence. With respect to the discrepancies between performance relative to BA and CA, 65% of late maturing girls reported superior performances when assessed for biological age, with a mean improvement in percentile values, from CA to BA, of 6%. Conversely, momentum scores were superior for early maturing girls when evaluated relative to CA compared to BA. Mean percentile scores were 12% greater in the early maturing females when evaluated with CA compared to BA. 79% of early maturing girls displayed superior momentum performances when assessed for chronological age rather than biological age. As with strength, no significant difference in performance by BA and CA was observed for the on-time maturing girls, with mean percentile scores falling close to the mean for both (49% for both BA and CA). The mean BA-CA discrepancy values differed statistically across early, on-time and late maturing females. Whilst the magnitude of the difference between the momentum discrepancy scores across early, on-time, and late maturing females was large, highlighting that momentum is strongly correlated with maturation in adolescent females.

The performance trajectory and results of maximal speed were of particular interest. Consistent with existing evidence, maximal speed increased linearly until approximately 12 years of age where the curve then began to flatten (Papaiakovou et al., 2009). The influence of maturity status on maximal speed performance in the present study was consistent with that for upper body strength and momentum. That is, the later maturing girls benefited from BA adjustments, whereas the early maturing girls did not. With respect to the discrepancies between performance relative to BA and CA, 93% of late maturing girls reported superior performances when assessed for biological age, with a mean improvement in percentile values, from CA to BA, of 14%. Conversely, speed scores were superior for early maturing girls when evaluated relative to CA compared to BA. Mean percentile scores were 13% better in the early maturing females when evaluated with CA compared to BA. 85% of early maturing girls displayed superior speed performances when assessed for chronological age rather than biological age. No significant difference in performance by BA and CA was observed for the on-time maturing girls, with mean percentile scores falling close to the mean for both (55% and 54% for BA and CA, respectively). The mean BA-CA discrepancy values differed statistically across early, on-time and late maturing females. The magnitude of the difference between the speed discrepancy scores across early, on-time, and late maturing females was large, highlighting that, in the present study, speed is strongly associated with maturation in adolescent females.

Interestingly, the impact of maturity status on momentum and speed performance may change during the adolescent period. Younger adolescents perform as described above in both the momentum and speed test, whereby early maturers performed better when compared relative to CA, whilst late maturers performed better when compared relative to BA. In contrast, at older ages both early and late maturing females displayed a superior momentum performance score when evaluated relative to BA compared to CA (Figure 7.2). In addition, adjusting for maturity status appears to have limited impact on maximal speed performance in older maturing females (Figure 7.5). These results may reflect the flattening of the curves at older ages. This suggests that, once individuals have gone further through adolescence, adjusting for maturity status has less impact than it does at younger ages. In addition to this, the mean sprint performance percentiles of early maturing females when evaluated relative to both BA and CA are worse than the 50th centile. That is, even before any adjustments for advanced maturation are made, these individuals are performing below expectations. In contrast, the mean percentile score for momentum performance of early maturing individuals, when adjusted for BA, remains superior to the mean (65th percentile) and that of later maturing females, when adjusted for BA, remains inferior to the mean (35%).

The results described above detail that adjustment for maturity status may have less impact on maximal speed and momentum performances at older adolescence of early maturing females. Additionally, even after adjusting for maturity status, performance of early maturing females remained worse than, and better than, the 50th centile in both speed and momentum tests, respectively. These results may be the consequence of an increase in body mass during adolescence, with the older individuals more likely to have gone through puberty and a period of peak weight gain (Malina, Bouchard and Bar-Or, 2004). With attention to maturation, early maturing females are more likely to be taller and heavier with greater amounts of fat mass. Late maturing girls, in comparison, are more likely to be smaller and lighter (Beunen et al., 1997; Malina, Bouchard and Bar-Or, 2004). The greater body mass of early maturing females may negatively impact sprinting performance due to the requirement to move this extra body mass in space, especially if this is in combination with insufficient strength gains (Malina, 2014). This could explain the sprinting performance results of early maturing females, whereby they remain below the 50th centile when expressed relative to both CA and BA. The greater body mass of early maturing females, and older adolescence, may, on the other hand, positively impact momentum performance. In studies evaluating momentum performance in male athletes, greater performance between two individuals who are travelling at the same speed is attributed to greater body mass (Barr et al., 2014). Thus, greater body mass could explain the momentum performances described for females, whereby even when maturation is controlled for, early maturing females still perform better, and later maturing females still perform worse, than the mean. In an applied sense, coaches may choose to focus on developing force generating capabilities in young female athletes to reduce the negative impact of body mass on speed performance (Oliver, Lloyd and Rumpf, 2013). Improving strength will also likely enhance momentum performance.

The performance trajectories created in the present study are the first to be derived from data collected with female schoolchildren, in athletic fitness tests with consideration for biological age. They are, however, consistent with those developed from data collected in elite, junior female cohorts (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Myburgh et al., 2020). In agreement with the present study, elite, early maturing tennis players displayed significantly better athletic performance when observed relative to chronological rather than biological age, whilst the opposite could be seen for late maturing elite females (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Myburgh et al., 2020). The magnitude of discrepancy between CA and BA percentiles was, however, much smaller for the normal females in the current study compared to the elite female athletes. For example, the CA-BA discrepancies for speed performance in the present study were 16%, 1%, and 13% for late, on-time, and early maturing females, respectively. Whereas in the elite, tennis cohort, the CA-BA discrepancies for speed performance were 31%, 0% and 30% for late, on-time and early maturing athletes, respectively. This suggests that, when adjustments are made for biological maturity, a much larger impact on performance is observed in elite, compared to normal, female adolescents. This difference could be due to the elite cohort having more individuals at the extremes of the maturity continuum, increasing the contrast between the least and most mature athletes. Also, performance scores are likely to be very good for the elite athletes, providing a greater opportunity for maturity status to have an impact. In contrast, the mean performance scores of normal females are closer to the 50th percentile, suggesting more individuals are closer to an average performance level and therefore, adjustment for maturation may have less of an impact.

In comparison to the male cohort previously discussed (Chapter Six), the CA-BA percentile discrepancy for late and early maturing females were slightly smaller than those observed for late and early maturing males. For example, the mean CA-BA discrepancy scores for late and early maturing males performing the upper body strength test were 16% and 19% respectively. In contrast, the mean CA-BA discrepancy scores for late and early maturing females carrying out the same performance test were 9% and 15% respectively. This suggests that adjusting for maturity status has a smaller impact on fitness in adolescent females than it does in adolescent males. These smaller differences observed in females compared to males may be due to the biological and physical characteristics associated with advanced maturation in females, such as greater gains of fat mass and reduced physical capabilities (Gillison et al., 2017). These results support the consistent evidence that biological maturation has less of an impact on physical fitness in females than it does in males (Malina, Bouchard and Bar-Or, 2004).

7.5.1 Practical Implications

The findings in this study have important considerations for teachers and other practitioners working with young female cohorts. This study highlights the importance of creating developmentally adjusted evaluations of physical performance to provide a truer reflection of physical performance and physical potential. The key finding in the study is that the evaluation of physical performance varied relative to biological and chronological age for early and late maturing girls. This highlights the effect biological maturity can have in masking or enhancing physical fitness performance (Malina, Bouchard and Bar-Or, 2004).

This study is the first to create performance trajectories of age-based standards for a normal female cohort, whilst considering biological age. Existing research has been conducted in elite samples (Ulbricht, Fernandez-Fernandez and Ferrauti, 2013; Myburgh et al., 2020). There are obvious differences in the fitness performance of the general, female adolescent population compared to that of the elite, athlete populations, with the elite athletes likely already selected for their superior fitness. This study, therefore, provides novel, contemporary performance trajectories that practitioners can use as a benchmark to better understand normal development.

The findings observed in this study also further highlight the importance of considering individual performance, both through the lens of chronological and biological age, throughout the entire adolescent period. Teachers and practitioners could create their own performance trajectories of age-based standards to track individual performance and evaluate individual performance against both CA and BA to better understand individual strengths and weaknesses and to create a more targeted athletic development programme (Ryan et al., 2018). Plotting individual results on trajectories will also determine the efficacy of a fitness training programme, establishing if performance improvements are above those expected for normal development.

Despite the varying impact of maturation on physical performance in females, as described above, the advantages associated with earlier maturation exist and are reflected in the present study through a superior momentum, upper body strength and speed performance of earlier maturing 11-to-15-year-olds when scores are shown relative to their CA rather than BA. Upon evaluating performance of early maturing girls relative to biological maturity status, strength, momentum, and speed scores decrease by 15%, 12% and 13% respectively. In contrast, later maturing girls performed better when scores were considered relative to BA rather than CA. The findings from the current study highlight the need for those working with youth populations to look past current physical performance. The strength performance of both early and late maturing girls, when adjusted for BA, are close to the 50th percentile. Thus, although many early and late maturing girls may present fitness scores that are comparatively good or poor for their age group, they are, from a developmental perspective, performing at a level that is expected for their stage of development.

The creation of normative performance curves that account for these developmental differences enhances the accuracy of fitness evaluation in young females which can be used to increase girl's awareness of normal developmental changes. Importantly, this can challenge the perceptions girls have of their fitness decreasing during adolescence (Cumming et al., 2011), showing girls' that in fact, fitness performance does not decrease, and their biological development should be taken into consideration to more accurately show this. Thus, the creation of age-based trajectories could be a valuable tool to educate girls on their true physical competency during adolescence. Fitness testing in schools is often scrutinised (Rowland, 1995), however carrying out testing with developmental differences accounted for provides a mechanism to improve adolescent girls' perceptions of fitness, which could go some way in reducing the dropout from activity that occurs during adolescence (Allison et al., 2007).

7.5.2 Limitations

Many of the limitations described in previous chapters are relevant for this study. As discussed in the previous chapter, the cross-sectional method of performance data collection allows the creation of performance trajectories. However, longitudinally tracking individuals over time would increase the accuracy of these trajectories. The non-invasive measure of maturity assessment employed by Gillson and colleagues (Gillison et al., 2017) and used in the current study to calculate biological age, has not yet been validated within samples from the United Kingdom. Anthropometrical differences were not accounted for in the current study. This could be especially important in female samples given the body composition changes experienced during puberty and the potential impact on fitness (Malina, Bouchard and Bar-Or, 2004). The creation of performance trajectories in the future should take these measures into consideration.

Future studies could also evaluate a greater range of sports specific fitness tests to create a complete testing battery of developmental standards for the general female adolescent population. As previously stated, these biologically adjusted development curves could be used to improve the perception girls have of their physical competency. Future studies could evaluate their success of doing so using questionnaires (Whitehead, 1995; Cumming et al., 2020).

7.5.3 Conclusion

In summary, the present study provides a novel approach to monitoring and evaluating the physical fitness of female adolescent schoolchildren. Further to this, the extent to which biological maturity status impacts fitness relative to developmental performance has been evaluated. Whilst other recent studies have created performance curves in elite populations, this study is the first to do so in normal female adolescents whilst considering biological age. This study highlighted the advantages offered by earlier maturation and the disadvantages with later maturation. Those females advanced in maturation performed better in the tests of fitness when considered relative to their chronological age compared to biological age, whilst the opposite was true for those individuals delayed in maturation. In addition to highlighting the impact of biological maturation on physical fitness, this study has provided a practical means to quantify this impact. This research is useful for teachers, coaches and practitioners working with young females as they can replicate the creation of the trajectories to better understand the individual performance of their females, resulting in improved physical development, enhanced understanding of true fitness and more informed talent identification practises.

CHAPTER EIGHT

THE IMPACT OF BIO-BANDING ON THE VARIANCE IN MATURATION, BODY SIZE AND FITNESS PERFORMANCE OF MALE AND FEMALE SCHOOLCHILDREN

8.1 ABSTRACT

PURPOSE: To examine the degree to which bio-banding, in comparison to existing school year groups, reduces within group variance in maturation, body size and performance in athletic tests of fitness among male and female school children. **METHODS:** Standardised tests of linear speed, initial sprint momentum, agility, upper body strength, lower body, and total body power and balance were administered to, and heights and weights measured, in male and female schoolchildren, aged 11-15 years. Biological maturation was determined using the Khamis-Roche method and percentage of predicted adult height used for determination of bio-banded groups (80-85%, 85-90%, 90-95% and 95-100% for the males and 85-90%, 90-95% and 95-100% for the females). Coefficients of variation and a series of approximate F tests were conducted to examine the degree to which the bio-banding resulted in changes in variance among the variables of interest. **RESULTS:** The practise of bio-banding resulted in a statistically significant reduction in variance for % PAS in both males and females ($p < 0.01$). In females, bio-banding led to statistically significant reductions in variance of height, weight, momentum and 10m speed across some maturity groups ($p < 0.01$), with the magnitude of the reduction in variance ranging from 19 to 66%. Although no statistically significant differences in the coefficients of variation for any tests of fitness were observed in the males, bio-banding did result in a reduction in variance in several attributes (height, weight, power, speed, momentum, strength and agility) in some maturity groups, with the magnitude of reduction ranging from 2% to 17%. **CONCLUSION:** Overall, bio-banding appears to be an effective strategy in reducing the variation in maturity and anthropometric variables and, in some instances, physical fitness in school children.

8.2 INTRODUCTION

Adolescence is a period of life where a positive engagement with physical activity and fitness are important to enhance the individual's both current, adolescent, and future, adult, health and well-being. Regular physical activity reduces the risk factors for many diseases, including diabetes, obesity and high blood pressure (Chaddha et al., 2017) and high levels of physical fitness are linked to both positive physical and mental health (Ortega et al., 2008). Despite this, adolescence is a period where participation in physical activity reduces (Allison et la., 2007) and over the past 30 years, fitness levels of young people have deteriorated (Tomkinson et al., 2003). Consequently, the numbers of overweight/obese children and adolescents are now at an alarmingly high level. Additionally, a rise in mental health, type II diabetes and a poorer quality of life, amongst other issues, are associated with poor physical fitness (World Health Organisation).

Improving one's physical fitness can have not only direct effects of reducing health risks, but can also enhance one's physical self-concept, confidence and perceptions of their body image (Neumark-Sztainer et al., 2006; Sabiston and Crocker, 2008). With children spending a large part of their time in school, schools can play an important role in combating poor levels of physical fitness. Schools have the opportunity to influence the perceptions and understanding children have of their fitness, which may also lead to improved physical activity habits. School-based physical fitness programmes and physical education lessons have the potential to address some of the aforementioned issues concerning poor fitness and activity levels. Schools, however, group children according to chronological age (CA), and individuals of the same chronological age can vary significantly in biological maturity (Malina, Bouchard and Bar-Or, 2004). Some individuals can mature in advance (early maturing) or delayed (late maturing) of their peers, leading to the possibility of differences of up to five to six years in maturity existing within a single age cohort (Johnson, 2015).

As discussed in previous chapters, variance in the timing of biological maturation can have significant implications on physical fitness. Early maturing boys and girls are stronger than those individuals that are on-time or late maturing (Malina, Bouchard and Bar-Or, 2004), whilst early maturing males are also more powerful and faster than their average and late maturing peers (Goto, Morris and Nevill, 2019). Variation in biological maturation can also have an impact on physique and body size. Early maturing boys and girls are, on average, taller and heavier than their on-time and late maturing counterparts (Malina, Bouchard and Bar-Or, 2004). In females this greater mass is predominantly fat mass and early maturing females are more likely to be overweight/obese than late maturing females, who are more likely to have a more linear physique (McNeill and Livson, 1963). Early maturing males, in contrast, generally have higher levels of lean muscle mass (Tønnessen et al., 2015).

Maturity-associated variations in body size, physique and functional capacity can have significant implications for athletic performance and selection into sports (Malina et al., 2015), as well as for perceptions of physical self-worth and body attractiveness, which, in turn can influence physical activity levels (Cumming et al., 2020). Recently, several strategies have been trialled to address some of these challenges. One such strategy is bio-banding. Bio-banding is the process of grouping individuals based upon maturity status and/or body size rather than chronological age (Cumming, Lloyd et al., 2017). Bio-banding is proposed as an alternative strategy to be used alongside chronological age groupings, rather than a substitution, and thus far has only been applied for short-term practise, such as in tournaments, matches and training sessions (Malina et al., 2019). Bio-banding aims to restrict variance in maturation and as a result reduce the variance in size and/or athleticism (Cumming, Lloyd et al., 2017).

To date, research pertaining the use of bio-banding is largely limited to sports whereby grouping athletes by weight or age is common practise. The growing research into the application of bio-banding in youth sport stems from concerns over mismatches of size and maturity on the optimal development of athletes, as well as youth welfare and safety concerns (Albuquerque et al., 2016). Additionally, researchers and practitioners are exploring the use of bio-banding in talent identification and strength and conditioning practises (Cumming, Lloyd et al., 2017). Several studies in elite youth soccer have experimented with bio-banding as a practise and initial results have suggested bio-banding emphasises the technical and tactical capabilities of a player, rather than physical qualities (Cumming, Brown et al., 2017; Bradley et al., 2019; Abbott et al., 2019). Several youth soccer academies from the English Premier League recently competed in a bio-banded tournament, where players were grouped on the basis of maturity status, as established by percentage PAS, as opposed to CA. Both early and late maturing players, as well as coaches, reported positive experiences from the tournament. Specifically, the bio-banded tournament was said to provide unique and varied challenges and learning experiences to the players (Bengsch, 2016). A recent study in U.S. Soccer grouped players for participation in a bio-banded tournament by two different types of bio-banded groups, namely maturity bands that were restricted by percentage of adult height, and maturity groups whereby the least to most mature were separated into quartiles within a CA group (Bunce, 2019). In this study, the responses of the early-maturing and later-maturing players, of both genders, reported similar experiences to those described above. Early maturing players experienced greater physical challenge in matches, whilst late maturers reported increased opportunities demonstrate technical and physical attributes, and also had more opportunities to display leadership skills (Bunce, 2019). This is likely due to players being more closely matched in maturity status, resulting in early maturing maturers being less able to rely upon their physical advantages, whilst late maturing players were afforded more opportunities to express their technical, tactical, and physical skills (Cumming, Brown et al., 2017).

Little research exists examining the impact of restricting the variance in maturation on the variance of physical performance in individuals, however one would assume that by reducing the variance in maturity, the variance in body size and physical performance would also reduce. Johnson et al., (Johnson et al., 2019) recently demonstrated that restricting maturity variance through percentage PAS groupings, led to reduced variance in momentum and speed performance of elite, youth soccer players. Similarly, Towlson et al., (Towlson et al., 2021) recently compared the variance in body size and physical performance of maturity groups and CA groups in young, elite soccer players. Maturity groups were established as pre-, mid-, and post-PHV and were calculated through Maturity Offset calculations. Results demonstrated the bio-banded groups restricted the variance in both anthropometric measurements and physical performance outputs (explosive power, agility, speed) of the soccer players. Although the maturity offset maturity method was used to measure maturity status, and so results should be interpreted with caution, this study provides initial insight into the possible implications of restricting maturity on physical fitness performance. No studies to date have, however, evaluated the application of bio-banding in non-elite populations. It should not be assumed that the preliminary evidence from the studies described above in elite athletes will be replicated in non-elite populations. Elite athletes are a homogenous, pre-selected group of individuals, whereas in a more heterogenous, non-elite population of school children, fitness is likely to be influenced by many factors, including motivation, self-esteem, confidence in the surroundings, body weight and training experience. In addition, the fitness performance of elite athletes will be more superior than that of school children and, therefore, grouping non-elite individuals into maturity groups may have less impact on fitness.

In light of the preceding discussion, the purpose of this study is to examine and investigate the degree to which bio-banding, in comparison to existing age-based grouping strategies, can restrict variance in maturation, body size and performance in athletic tests of fitness among school children. Assuming bio-banding restricts maturity associated variance in size and physical fitness, it is hypothesised that the variance in size and physical fitness in school children will be significantly lower when they are grouped relative to their biological maturity status and not their chronological age.

8.3 METHODOLOGY

8.3.1 Participants

Consistent with previous chapters, male and female schoolchildren aged 11 to 15 years took part in the physical fitness and measurement of anthropometrics during the academic years of 2014-15 and 2015-16. Participants were assessed once, providing a cross-sectional data sample. For the purposes of analysis, within this study participants were grouped according to school year group and maturity status bio-banded groups and, therefore, not all participants that participated in the fitness testing were involved in the analysis. In total, 414 females were grouped into bio-banded groups and 183 were grouped into school year groups. 191 males were grouped into bio-banded groups and 194 were grouped into school year groups.

8.3.2 Ethics and Consent

This study was approved by the Research Ethics Approval Committee at the host University. Informed written consent was obtained via the school's head teacher acting *loco parentis* and a parental opt out option was given to every individual. Self-assent was obtained for the participant. The schoolteachers were informed about the procedures and aims of the study prior to completion and only those participants that indicated a willingness to take part were included.

8.3.3 Physical Fitness and Anthropometric Measurements

All fitness testing was carried out during the participants' normal physical education lesson. For a detailed description of height and weight measurement please refer to Chapter Three. The fitness tests employed were; hand grip dynamometer to assess upper body strength; a linear sprint to assess momentum; and a Y-Balance test to assess balance performance. For a detailed description of fitness testing protocols and assessment measurements please refer to Chapter Three.

8.3.4 Maturity Measurements

The percentage of predicated adult height attained at the time of testing was used as the indicator of maturity status. Decimal age, height, and weight of the individual, and mid-parent height, were used to predict mature, adult height for each participant using equations developed on the Fels Longitudinal Study sample in south-central Ohio (Khamis and Roche, 1994). Parental heights were self-reported prior to the testing session and were adjusted for overestimation (Epstein et al., 1995). The current height of each participant was expressed as a percentage of their predicted mature/adult height. Percentage of predicted adult height was the measure used for the bio-banded groups (Cumming et al., 2017). The bio-banding groups used within this study were 80-85%, 85-90%, 90-95% and 95-100% for the males and 85-90%, 90-95% and 95-100% for the females. This is consistent with the bio-band groupings used by Malina et al., (Malina et al., 2019) in the recent US Soccer bio-banding tournament whereby these groupings approximately halved the variance in maturation compared to that observed within chronological age groups.

8.3.5 Statistical Analysis

Data analysis was completed using Microsoft Excel to calculate means, standard deviations, quartiles and coefficient of variation. The coefficient of variation was calculated by (standard deviation / mean) x 100. The F and p values were derived from approximate F-test for equality of a coefficient of variation, using an online statistical calculator (Comparison of Coefficients of Variation calculator (scistat.com)). Minimal statistical significance was set at ($p < 0.05$).

8.4 RESULTS

Table 8.1 displays the mean, standard deviation and coefficient of variation for the female participants grouped according to school year age group. The greatest variation in body weight, % PAS, power, maximal speed (20m and 30m) and strength was in the Year 6 age group. The greatest variation in height and agility was in the Year 7 group, whilst the greatest variations in acceleration (10m speed), momentum and balance were in the Year 8 group. Table 8.2 compares the mean, standard deviation and coefficient of variation across the female participants when grouped relative to their bio-band (85-90%, 90-95% & 95-100% PAS). The greatest variation in most of the fitness attributes in females occurred in the 85-90% PAS maturity group, with the exception of momentum (95-100% PAS) and strength and agility (90-95% PAS). The greatest variation for height and body weight was observed in the 95-100% group.

The maturity groups selected for comparison to school year groups were based upon the average % PAS for each school year group. As a result, for the female analysis, bio-banded groups of 85-90%, 90-95% and 95-100% were analysed relative to school year groups 6, 7 and 8, respectively. Whilst for the male analysis, bio-banded groups of 80-85%, 85-90%, 90-95% and 95-100% were compared to school year groups 7, 8, 9 and 10, respectively. A series of approximate F tests were conducted to examine the degree to which the bio-banding strategy resulted in a change in variance among the variables of interest. Those analysis that presented statistical significance between age and maturity groups are displayed in Figures 8.1-8.6 and Figures 8.1, 8.2, 8.3, 8.4, 8.5 and 8.6 display the variation in % PAS (females), height (females), weight (females), momentum (females), height (males) and %PAS (males), respectively.

For the Year 6 school girls, when evaluated against the 85-90% PAS maturity group, the practise of bio-banding resulted in a statistically significant reduction in variance of %PAS ($F = 9.03$, $p < 0.001$, magnitude of reduction = ↓ 66%), weight ($F = 3.41$, $p < 0.01$, ↓ 47%) and momentum ($F = 2.79$, $p < 0.05$, ↓ 41%). For the Year 7 schoolgirls, when analysed in comparison to the 90-95% maturity group, the bio-banded strategy resulted in a statistically significant reduction in variance of %PAS ($F = 4.75$, $p < 0.001$, ↓ 54%), height ($F = 2.35$, $p < 0.001$, ↓ 35%), weight ($F = 2.17$, $p < 0.01$, ↓ 33%) and momentum ($F = 2.16$, $p < 0.01$, ↓ 33%). For the Year 8 school girls, when analysed in comparison to the 95-100 %PAS maturity group, the practise of bio-banding resulted in a statistically significant reduction in variance of %PAS ($F = .30$, $p < 0.001$, ↓ 46%), weight ($F = .56$, $p < 0.001$, ↓ 26%), 10m speed ($F = .66$, $p < 0.05$, ↓ 19%) and momentum ($F = .53$, $p < 0.001$, ↓ 28%). In contrast, bio-banding resulted in a significant increase in variance in agility performance ($F = 1.55$, $p < 0.05$, ↑ 20%). In the female cohort, although not statistically significant, bio-banding did result in a reduction in variance in height (Year 6), lower body power (Year 6 and 8), total body power (Year 6 and 8), agility (Year 6), strength (Year 6 and 8), 20m speed (Year 7) and balance (Year 8) and the magnitude of variance in the reduction of coefficient ranged from 2% to 26%.

When considering the male analysis, for the Year 7 schoolboys, when evaluated against the 80-85% PAS maturity group, the practise of bio-banding resulted in a statistically significant reduction in variance of %PAS ($F = .32$, $p < 0.01$, magnitude of reduction = ↓ 44%) and height ($F = 0.45$, $p < 0.05$, ↓ 35%). For the Year 8 schoolboys, when analysed in comparison to the 85-90% maturity group, the bio-banded strategy resulted in a statistically significant reduction in variance of %PAS ($F = .18$, $p < 0.001$, ↓ 58%). For the Year 9 schoolboys, when analysed in comparison to the 90-95 %PAS maturity group, the practise of bio-banding resulted in a statistically significant reduction in variance of %PAS ($F = .28$, $p < 0.001$, ↓46%). For the Year 10 schoolboys, when analysed in comparison to the 95-100 %PAS maturity group, the practise of bio-banding resulted in a statistically significant reduction in variance of %PAS ($F = 2.28$, $p < 0.01$, ↓ 34%). In this male cohort, although not statistically significant, bio-banding did result in a reduction in variance in height (Year 8 and 9), weight (Year 10), total body power (Year 8 and 9), lower body power (Year 9), 10m speed (Year 8), 20m speed (year 8), 30m speed (Year 8), momentum (Year 7, 8, 9 and 10), strength (Year 7 and 8) and agility (Year 10). The magnitude of variance in the reduction of coefficient ranged from 2% to 17%.

Table 8.1. Mean, standard deviation and coefficient of variation (CV) of anthropometric, % PAS and fitness variables for female school children grouped by school year group

School Year	6 (N= 24)		7 (N= 79)		8 (N= 80)	
	M (SD)	CV (%)	M (SD)	CV (%)	M (SD)	CV (%)
Chronological Age	11.39 (±0.21)	1.87	12.31 (±0.29)	2.38	13.27 (±0.28)	2.08
Height (cm)	146.1 (±5.86)	4.01	154.7 (± 8.13)	5.26	159.5 (±6.55)	4.11
Body Weight (kg)	42.4 (±11.13)	26.24	46.7 (±8.13)	23.62	53.2 (±12.05)	22.64
% PAS	89.3 (±3.73)	4.18	93.1 (±3.02)	3.25	96.4 (±2.07)	2.15
Lower Body Power (cm)	19.95 (±5.45)	27.34	22.40 (±4.62)	20.62	20.88 (4.61)	22.10
Total Body Power (cm)	21.7 (±5.51)	25.40	25.4 (±4.96)	19.52	23.87 (±5.13)	21.50
10m Speed (s)	2.27 (±0.19)	8.50	2.13 (±0.14)	6.57	2.15 (±0.23)	10.47
20m Speed (s)	4.15 (±0.37)	8.87	3.87 (±0.30)	7.71	3.89 (±0.31)	7.88
30m Speed (s)	6.16 (±0.62)	10.04	5.61 (±0.49)	8.78	5.71 (±0.49)	8.63
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	186.78 (±42.71)	22.87	219.10 (±50.02)	22.83	248.70 (±58.27)	23.43
Agility (s)	3.39 (±0.31)	9.10	3.26 (±0.32)	9.72	3.28 (0.25)	7.74
Upper Body Strength (kg)	17.63 (±4.81)	27.29	21.28 (±4.14)	19.43	23.03 (±4.72)	20.50
Balance (cm)	186.15 (±19.24)	10.34	216.63 (±23.86)	11.01	204.37 (±26.48)	12.96

Table 8.2. Mean, standard deviation and coefficient of variation (CV) of anthropometric, % PAS and fitness variables for female school children grouped by % PAS maturity group

Maturity Group	85-90% (N= 22)		90-95% (N = 61)		95-100% (N= 331)	
	M (SD)	CV (%)	M (SD)	CV (%)	M (SD)	CV (%)
Chronological Age	11.82 (±0.52)	4.43	12.56 (±0.67)	5.36	14.32 (±0.92)	6.40
Height (cm)	144.3 (±4.34)	**3.01**	153.43 (±5.26)	**3.43**	164.39 (±6.87)	4.18
Body Weight (kg)	36.44 (±5.06)	**13.89**	43.88 (±6.94)	**15.81**	57.51 (±9.61)	**16.72**
% PAS	88.23 (±1.23)	**1.39**	92.91 (±1.38)	**1.49**	98.25 (±1.15)	**1.17**
Lower Body Power (cm)	21.97 (±5.77)	**26.25**	22.33 (±4.45)	19.92	23.91 (±5.06)	**21.15**
Total Body Power (cm)	24.00 (±6.00)	**24.98**	25.49 (±5.11)	20.04	27.47 (±5.80)	**21.13**
10m Speed (s)	2.20 (±0.20)	8.95	2.16 (±0.17)	7.96	2.02 (±0.17)	**8.52**
20m Speed (s)	3.99 (±0.39)	9.75	3.90 (±0.29)	**7.41**	3.62 (±0.31)	8.71
30m Speed (s)	5.85 (±0.68)	11.59	5.68 (±0.50)	8.78	5.21 (±0.52)	9.92
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	166.30 (±22.41)	**13.48**	204.10 (±31.25)	**15.31**	285.91 (±47.97)	**16.78**
Agility (s)	3.26 (±0.29)	**8.95**	3.27 (±0.32)	9.94	3.03 (0.29)	9.64
Upper Body Strength (kg)	17.00 (±3.42)	**20.09**	19.90 (±4.07)	20.46	28.44 (±5.68)	**19.99**
Balance (cm)	205.36 (±27.19)	13.24	210.14 (±25.23)	12.01	227.31 (±26.85)	**11.81**

Text in bold represents CV's which are reduced compared to the comparable school year group.

Table 8.3. Mean, standard deviation and coefficient of variation (CV) of anthropometric, % PAS and fitness variables for male school children grouped by school year group

School Year	7 (N= 32)		8 (N= 32)		9 (N= 63)		10 (N = 67)	
	M (SD)	CV (%)	M (SD)	CV (%)	M (SD)	CV (%)	M (SD)	CV (%)
Chronological Age	12.27 (±0.29)	2.40	13.17 (± 0.40)	3.02	14.30 (± 0.33)	2.32	15.12 (±0.35)	2.33
Height (cm)	152.25 (±8.12)	5.33	163.02 (±8.32)	5.11	167.38 (±7.73)	4.62	171.32 (±6.60)	3.85
Body Weight (kg)	44.61 (±8.33)	18.67	56.64 (±12.90)	22.78	54.59 (±9.08)	16.63	59.00 (±14.44)	24.48
% PAS	83.83 (±2.67)	3.19	88.87 (±3.60)	4.05	92.80 (±2.52)	2.72	95.89 (±2.10)	2.19
Lower Body Power (cm)	25.75 (±4.77)	18.52	24.04 (±4.58)	19.05	29.50 (±6.45)	21.85	30.47 (±5.33)	17.50
Total Body Power (cm)	29.57 (±5.07)	17.14	28.34 (±5.60)	19.78	33.52 (±6.75)	20.13	35.21 (±6.65)	18.90
10m Speed (s)	1.97 (±0.09)	4.32	2.10 (±0.17)	8.31	1.88 (±0.12)	6.30	1.85 (±0.12)	6.58
20m Speed (s)	3.55 (±0.16)	4.48	3.68 (±0.32)	8.62	3.38 (±0.23)	6.79	3.24 (±0.22)	6.91
30m Speed (s)	5.12 (±0.26)	5.10	5.30 (±0.50)	9.51	4.75 (±0.37)	7.72	4.59 (±0.35)	7.54
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	226.59 (±43.84)	19.35	266.20 (±54.80)	20.59	291.72 (±57.63)	19.76	321.53 (±76.10)	23.67
Agility (s)	2.85 (±0.18)	6.37	3.04 (0.27)	8.98	2.78 (±0.21)	7.72	2.69 (±0.22)	8.34
Upper Body Strength (kg)	24.23 (±4.95)	20.41	27.66 (±9.17)	33.18	30.83 (±7.09)	23.01	37.20 (±9.67)	25.99
Balance (cm)	152.25 (±8.12)	5.33	163.02 (±8.32)	5.11	167.38 (±7.73)	4.62	171.32 (±6.60)	3.85

Table 8.4. Mean, standard deviation and coefficient of variation (CV) of anthropometric, % PAS and fitness variables for male school children grouped by % PAS maturity group

School Year	80-85 (N= 32)		85-90 (N= 35)		90-95 (N= 74)		95-100 (N = 50)	
	M (SD)	CV (%)	M (SD)	CV (%)	M (SD)	CV (%)	M (SD)	CV (%)
Chronological Age	12.14 (±0.58)	4.78	13.11 (±0.85)	6.48	14.33 (±0.68)	4.72	14.90 (±0.64)	4.30
Height (cm)	149.53 (±5.36)	**3.58**	159.89 (±7.25)	**4.54**	168.70 (±6.50)	**3.85**	173.72 (±6.93)	3.99
Body Weight (kg)	44.09 (±8.73)	19.81	50.97 (±12.03)	23.59	56.55 (±9.87)	17.45	63.41 (±14.68)	**23.16**
% PAS	82.72 (±1.48)	**1.78**	87.99 (±1.49)	**1.70**	92.99 (±1.35)	**1.45**	96.87 (±1.41)	**1.45**
Lower Body Power (cm)	23.98 (±4.95)	20.63	26.08 (±4.99)	19.12	28.50 (±5.91)	**20.74**	31.08 (±7.02)	22.60
Total Body Power (cm)	27.62 (±5.68)	20.55	29.48 (±5.57)	**18.90**	32.82 (±6.32)	**19.25**	36.03 (±7.51)	20.85
10m Speed (s)	2.08 (±0.16)	7.77	2.02 (±0.16)	**7.85**	1.92 (±0.14)	7.48	1.84 (±0.13)	7.13
20m Speed (s)	3.71 (±0.28)	7.45	3.59 (±0.27)	**7.62**	3.39 (±0.27)	7.94	3.23 (±0.25)	7.60
30m Speed (s)	5.38 (±0.45)	8.39	5.16 (±0.45)	**8.74**	4.78 (±0.45)	9.39	4.58 (±0.38)	8.23
Momentum ($kg \cdot m^{-1} \cdot s^{-1}$)	211.75 (±36.45)	**17.21**	246.44 (±45.30)	**18.38**	295.49 (±53.86)	**18.23**	345.38 (±74.60)	**21.60**
Agility (s)	2.99 (±0.25)	8.51	2.95 (±0.29)	9.91	2.78 (±0.23)	8.41	2.67 (±0.22)	**8.15**
Upper Body Strength (kg)	22.16 (±4.45)	**20.08**	26.08 (±7.96)	**30.51**	32.51 (±7.87)	24.22	38.41 (±10.11)	26.33
Balance (cm)	208.45 (±27.96)	13.41	213.53 (±26.31)	12.32	228.27 (±22.03)	9.65	237.99 (±22.31)	9.37

Text in bold represents CV's which are reduced compared to the comparable school year group.

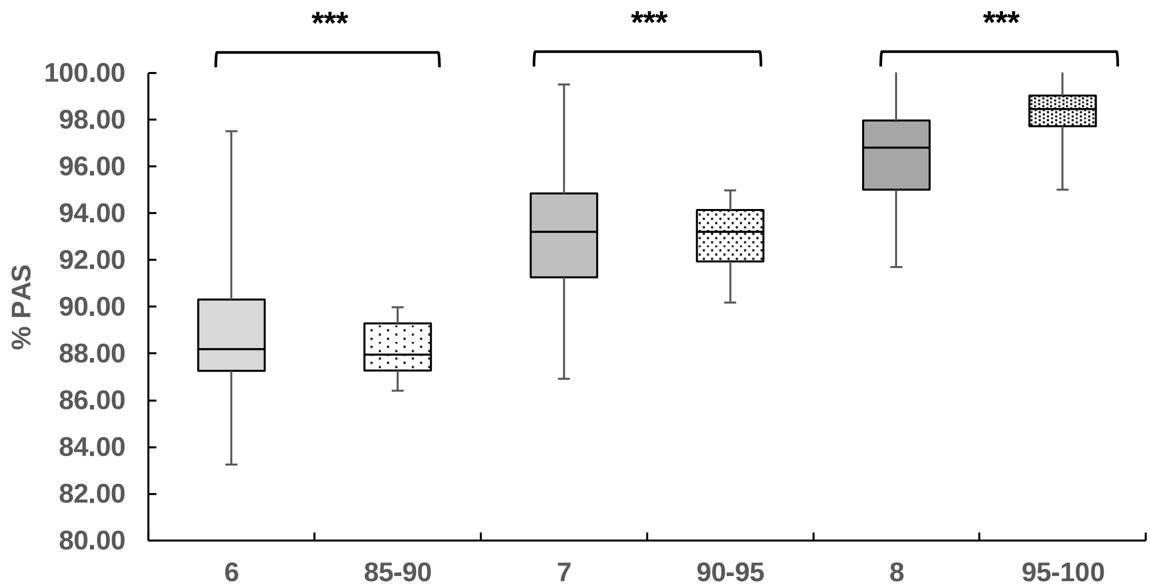


Figure 8.1 The variation in female % PAS compared between school year groups (year 6, year 7 and year 8) and bio-banded groups (85-90%, 90-95% and 95-100%)

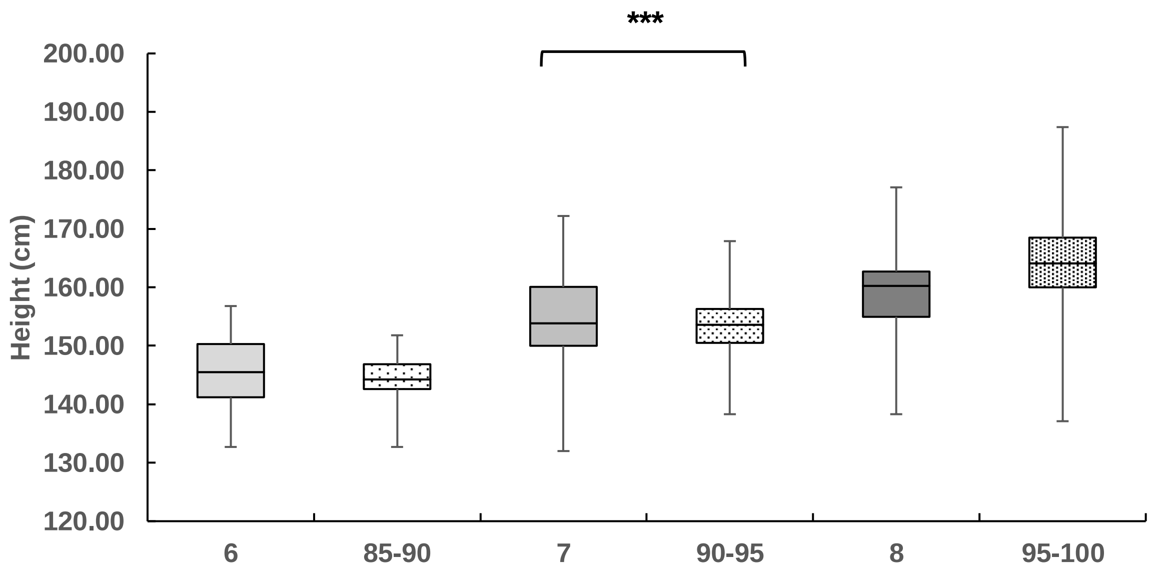


Figure 8.2 The variation in female height compared between school year groups (year 6, year 7 and year 8) and bio-banded groups (85-90%, 90-95% and 95-100%)

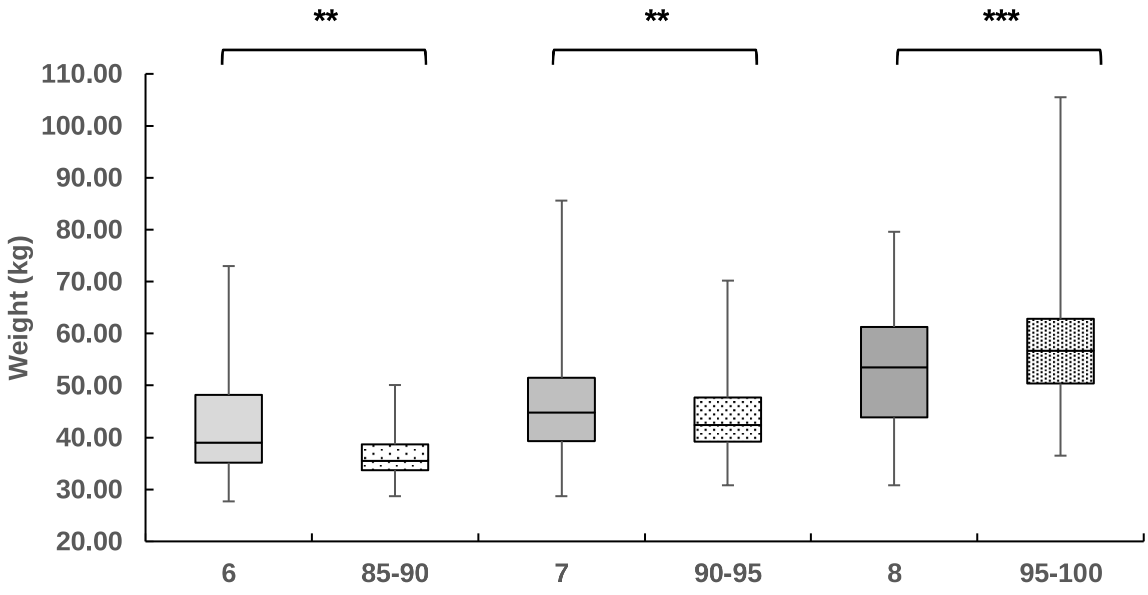


Figure 8.3 The variation in female weight compared between school year groups (year 6, year 7 and year 8) and bio-banded groups (85-90%, 90-95% and 95-100%)

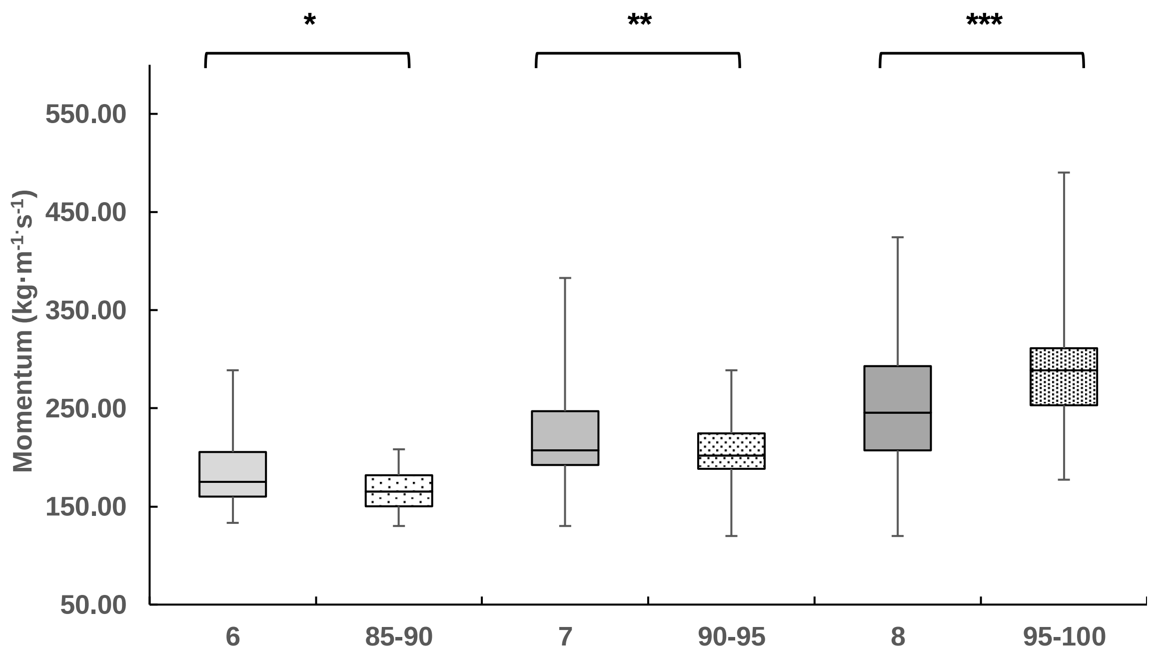


Figure 8.4 The variation in female momentum performance compared between school year groups (year 6, year 7 and year 8) and bio-banded groups (85-90%, 90-95% and 95-100%)

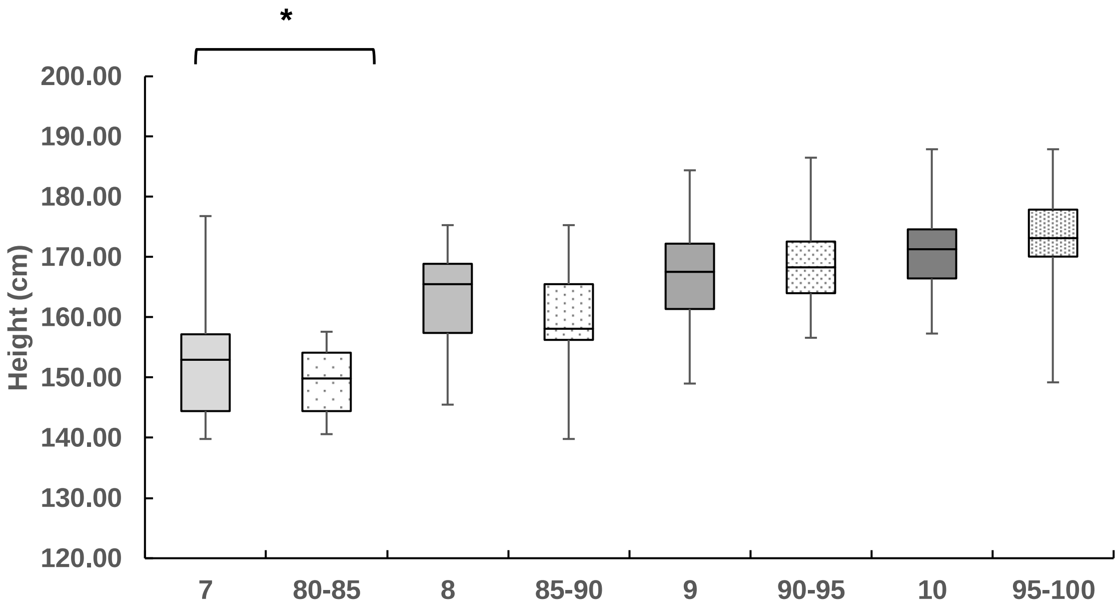


Figure 8.5 The variation in male height compared between school year groups (year 6, year 7, year 8 and year 9) and bio-banded groups (80-85%, 85-90%, 90-95% and 95-100%)

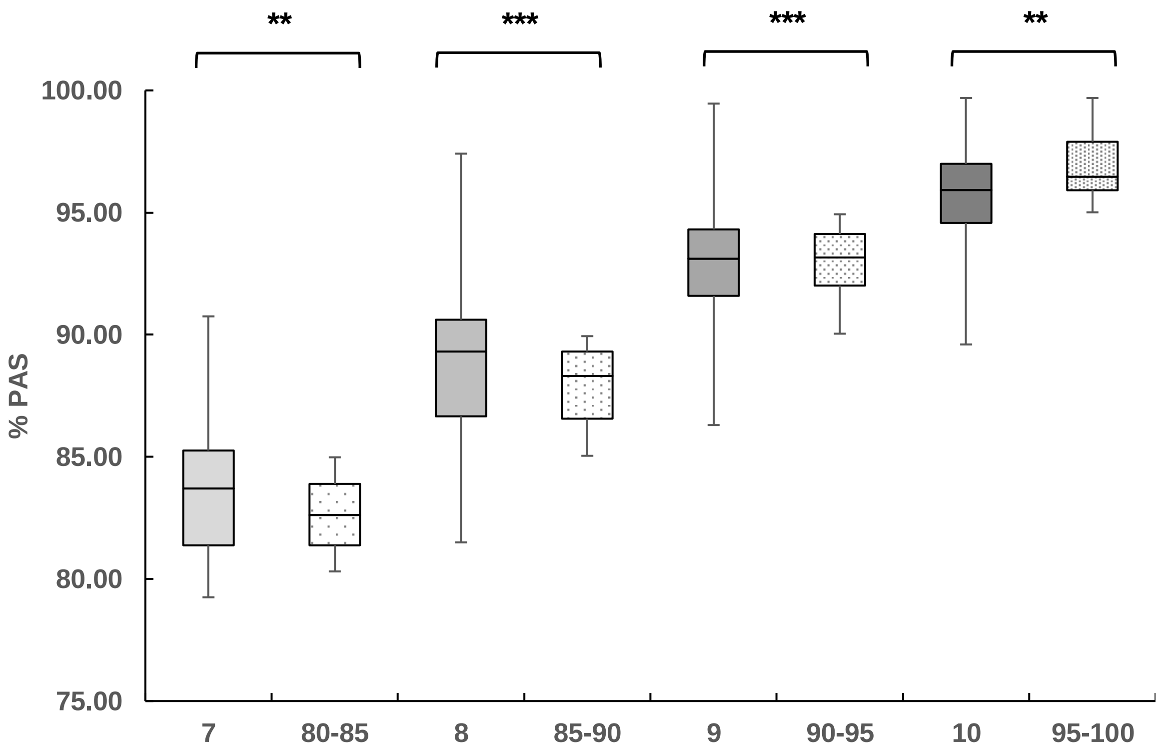


Figure 8.6 The variation in male % PAS compared between school year groups (year 6, year 7, year 8 and year 9) and bio-banded groups (80-85%, 85-90%, 90-95% and 95-100%)

Represents statistical differences in the coefficients of variance between the age groups and bio-banded groups

* $p < 0.05$ level

** $p < 0.01$ level

*** $p < 0.001$ level

8.5 DISCUSSION

This study aimed to examine the extent to which grouping schoolchildren by maturity status (bio-banding), in comparison to school year group, would reduce the variation in physical performance in a series of athletic tests of fitness. As predicted, bio-banding the school children resulted in significantly reduced coefficient of variation for % PAS across all groups, for both males (Figure 8.6) and females (Figure 8.1). This reduction in variations was not, however, reflected consistently across fitness variables. Perhaps unexpectedly, the bio-banding strategy resulted in little impact on the variation of fitness performance in the male children. No statistically significant differences in the coefficients of variation for any tests of fitness were observed across the bio-banded and school year groups in males. Very little research has previously been conducted in this field, however, the results presented in this study differ from those observed recently by Johnson et al., (2019) who showed that bio-banding, compared to chronological age groups, significantly reduced the variation in momentum and size in elite, male soccer players. The bio-banding strategy in the female schoolchildren did, however, have a greater impact on reducing the variation in fitness performance and anthropometrics than it did in the boys. Statistically significant reductions in variance were observed when maturity was restricted in height, weight, momentum and 10m speed in some maturity groups.

The coefficients of variation of the percentage of peak adult stature were significantly lower across all groups using the bio-banding strategy compared to the school year groupings in both the male and female cohorts (Figure 8.6 and Figure 8.1, respectively). This suggests that grouping adolescents by % PAS is a useful strategy to reduce the variation in maturation in school children. This is consistent with previous research in elite athletes (Johnson et al., 2019; Malina et al., 2019). Whilst limited impact on fitness performance was observed in the present study, it is possible that the bio-banding strategy may have an impact in other developmental areas, such as the development of psychosocial factors. Research in elite, young footballers has observed several psychosocial traits to be heightened through bio-banding, such as the opportunity for enhanced leadership qualities in late maturing individuals ‘playing down’ an age group and the exposure of greater team-orientated skills in early maturing individuals ‘playing up’ an age group (Cumming, Brown et al., 2017; Cumming, Searle et al., 2018). Should the bio-banding strategy elicit these qualities in normal school children, this may be of benefit to schoolteachers when considering the holistic development of adolescents through sport and activity.

In the female schoolchildren, the coefficients of variation for % PAS (Figure 8.1), weight (Figure 8.3) and momentum (Figure 8.4) were significantly lower in the bio-banded group compared to the school year groups. Variation in height was significantly reduced in the 90-95% PAS maturity group and reduced in the 85-90% maturity group, but not statistically significant (Figure 8.2). The results presented for height and weight suggest bio-banding is most beneficial at reducing variation in these anthropometric variables in the 90-95% PAS maturity group. This likely reflects the period of PHV, which occurs on average at approximately 92% PAS (Tanner., 1962; Baxter-Jones., 2013). Therefore, should teachers or coaches wish to reduce variation in body size or maturation in adolescent females for lessons, competition, training or talent identification, bio-banding individuals by maturity groups appears to be a beneficial strategy.

The variation in momentum performance was significantly reduced in all female bio-banded groups (Figure 8.4). This is likely the result of a reduction in body weight when females were grouped by maturity status rather than school year. Momentum is the product of velocity and mass (Baker and Newton., 2008), thus a reduced variation in body mass due to bio-banding likely reduces the variation in momentum performance. The current study suggests that restricting maturation in individuals may have the greatest impact of reducing variance in momentum performance in the school year groups 7 and 8, and likely around the period of PWV in the 95-100%

maturity group, which occurs on average 0.5-1.0 years after PHV (Tanner., 1965). This finding could have useful implications in collision sports, such as rugby. For training purposes, to reduce the possible advantages body weight and momentum may have, coaches could bio-band girls, especially when working with girls close to, and going through, PHV and PWV. This may allow for a greater demonstration, and development, of technical skills and other important attributes needed in rugby.

In the girls, although not statistically significant, bio-banding did result in a reduction in variance in lower body power (Year 6 and 8), total body power (Year 6 and 8), agility (Year 6), strength (Year 6 and 8), 20m speed (Year 7) and balance (Year 8). Therefore, although bio-banding did not significantly impact fitness performance across many of the tests, a trend towards reduced variance in several fitness qualities was observed. Additionally, bio-banding in the girls appears to have most significance in Year 6 and 8, where the females are, on average, 11- and 13-years old, respectively. This may reflect the pubertal changes that are taking place at these ages, and possibly the initial pubertal changes seen in the 11-year-olds and the period of PWV in the 13-year-old girls. No other studies have examined the use of bio-banding as a tool to restrict fitness variation in female adolescents, therefore the current study provides novel research in this area and suggests bio-banding may be a beneficial strategy to restrict variance in fitness performance, particularly during puberty and the period of PWV.

In the males, whilst the variation in several fitness attributes was reduced when expressed in bio-banded groups compared to school year groups, none were significantly reduced (See Table 8.4). Specifically, the variation in momentum was reduced for all groups, whilst strength was reduced in the 80-85% and 85-90% PAS. Additionally, the variation in lower body power and speed across all distances was reduced in the 85-90% PAS maturity group, the variation in total body and lower body power was reduced in the 90-95% PAS maturity group and the variation in agility performance was reduced in the 95-100% maturity group.

With regards to body size in males, unexpectedly the bio-banded maturity groups had little effect at reducing the variation in height and weight. The variation in height was significantly reduced in the 80-85% PAS maturity group and was reduced, but not significantly, in the 85-90% and 90-95% PAS maturity groups, when compared to school year groups 7, 8 and 9 respectively. Variation in weight was reduced, but not significantly, in the 95-100% PAS maturity group when compared to school year group 10. These findings are in contrast to those recently demonstrated by Towlson et al., (Towlson et al., 2021), who observed the variance of height and weight to be reduced when U14 and U15 male soccer players were bio-banded through various Maturity Offset methods into pre-, circa- and post-PHV groups. However, the results from the present study support those observed by Johnson et al., (Johnson et al., 2020) who demonstrated that variance in height and weight were reduced in some, but not all, bio-banded groups of elite, male footballers. The contrasting findings across the various studies are likely the result of the variation in maturity assessment methods used and differences in populations. Further research is required to explore the use of bio-banding strategies as a means to reduce anthropometric variance in both elite and non-elite male populations.

The results described above may be surprising, particularly with regards to the boys. Although a recent strategy, initial findings exploring the use of bio-banded adolescent groups to restrict variance in maturity, and so to limit maturity associated differences in size and athleticism, have been encouraging. Research in elite, male football has shown that bio-banded training emphasises technical and tactical application rather than physical qualities and may benefit both early and late maturing players. In maturity restricted groups, early maturers are unable to rely on their physical advantages whilst late maturers, in contrast, are better able to express their physical qualities as well as their technical and tactical skills (Cumming, Brown et al., 2017). Due to the apparent benefits maturity-restricted grouping provides, one would assume that maturity-associated variance in athleticism would be observed. However, despite the expectations that placing children in bio-banded groups rather than age groups would restrict the variation in physical aptitude, the results observed in the current study somewhat support those recently established by Johnson et al., (Johnson et al., 2019). Johnson et al., (Johnson et al., 2019) demonstrated that bio-banding elite, male footballers significantly reduced variation in some, but not all, measured attributes. Specifically, variation was reduced in maturation, height, mass and momentum but not in speed performance.

The present study has shown that, whilst there was a tendency for a reduced variance in some physical qualities upon bio-banding the boys and girls, few statistically significant differences were observed, with the exception of female momentum performance. It is possible that bio-banding may have a greater impact on restricting variance in fitness performance in elite athletes (Johnson et al., 2020; Towlson et al., 2021). There are many contributing factors to individual variation in fitness performance, including genetics, training history, coaching experiences, technique and body weight (Malina, Bouchard and Bar-Or, 2004). A sample of school children are likely to be a more heterogenous cohort with regards to their fitness, and the factors described above, than elite athletes. Elite athletes are usually pre-selected into a sport for their talent and physical aptitude and likely a more homogenous cohort than groups of school children (Pearson, Naughton and Torode, 2006). It is, therefore, possible that there is a greater variation in fitness and contributing factors in the school children, compared to elite athletes, resulting in bio-banding strategies having less of an impact. Another contributing factor to the lack of statistically significant reduction in fitness variance in the school children could be the motivation of the children to perform the fitness tests. Rowland (Rowland, 1995) has suggested that fitness testing is “demeaning, embarrassing and uncomfortable”, whilst peer acceptance is a critical reward-seeking behaviour in adolescents (Barrett, 1996). Therefore, with a lack of an external goal for the schoolchildren compared to elite athletes when performing the testing, i.e., no implications for talent identification/selection, questions could be asked over the motivation of the schoolchildren and, therefore, the effort levels applied during fitness testing. Another difference between normal school children and elite athletes is the likely familiarisation of test completion. Fitness testing is commonplace in elite sport (Pion et al., 2014) and performance in fitness tests improves with familiarisation of test (Gumieniak, Gledhill, and Jamnik., 2018). It is likely that for most of the school children it may have been the first time they will have completed the tests, and although pre-testing practise was performed, this lack of familiarisation may have blunted the influence of bio-banding. Thus, effort levels, motivational factors and test familiarisation may have a greater impact than maturity groupings in the school children.

8.5.1 Practical Implications

Given the impact biological maturation and relative age can have on fitness (Malina, Bouchard and Bar-Or, 2004; Carling et al., 2009; Nakata et al., 2017), psychosocial factors (Davison et al., 2007; Gibbs, Jarvis and Dufur, 2012) and athlete selection (Malina et al., 2015), it is an important concept to understand when working with youth populations in both schools and athletic development programmes. Bio-banding is a fairly new concept and thus far only studies using elite, athletic cohorts have been carried out (Cumming, Searle et al., 2018; Cumming, Brown, et al., 2019; Malina et al., 2019; Johnson et al., 2020; Towlson et al., 2021). The present study provides novel findings on how bio-banding could be used as a strategy to reduce the variation in body size and some physical qualities in male and female school children.

Bio-banding of school children could provide a more individual approach to physical development due to the developmentally sensitive nature of bio-banding individuals. Teachers and practitioners may consider using bio-banding to create a more physically equal environment in lessons or training sessions. This could provide individuals with opportunities to develop other skills and attributes, such as psychosocial qualities, and also offers a more varied developmental stimulus (Cumming, Brown, et al., 2017). For example, teachers and coaches could use bio-banding to enhance opportunities for late maturers to adopt leadership positions, or early maturers to enhance their team-working skills. Physical activity levels reduce during adolescence (Allison et al., 2007) and whilst there are many factors contributing to this decline; self-esteem, perception of body image and physical self-concept are all contributing factors during the adolescent period (Cumming et al., 2012). Implementing a bio-banded strategy within P.E. lessons at school provides an opportunity for individuals more closely matched in their anthropometrics and physique to participate together. This may subsequently increase the enjoyment and effort exerted by individuals and ultimately, have a positive impact on physical activity levels and fitness.

Bio-banding will also allow teachers and practitioners to educate children on the developmental changes taking place during adolescence and the impact of this on body size, shape and fitness. An increased understanding of the changes that take place during adolescence may enhance one's positive perception of these changes. Earlier maturation is associated with lower perceptions of body attractiveness and physical self-worth, and, in turn, reduced participation in physical activity (Cumming et al., 2020). Improving the understanding youth, and teachers alike, have of the developmental changes that take place during adolescence, and combining this with a practical tool such as bio-banding, could improve physical self-concept and physical activity levels in children and adolescents.

In addition, bio-banded strategies could be used in elite sport alongside the previously discussed developmental performance curves, to promote a more varied developmental environment and to create a training environment centred around the individual athlete. Bio-banding offers a solution to the maturity-associated selection biases that exist in many sports (Malina et al., 2015). It will create a more homogenous physical and anthropometric playing environment for coaches to assess the technical and tactical skills of the athletes more fairly, which, in turn, should help reduce (sub)conscious selection biases based on the transient maturity-associated physical and anthropometrical advantages as often observed in early maturers (Malina et al., 2015). The incorporation of bio-banded practises into training sessions will also create a more varied developmental environment for athletes and thus may be useful for talent development, in addition to talent identification (Malina et al., 2019). Maturity grouped sessions have the potential to promote the expression of technical, tactical and psychosocial qualities in a more varied manner (Cumming, Searle et al., 2018; Cumming, Brown, et al., 2019). The use of bio-banding in football matches has suggested more passes, touches and shots on goal were observed in comparison to age-group equivalent matches (Thomas et al., 2017). However, it should be noted, that bio-banding strategies are suggested in combination with, and not a replacement for, chronological age group training.

8.5.2 Limitations

Whilst this study has provided an understanding of how the variation in body size and fitness of normal school children varies when bio-banding children into maturity groups according to % PAS, the findings are specific to the tests of athletic fitness used in this study and cannot be generalised to other physical qualities. Although in the present study bio-banding did reduce differences in maturity across all groups and did reduce variation in some fitness qualities, future research could investigate changing the cut-off percentages of PAS maturity bandings. The few studies that have considered bio-banding individuals have used the maturity groups used in the present study (5% band width), these may, however, not be the most appropriate for the most effective bio-banding strategy. Different maturity groups may also be more suitable for each sex, given the variation in maturation between genders. Investigating different maturity groupings in a sex-specific manner would help practitioners better identify those bands that are most effective for reducing maturity associated variance in body size and physical fitness.

8.5.3 Conclusion

This study is the first to consider a bio-banding strategy in a normal, non-elite adolescent population. It has shown that restricting variance of maturity status resulted in a tendency for a reduced variance in fitness and anthropometric variables in boys and girls. Few statistically significant differences were however observed, particularly in the male adolescents. The greater influence of bio-banding on females than males may be the result of the greater impact of bio-banding on restricting variance in heights and weight in the females. Given no other studies have explored the use of bio-banding in a normative population, and with the positive findings of its use in elite sport, future research should continue evaluating bio-banding as a tool to enhance athletic development and engagement in activity in the paediatric population.

CHAPTER NINE

THESIS DISCUSSION

9.1 DISCUSSION

This primary purpose of this thesis was to explore the relationships among biological maturation, relative age and physical fitness in adolescent schoolchildren. The following chapter will discuss some of the critical factors considered when designing the methodology and carrying out the data collection processes. It will also discuss the results of the studies, and their potential applications in a real-world context (i.e., school system).

Methodology Considerations

Data collection took place across eleven secondary schools in the Southwest of England and, in total, 997 schoolchildren, aged 11 to 15 years, participated. Of this, there were 684 females and 313 males tested. Whilst the aim of the studies was to recruit as many schools, and so participants, as possible to increase the reliability and accuracy of the data, time and practical resource were the greatest barriers to collecting data. As discussed in Chapter Three, the administration required to organise data collection in schools is vast and time consuming. In addition, the availability of both the schools and the data collection assistants was also a challenge to the data collection processes. Priori power analysis using G Power was used to determine the minimal sample size needed for the regression and correlational analysis. It was determined that the minimal sample size was 85 and 67 for the regressions and correlations, respectively. Both the total male (n = 212) and female (n = 418) cohorts used in the study analysis were notably greater than the minimal sample size for required for significance and thus, it can be argued that the current sample provides a substantial meaningful population from which to analyse and derive meaning from the research questions.

The method of maturity assessment used in the studies throughout this thesis was the Khamis-Roche method for determining percentage of predicted adult stature. Although this method may not be as accurate as the “gold standard” method of measurement, skeletal age assessment (Baxter-Jones, Eisenmann and Sherar, 2005), it was chosen because of its non-invasive and practical nature. As a method, it is comparatively easy to apply and provides a wealth of information, including insight as to maturity status, timing, and future growth status of an individual (PAS, current % PAS, BA, maturity status (early, on-time, or late), growth spurt status (pre-PHV, mid-PHV, post-PHV)) (Malina, Bouchard and Bar-Or, 2004). This method can also be easily integrated within existing programmes that measure height and weight of youth in school contexts.

The non-invasive nature of assessment, ease of application and breadth of information obtained provide good justification for the use of percentage of predicted adult stature as an index of maturity in this thesis. There are, however, several limitations with using this method. In total, 313 and 684 male and female schoolchildren, respectively, were involved in the data collection process of the studies, however of these, only 212 and 418 males and females, respectively, satisfied all aspects of data collection. One of the main barriers to achieving a full data set for a participant was obtaining the biological parental heights needed for Khamis-Roche maturity assessment. This is a hurdle teachers and coaches must overcome to complete Khamis-Roche assessments of maturity. A method commonly employed to reduce this issue is the self-reporting of heights (Epstein et al., 1995). Schools could ask parents to self-report their height when registering their child with the school. This information could be requested on the basis that it will allow the school to provide training programmes and competition that is most developmentally appropriate for each child. However, the self-reporting of heights raises an additional challenge of accuracy of measurement. The potential for inaccuracy of data through self-reporting is often highlighted as a methodological issue for researchers and coaches to contend with (Kerlinger., 1986; Bowman and DeLucia., 1992). Self-reported parents' heights are often overestimated and were therefore adjusted for overestimation in the studies using equations established by Epstein et al., (Epstein et al., 1995). An additional challenge that arises from needing parent's heights exists for participants not in contact with one, or both, of their biological parents (i.e., those that are adopted). For these participants an accurate assessment of biological maturation using the Khamis-Roche method is not possible (Salter et al., 2021). Where this occurred in this thesis, participants participated in the testing session, however their data was not included for analysis.

An alternative non-invasive method of maturity assessment commonly used in sport is the Mirwald Maturity Offset method. This method can predict age at PHV and Mirwald et al., (Mirwald et al., 2002) initially claimed to predict this to within 1-year 95% of the time for individuals between 10 and 18 years. Mallina and Koziel (Malina and Koziel., 2014), however, identified systematic discrepancy between the predicted and observed PHV. Specifically, the timing of PHV is underestimated at younger ages and overestimated at older ages, and this error is exaggerated in early- and later-maturing individuals. These limitations may be particularly problematic when considering athletes on an individual basis. A more recent iteration of the Maturity Offset equation has been proposed (Fransen et al., 2018), however concerns over accuracy of PHV estimation remain (Nevill and Burton., 2018; Teunissen et al., 2020). For example, an error of 2 to 3 years in predicted age at PHV might result in an athlete being misclassified as pre-, circum- or post-PHV.

The Khamis-Roche method, in comparison to the variations of the MO method, reports predicted adult stature to within 2.2 and 5.3cm for the 50th and 90th percentile, respectively. Although this error increases to 2.8-7.2 cm for age groups around the growth spurt (Malina et al., 2019). The Khamis-Roche method has shown good accuracy and use in many sports, including American football (Malina et al., 2007), soccer (Malina et al., 2012), roller hockey (Coelho-e-Silva et al., 2010) and tennis (Myburgh et al., 2019). Additionally, Parr et al., (Parr et al., 2020), upon recent comparison of the Mirwald Maturity Offset and Khamis-Roche method, established timing of PHV, from longitudinal analysis, was predicted accurately 96% of the time using the Khamis-Roche method and 61% of the time using the Maturity Offset method. Despite the limitations of the Khamis-Roche method of maturity assessment described above, existing research supports the choice of its use over the alternative non-invasive Mirwald Maturity Offset method (Teunissen et al., 2020; Parr et al., 2020; Salter et al., 2021).

Fitness Testing in Schools

Schools are important stakeholders in the health and fitness of children (Ortega et al., 2008). Children spend large periods of their time at school, participate in weekly PE lessons and there are multiple opportunities for extra-curricular sporting activity. Whereas fitness testing is a common component in sport and athletic development programmes, concerns have been raised over whether fitness testing is a suitable tool in schools to increase engagement and enjoyment of physical activity. Those that argue for fitness testing in schools propose that it promotes a healthy lifestyle, motivates young people to improve their fitness and can enhance goal-setting and self-monitoring skills (Whitehead, Pemberton and Corbin, 1990; Pate, 1994; Wiersma and Sherman., 2008). Advocates emphasise the need to use it as an educational and awareness tool and suggest that all children have the potential to meet basic fitness standards (Silverman, Keating and Phillips, 2008). In contrast, others question the role testing can play in demotivating and negatively influencing young people's attitudes towards fitness (Rowland., 1995; Corbin, Pangrazi and Welk, 1995; Keating, 2003), particularly those children that are overweight or have a lower competency than others (Chen, Harris and Cale, 2004). Where the focus of fitness testing is solely on comparisons of individuals, and in combination with the negativity that surrounds a poor fitness score, it is easy to see why there are many critics (Rowland., 1995; Naughton, Carlson and Greene, 2006). The feasibility of conducting fitness testing in schools is also often cited as a challenge, primarily due to methodological barriers (Keating, 2003; Silverman, Keating and Phillips, 2008). This thesis, however, enhances support that fitness testing can readily be carried out in schools, showing that appropriate athletic tests can be operationalised with minimal equipment and cost.

A key consideration concerning fitness testing in schools is, however, the motivation and effort levels of the participants to perform the tests (Wiersma and Sherman., 2008). Assessors will have little worry about the motivation of athletes in sports clubs performing testing to the best of their ability because of competition for selection. However, in a school environment, this motivational factor does not exist, and every individual will need to be internally motivated to perform each test to their maximum effort. This could lead to issues with the reliability and accuracy of testing results. This issue was minimised in the present studies by the testing instructors motivating every individual to give maximal effort levels whilst they were performing the test. Additionally, an environment was encouraged whereby the schoolchildren themselves were motivating their peers.

Unlike assessments in Maths or English, physical fitness testing has the potential to be more emotionally and physically exhausting in a public manner, in front of peers. Adolescents may fear peer judgement and Rowland (Rowland, 1995) has suggested that fitness testing is “demeaning, embarrassing and uncomfortable”. There is, therefore, a responsibility to conduct fitness testing in a sensitive and considerate manner. In large group settings, such as in the present studies, the confidentiality and sensitivity of individual measurements can be a challenge to maintain, and this was a primary consideration during data collection processes to enhance engagement in testing. Communication with each school prior to attending the school for data collection ensured the testing session could be conducted appropriately for all involved. For example, height and weight measurements were taken in a confidential manner through agreement of best location so other children could not view the scales. As previously noted, it is important that practitioners measuring both size and fitness in schools do so for the appropriate reasons and for the primary benefit of the child.

For health promotion purposes some people have argued that alternative strategies such as measuring the amount of physical activity participated in, understanding the barriers to physical activity and the facilities and resources available and the support and environment that surrounds the individuals may be a more impactful strategy than fitness testing (Naughton, Carlson and Greene, 2006). However, fitness testing the normal population has benefits for use in both schools and elite sport. Normative benchmark standards for fitness are regularly used globally to understand the fitness levels and health of a nation (Ruiz et al., 2010; Tremblay et al., 2010; Pate et al., 2013). Strong support for fitness testing in schools comes from those who want to observe secular trends in fitness for the benefit of public health (Pate., 1991; Fuhner et al., 2021). Physical activity levels in adolescence decline from childhood (Allison et al., 2007) and a large percentage of youth do not undertake the recommended amount of physical activity (Griffiths et al., 2013). Physical fitness levels of youth are also declining (Tomkinson et al., 2003) and obesity levels are rising (Bürgi et al., 2011). Tracking of adolescent fitness performance in a developmentally aligned manner has potential to help understand where, and how, to address the problems we have with the fitness of a nation. The present studies add to the contributions in this field, providing contemporary data in fitness tests that assess physical qualities that are important athletic fitness (Bergeron et al., 2015).

The discussion above highlights evidence to both support and disagree with the role fitness testing can play in schools. Those in support of fitness testing in schools highlight the education it can provide in a comparable manner to literacy and mathematical tests. Learning can take place from carrying out the tests, from the results of the tests and from the setting of individual goals (Silverman, Keating and Phillips, 2008). Critically, if fitness testing results are to contribute to the health and fitness education of children it is important to visualise and use the data effectively. The solutions provided in this thesis present opportunities to create more individual and developmentally aligned methods of presenting and sharing fitness testing results to enhance the connection and effectiveness of the children to their fitness. Additionally, fitness testing can develop self-evaluation and problem-solving skills to enhance engagement and connection with a sustainable, physically active lifestyle (Naughton, Carlson and Greene, 2006). Clearly, creating a positive and supportive environment whilst conducting any form of fitness assessment or monitoring will enhance the effectiveness and enjoyment of it (Wiersma and Sherman., 2008). This thesis has emphasised the need to consider biological maturation in relation to fitness performance to create a more accurate and fair means of understanding individual fitness performance and has shown that carrying out fitness testing in schools is effective.

Gender Differences

For the large part, the male and female cohorts were analysed and discussed separately within this thesis (with exception of Chapter Eight) due to the gender differences associated with biological maturation (Malina, Bouchard and Bar-Or, 2004). However, comparison of data revealed key gender differences. In all tests of fitness, except balance, the boys outperformed the girls across all age groups. The greatest performance differences were in the momentum and strength tests. The gender differences were greatest across all tests of fitness (except balance) from ages 13 and 14 onwards. It is well understood that from the period of puberty adolescent boys outperform girls in most tests of physical fitness (Malina, Bouchard and Bar-Or, 2004) and the findings in this thesis support this. At puberty, males experience a testosterone underpinned neuromuscular spurt which leads to improvements in strength, speed, agility and power (Malina, Bouchard and Bar-Or, 2004; Goto, Morris and Nevill, 2019). Female adolescent fitness, in contrast, usually plateaus around puberty and the period of PWV where fat mass increases occur (Viru et al., 1999; Malina, Bouchard and Bar-Or, 2004). These sex-specific changes in fitness performance during adolescence are also observed in this thesis; Chapter Four showed male fitness to improve sequentially with age; whilst Chapter Five demonstrated female fitness to improve at the younger age groups and then plateau at around 14 years of age in many of the tests. Further support from this thesis for a more continued performance improvement in males compared to females can be seen in the pairwise comparisons performed in Chapters Four and Five; the largest consecutive age group differences in fitness performance in the females occurred between ages 11 to 12 years in the majority of tests; whereas in the male cohort, the largest consecutive age group difference for more than half of the fitness tests occurred later, from age 12 onwards. The curves of the performance trajectories created in Chapter Seven also highlight a plateau in female fitness performance in the age range tested.

The observation that females outperformed males in the balance test across all ages, except age 14 years, is interesting and supports existing research (Cratty, 1979; Mickle, Munro and Steele, 2011). There are several factors that may lead to a better balance performance of female adolescents than males. At all ages, except for age 12 years where average height was approximately the same, the average height of the male participants was greater than that of the females. This greater height of the males results in a heightened COM and an increased COM height can negatively influence postural sway (Ojie, Saatchi and Saatchi., 2020) and the muscular control of lower limb joints (Quatman et al., 2005). These two factors may negatively imfluence balance perofrmance. In addition, 'athletic awkwardness' has more commonly been disucssed to occur in males than females (Ryan et al., 2018). Athletic awkwardness, that is, reduced motor control and coordination, may also negatively influence balance performance in the boys (Quatman-Yates et al., 2012; Ryan et al., 2018). Lastly, the earlier maturation of fermales visual, vestibular and proprioceptive systems compared to males may also contribute to a superiour performance systems (Cratty, 1979; Mickle, Munro and Steele, 2011).

This thesis revealed gender differences in the relationship between biological maturation and physical fitness. In both the male and female cohorts, biological maturation was significantly correlated with several physical qualities. Perhaps surprisingly, in all the tests of fitness, except upper body strength and balance, a stronger correlation was observed between biological maturation and fitness performance in the females than males, although not all of these correlations were statistically significant. In addition, biological maturation was significantly and positively correlated with upper body strength, momentum and agility and significantly but negatively correlated with speed in power in the females. Whereas in the male cohort, maturation was significantly and positively correlated with upper body strength and momentum only. These findings are, perhaps, surprising, however, there is a lack of research assessing these athletic fitness tests in normal children using the Khamis-Roche z-score as a measure of maturity and so existing, comparable evidence, is minimal.

The surprisingly stronger relationship between maturation and fitness in females than males observed in this thesis may be the result of the progress female sport has made in recent years (Fink, 2015). Much of the existing research that compares the influence of maturation on fitness, and the gender differences within this, have likely taken place at a time where investment and intense training was less common in females. This advancement in female sport, and the athletic capabilities of the athletes with this, may have led to an increased variance in female fitness which may allow for maturation to make a bigger impact on performance. Although my thesis evaluated fitness performance of normal schoolchildren, this progress of female sport may have impacted the fitness of the young, female population in general and may explain why greater relationships between maturity and fitness are now being observed. In line with this reasoning, the bio-banding strategy employed in Chapter Eight demonstrated a greater impact on reducing the variation in fitness performance and anthropometrics in the girls than it did in the boys. When maturity was restricted, reductions in variance were observed in height, weight and momentum in some maturity groups in the females, however, restricting maturity in the bio-banded groups had no impact on reducing the variance for any tests of fitness, and very little on the anthropometric variables, in the males. In general, although not statistically significant, there was a trend for bio-banding in the female cohort to reduce variance in fitness more so than in males. This again may be considered surprising, however, there is no existing research analysing the impact of bio-banding in females, and very little has been conducted in males (Johnson et al., 2019; Towlson et al, 2021). The gender differences observed may be the result of maturity-associated anthropometric changes in females. Restricting maturity had a greater impact on restricting variance in both height and weight in females compared to males. This may contribute to the greater impact of bio-banding on female fitness performance.

Operationalising Knowledge From The Thesis – School Sport

The overall findings from this thesis have important implications for teachers and practitioners working in school and community-based sport. There are three key strategies that could be implemented to operationalise the findings from this thesis, namely, 1) teachers and practitioners could create their own performance trajectories from their own cohort of children, creating age-based standards for their own choice of tests; 2) external strength and conditioning systems could be used to create the trajectories for use. The benefit of this is that these systems may build up vast amounts of data from many schools which would increase the reliability and accuracy of data; 3) following assessment of maturation of the children, either through use of the Khamis-Roche method utilised in this thesis or an alternative non-invasive method, such as the easy plotting of growth curves, the bio-banding strategy utilised in Chapter Eight can easily be implemented in schools.

Implementation of one of the aforementioned strategies would benefit schools in a number of ways. Firstly, it would allow for a better understanding of individual adolescent development and individual fitness performance. This would help create a person-centred approach to fitness development in school sport. The plotting of individual performance on fitness performance trajectories would allow for a better understanding of individual strengths and weaknesses to aid fitness development. This will allow for determination of whether an individual is performing better than, or worse than, where they would be expected to be. As described in previous chapters, maturation can mask true athletic potential (Malina et al., 2015), plotting performance on trajectories of age-based standards allows teachers to understand an individual's strengths/weaknesses and where maturation may be masking, either in a positive or negative way, true performance. Additionally, the monitoring of performance on trajectories, will help understand the efficacy of fitness programmes and whether they are having a positive influence on fitness over time.

Secondly, the findings and strategies established in this thesis could be used to help develop psychological traits by enhancing the understanding of true physical fitness. The results in this thesis demonstrated that, for both the male and female cohorts, evaluations of fitness performance varied relative to biological and chronological age. Namely, in both sexes, those individuals who matured in advance of their peers performed better in certain fitness tests (upper body strength, momentum, balance and maximal speed) when considered according to their CA compared to their BA. In contrast, those individuals who matured later than their peers performed better in the same tests when considered relative to BA rather than CA. Teachers could use this knowledge to enhance the understanding a child has of their own development and true fitness performance. This may benefit late maturing boys and girls, in particular, increasing their confidence and physical self-concept (Simmons and Blyth, 1987) by educating them that their inferior performance in fitness tests compared to their peers may be the result of individual differences in biological maturation, rather than a poorer functional capacity.

Importantly, the creation of performance trajectories that account for developmental differences could be used to increase the awareness of normal developmental changes of females in particular, during adolescence. Crucially, this could challenge the negative perceptions girls have that their fitness declines during this period (Cumming et al., 2011), showing them, and those that work with them, that biological development should be considered to reflect natural fitness changes more accurately, and that their fitness does not decline during this period. Physical self-concept is an important determinant of physical activity participation levels (Sabiston and Crocker, 2008) and it is well known that physical activity levels decline during the adolescent years (Finne et al., 2011). The decrease in physical activity participation during the teenage years in females particularly is clearly an area of concern for NGB's and the government; Sport England's government backed 'This Girl Can' campaign was borne out of the fall in activity levels during adolescence and aimed to encourage girls to stay in sport through their entire lifespan. It would be interesting to further explore the use of promoting the positive fitness changes in female adolescents through fitness testing and the creation of trajectories on the impact on the perceptions females have of their own fitness, and subsequently whether this positively influences motivation/drop out of sport.

Thirdly, employing a bio-banding strategy in school sport, that is grouping children in maturity groups for training and competition, may help develop technical, tactical and psychosocial characteristics more so than they would otherwise develop in the traditional chronological age groups in schools. This is due to the potential for a greater restriction of body size and physical qualities through bio-banding (Cumming, Brown et al., 2017; Bradley et al., 2019; Abbott et la., 2019). Although limited significant results were observed when maturation was restricted in the current study, this is the first study to evaluate bio-banding in a non-elite, youth population, so further research is needed to improve understanding of a possible use in school sport. The technical, tactical and psychosocial benefits that initial research on bio-banding in elite sport has shown were not evaluated in this thesis (Cumming, Brown et al., 2017; Bradley et al., 2019; Abbott et al., 2019). Future research should also consider these developmental areas to better understand the effectiveness of bio-banding in school sport.

Lastly, the findings from this thesis demonstrate the need to consider the physical fitness of adolescents in a developmentally adjusted manner to better understand the health and fitness of the nation. In a similar manner to Gillison et al., (Gillison et al.,

2017) who used biologically adjusted methods to determine the BMI of individuals more accurately, this thesis demonstrates that the reflection of adolescent fitness relative to BA rather than CA will more accurately reflect fitness.

Each of the strategies suggested above should be accompanied by education within schools and many scholars believe for the effective implementation of fitness testing in schools it is imperative to combine it with education (Cale and Harris., 2002; Silverman, Keating and Phillips., 2008). Additional resources could be created to enhance understanding of growth, maturation and development to improve children's understanding of the changes that take place. In addition, the main and interactive effects of maturation on adolescent fitness should be explained to children. This could help increase motivation to participate in sport, enhance engagement in one's own fitness development and may help form more sustainable, life-long positive habits (Ferkel et al., 2014).

Operationalising Knowledge From The Thesis – Elite Sport

The main purpose of this thesis was to enhance understanding of the influence of relative age and maturation upon athletic fitness tests of school children. Although the study itself was conducted in the context of schools, several of the key findings from this thesis have relevance for the processes of talent identification and development in sport.

The creation of performance trajectories allows for a more accurate and advanced evaluation of both current performance and future potential by accounting for the impact of biological maturation and is particularly useful for talent identification processes and sports selection programmes. As discussed in previous chapters, a selection bias exists in many male sports (Malina et al., 2015) and although not as consistently observed as in female sports, a maturity-associated selection bias also exists in some female sports (Erlandson et al., 2008; Myburgh et al., 2016). The advantages associated with earlier maturation are reflected in the results in Chapter Six and Seven; for early maturing boys and girls, when fitness scores were observed relative to an individual's CA rather than BA, performance was better. In contrast, later maturing individuals performed better when scores were considered relative to BA rather than CA. The findings from this thesis suggest that, during talent identification and selection processes, should a coach consider an athlete's physical performance only in relation to their chronological age, performance could be misinterpreted. A failure to consider the impact of biological maturation on fitness performance may contribute towards the selection bias towards early maturers in many sports (Malina et al., 2015) as well as early maturers having enhanced chances to progress through youth academy pathways and receive professional contracts (Cumming et al., 2017). Once selected, early maturers are also more likely to receive better coaching, enhanced sports science and medical support, greater competition opportunities and better training facilities (Vaeyens et al., 2006; Meylan et al., 2010; Whiteley, Johnson and Farooq, 2017). In addition, maturity status appears to influence coaches' perception of talent, with football coaches grading and evaluating early maturing males better than their peers (Hill et al., 2020). This suggests maturity-associated biases go beyond fitness onto the field of play. The present study highlights the importance of considering biological maturation and relative age in youth sport to enhance understanding of an athletes future athletic potential (Baxter-Jones, Eisenmann and Sherar, 2005) and to help reduce the selection biases towards early maturing athletes (Malina et al., 2015).

A lack of development measures for assessing physical fitness was highlighted as a concern in the BASES Expert Statement on Trainability During Childhood and Adolescence (Barker et al., 2014). Comparison to normative, biological age-adjusted data will give practitioners a better understanding of the athlete's strengths and weaknesses, and a better determination of the success of a training programme, establishing whether it has helped develop an individual above and beyond their normal development. In addition, were a sports team to create their own performance trajectories and plot individual performance scores on these, they have a method of establishing measurable differences between the CA percentile and the BA percentile, which subsequently helps to understand if the individual is on track, ahead of, or behind their peers (Myburgh et al., 2020). This will allow for more informed, individually developed physical development programmes (Ryan et al., 2018).

Research on the use of bio-banding within elite sport is growing, with studies exploring its use in athlete welfare (Albuquerque et al., 2016), talent identification (Cumming, Lloyd et al., 2017), physical development (Towlson et al., 2021) and development of technical, tactical and psychosocial characterisitcs (Cumming, Brown et al., 2017; Bradley et al., 2019; Abbott et al., 2019). To date, however, no research has explored bio-banding of a non-elite population of schoolchildren. The findings from this thesis add to the developing body of research in this field.

More developmentally sensitive measures of performance may also benefit young athletes themselves. Increased awareness of the athletic benefits associated with advanced maturity in males may reduce complacency amongst early maturers, ensuring they do not develop a false sense of their athletic competence and they continue working hard to develop technical, tactical, cognitive, and physical skills. Similarly, more developmentally aligned measures may reassure later maturing individuals that they are physically capable and may help explain why they are not performing as well as their more mature yet chronologically age-matched peers. Such an approach should ideally be accompanied by an educational programme for athletes and parents, increasing awareness and knowledge of the impact of growth and maturation in physical domains.

Recommendations for Future Research and Practise

This thesis has explored practical strategies to consider individual differences in growth, maturation and relative age for the evaluation and development of adolescent fitness, that have only, thus far, been considered in elite sport. Future research and practise should focus on developing these in school sport.

Bio-banding is a new concept and different findings were observed in the current study on schoolchildren, to existing research in elite athletes. Further research is required to better understand the potential use of bio-banding in school sport. Given the variation in body size and physique likely observed in individuals competing in school sport, presumably more so than in elite sport whereby individuals are selected for their optimal body shapes and functional capacities (Malina, 2015; Whiteley, Johnson and Farooq, 2017), it is possible bio-banding could be a useful tool for schools to reduce anthropometric variance and enhance technical, tactical and psychosocial attributes. Although in the present study bio-banding did reduce differences in maturity across all groups, this was not observed consistently across anthropometric and fitness variables. Future research could investigate changing the cut-off percentages of PAS maturity bandings and this could be considered differently for boys and girls. Investigating different maturity groupings in a sex-specific manner would help identify the maturity banding most suitable for reducing maturity associated variance in body size and physical fitness.

Petitpas et al., (Petitpas et al., 2004) suggests psychosocial growth is more likely to occur when young people are a) engaged in a desired activity within an appropriate environment, b) surrounded by a positive group, c) learn and acquire skills, and d) benefit from processes of evaluation. In addition, creating a psychologically safe environment can allow a positive sports experience to take place where individuals are willing to take risks and learn from their mistakes (Danish et al., 1993) and it is argued that the type of learning environment created, and the experiences of the individuals, are more important than playing the sport itself for building self-esteem, persistence and developing skill (Roberts, Treasure and Kavussanu, 1997; Eccles, Wigfield and Schiefele, 1998; Smith and Smoll, 2002). Future research could explore the use of the two practical strategies explored in this thesis, bio-banding and performance trajectories considering individual development, to create a more positive, learning environment in schools to foster psychosocial, as well as physical, development. Additionally, as discussed throughout this thesis, this may also benefit adolescent females by creating a more positive environment where they can feel positive about their fitness which may subsequently increase girls' engagement in physical activity. The impact of this could be evaluated through use of questionnaires or interviews (Whitehead, 1995; Cumming et al., 2020).

Future research would benefit from using longitudinal data to create a more accurate understanding of growth, maturation and adolescent fitness. There may be challenges with achieving this in schools, however it would further the understanding of how fitness performance changes during adolescence. As well as this, future studies could evaluate a greater range of fitness tests to create a complete testing battery of developmental standards for the adolescent population.

From an applied perspective, the future direction of the knowledge gained from this thesis should firstly involve implementing the strategies suggested in this thesis to create a more developmentally aligned, individual and positive fitness development environment. As highlighted in this thesis, it is important to consider adolescent fitness in a developmentally sensitive manner. Therefore, any evaluations of fitness that take place, whether in school sport or PE classes, or talent identification in elite sport, should include consideration for biological maturation. In combination with this, educational resources could be created to further the understanding of the young people, and practitioners, alike, on key areas of growth, maturation, relative age and adolescent fitness to enhance motivation and engagement.

CHAPTER TEN

THESIS CONCLUSION

10.1 CONCLUSION

This thesis has described the age-related changes in fitness that take place in male and female youth across a series of athletic tests of fitness. This thesis is also the first to assess the main and interactive effects of relative age and biological maturation upon the performance of a general male and female adolescent population in athletic fitness tests and has provided novel research into the performance of females in tests of momentum and balance. This thesis is also the first to create developmentally aligned age-based standards and protocols to account for individual differences in biological maturation when evaluating physical fitness in the general population. Finally, it is the first research to explore the use of a bio-banding strategy to restrict variance in maturation, body size and fitness performance in a non-elite population. The findings presented in this thesis provide valuable insight for those individuals (i.e., coaches, practitioners, educators) working with youth in elite sport and in schools, alike.

As expected, age-associated changes were observed in the fitness tests when applied to the general population. This is consistent with findings for more generic fitness tests in this population (Little, Day and Steinke, 1997; Viru et al., 1999; Malina, Bouchard and Bar-Or, 2004). It is important for practitioners to recognise the marked improvement in fitness which occurs through age groups in the male schoolchildren. This could have important implications for physical development as well as success in sport during the adolescent period. Although not as marked as in males, female fitness did generally increase with age in the fitness tests, demonstrating that, contrary to girls' perceptions, fitness does improve during these stages of development. The results presented in this thesis could be used to counter the negative perceptions of a decline in fitness in females during the adolescent period (Cumming et al., 2011). Incorporating fitness testing within PE classes could help girls understand they are not getting less fit, which could act as a powerful education tool to enhance perceived ability and may help reduce teenage dropout of physical activity (Finne et al., 2011).

The contemporary, age-associated physical fitness data created in this thesis could provide schoolteachers with a more accurate means of measuring fitness in schoolchildren. Whilst the fitness tests used in this thesis were chosen for their relevance to sport, developing musculoskeletal fitness and fundamental athletic competency whilst young has been shown to increase the motivation to exercise (Wang and Biddle, 2007), enhance well-being (Ryan and Deci, 2000), reduce fat mass and obesity levels (Ortega et al., 2008) and improve health as an adult (Pinedo-Villanueva et al., 2019). Rather than relying on data obtained from elite populations, where results are likely superior due to the training and fitness regimes elite athletes are exposed to, schoolteachers and community educators can use data developed from the normative sample used here to provide a more accurate and truer reflection of paediatric fitness.

Contrary to ley opinion, this thesis observed that, in both adolescent males and females, relative age and biological maturation acted independently from one and another on fitness test performance. Whilst the results presented here will not be surprising to those with expertise in the field, at times the two constructs are often talked about as the same thing in academic research and applied practice. The findings from this thesis counter this narrative and highlight the need to consider them as separate constructs, providing evidence that both must be considered independently when working with youth athletes.

The independent nature of relative age and biological maturity was also illustrated in their respective associations with physical fitness. Biological maturation was significantly associated with several fitness variables in female adolescents, namely; advanced biological maturation was associated with superior performance in tests of upper body strength and momentum whereas delayed maturation was associated with better performance in tests of power and speed. Relative age showed a significant but small association with upper body strength. An association was observed between maturation and performance in upper body strength, momentum and balance tests in the male cohort; specifically, early maturing males demonstrated superior performance in tests of upper body strength and momentum whereas late maturing males performed better in the balance test. Relative age was unrelated to fitness performance, however, once whole age differences were controlled for, relative age was positively associated with maximal speed and inversely associated with balance performance. That is, once whole age differences were controlled for, relatively older males displayed a faster maximal sprint speed but a worse balance performance than those individuals relatively younger. Importantly, no interactive effects of relative age and maturation upon fitness were observed, with the exception of upper body strength in males.

The understanding that relative age and biological maturation are separate constructs, acting independently on fitness, is critical to understand youth sport. It is also important for talent identification and confirmation. Many practitioners and coaches refer to these processes as being one and the same. This can lead to misinformed athlete selection and investment decisions, both in elite and non-elite sport. For example, within the Football Association, a lack of understanding of how biological maturation and/or relative age may, or may not, impact athletic performance could lead to leniency being given to a player because they are 'less mature', 'less well developed' or 'younger'. These terms are often used interchangeably to describe a player who is either smaller in size and stature and so is assumed to be less mature, or who is relatively younger and so is also assumed to be less mature. The findings from this thesis highlight the importance of monitoring biological maturation and correctly and appropriately using the information within youth talent pathways.

One of the key strategies that practitioners can implement as a result of the studies presented in this thesis is the creation of performance trajectories of age-based standards to better understand individual fitness performance relative to both BA and CA. Results demonstrated that, for both the male and female cohorts, evaluations of fitness performance varied relative to biological and chronological age. Namely, in both sexes, those individuals who matured in advance of their peers performed better in certain fitness tests (upper body strength, momentum, balance and maximal speed) when considered according to their CA compared to their BA. In contrast, those individuals who matured later than their peers performed better in the same tests when considered relative to BA rather than CA. These findings highlight the importance to consider individual differences when evaluating the physical fitness performance of young people. In addition, the performance trajectories could be used to educate adolescents, in particular late maturing males and females, that their inferior performance in fitness tests compared to their peers may be the result of individual differences in biological maturation, rather than a poorer functional capacity.

Bio-banding is a reasonably new strategy being explored in research and elite sport, and is the process of restricting the maturation of individuals by grouping them by maturity status, rather than CA. Through this it aims to reduce the variance in body size and/or athleticism to create greater opportunities for the expression of technical, tactical and psychosocial qualities in sport (Cumming, Lloyd et al., 2017). Despite promising findings from recent research demonstrating bio-banding restricting variance in physical fitness in elite athletes (Johnson et al., 2019; Towlson et al., 2021), findings from this thesis observed that, whilst there was a tendency for bio-banding to reduce variance in fitness in the boys and girls, few statistically significant differences were seen. The bio-banding strategy, however, had a greater impact in the females than males, with significant reductions in variance observed when maturity was restricted in height, weight, momentum and 10m speed in some maturity groups. The greater influence of bio-banding on females than males may be the result of the greater impact of bio-banding on restricting variance in heights and weight in the females. This suggests a possible beneficial role bio-banding could play in school sport, whereby restricting the variance in maturity, height and weight in females, it may allow for the greater opportunities and expression of technical, tactical, and psychosocial attributes. Research in elite athletes has shown some success in adopting a bio-banding strategy for greater development of technical and tactical metrics of the sport, as well as psychosocial characteristics (Cumming, Brown et al., 2017; Bradley et al., 2019; Abbott et la., 2019), factors which were not explored in this thesis but would be worth researching in normal schoolchildren. No other studies have investigated bio-banding in female populations, either elite or non-elite, or in male schoolchildren. Clearly, further research is required.

It is the hope that the findings from this thesis help enhance the knowledge of teachers and practitioners working in school and elite sport. Furthermore, the practical strategies explored in this thesis, both the creation of trajectories of age-based standards and bio-banding, provide practical solutions to use in adolescent fitness development. They allow for improved evaluation and development of fitness using a developmentally aligned and individual approach.

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From: Emma Dowden <E.Dowden@bath.ac.uk>
Sent: 11 February 2016 14:38
To: Corinne Yorston <C.Yorston@bath.ac.uk>
Cc: Sean Cumming <S.Cumming@bath.ac.uk>
Subject: REACH EP 15/16 138

Dear Corinne,

Title: The assessment of the physical fitness, physical activity levels and biological maturation of school children
Reach Reference number EP 15/16 138 (amendment to REACH EP 14/15 117)

The above application amendment was reviewed by the Research Ethics Approval Committee for Health (REACH) under Chair's Action on 5th February 2016 and noted in the REACH meeting held on the 10th February 2016

On behalf of the Committee, I am pleased to confirm that the Committee would be happy to provide a favourable ethical opinion of the above research, (on the basis described in the application form and supporting documentation).

Please inform REACH about any substantial amendments made to the study if they have ethical implications.

Kind Regards,

Emma

Emma Dowden, Research Programme Coordinator

University of Bath
Department for Health
University of Bath, Bath BA2 7AY, United Kingdom | Telephone: +44 (0)1225 383891|
Email: e.dowden @bath.ac.uk

Full title of study: The assessment of physical fitness, physical activity level and biological maturation of school children.

REACH reference number: EP 14/15 117

- The Committee requested confirmation that the Researchers going into the schools will have checked the requirement for a DBS check with the University safeguarding policy:

- The University child protection and safeguarding policy has been studied and I will make sure I am consistent with the procedures and guidelines set out in the policy whilst undertaking my research. All measurements will be carried out by myself and a team of trained sports scientists, all of whom will have successfully completed a disclosure and barring service check.

- Given the various physical tests that are performed as part of the study, the Committee requested assurance that Researchers will be aware of school procedures for minor injuries.

- Prior to carrying out any research within any of the schools, knowledge of the schools individual minor injury procedures will be obtained and taken into full consideration during the study.

- It was noted that material needs to be updated to refer to the Department for Health throughout, rather than 'Department of Health'.

The material has all been updated to refer to the Department for Health

ANNEX ONE ***Department for Health***
Research Ethics Approval Committee for Health

Checklist for all researchers

The Department for Health requires all members of staff and students who are planning research projects to consider the ethical implications of the work which they undertake. This is important in all research projects but is ***essential*** in those projects which involve human participants.

The Department has agreed on an ethical review process which has a fast track for those projects which either do not have ethical implications and thus do not require full scrutiny, or where scrutiny will be given by another body (in particular an NHS Research Ethics Committee [REC]). Projects that fall outside of these categories will need to make a full submission to the Research Ethics Approval Committee for Health.

Name	Corinne Yorston
Project Title	The assessment of the physical fitness, physical activity level and biological maturation of school children.

PART A: Determining the nature of your research and the route for ethical approval you need to follow (please tick the route you will follow for your ethical approval):

My research project has been successful in receiving external funding by the ESRC
(full consideration is required by the SSREC. Further details can be obtained from:
http://www.bath.ac.uk/internal/research/ssrec/. For audit purposes a copy of the SSREC application
& decision letter as well as this form and EIRA1 will need to be returned to the Department
for Health Department Co-ordinator) (Annex 3) ☐

My proposal is currently at the stage of application for funding (tick box)
Please complete annex 1 & 2 for REACH audit purposes. Further approval may be required once funding is approved (please refer to relevant statement below) ☐

My research project does not involve the use of human subjects or only involves secondary
data analysis **(full consideration is not required, complete the checklist and the implications form for audit purposes and return to the Department Co-ordinator; Principal investigator,second reader and researcher to sign and return to the Department**
Co-ordinator (Annex 2 or 3)) ☐

My research meets the requirements for submission to an NHS REC (e.g. Involves human
subjects, requires access to NHS patients or includes adults lacking capacity)
(full consideration is required by the appropriate NHS REC; complete the checklist
and ethical implications form for audit purposes and return to the Department
Co-ordinator (Annex 2 or 3) together with the evidence of NRES approval) ☐
(Where NHS REC approval is required, please provide details of who is sponsoring this project)

The University is acting as a sponsor for my research. ☐

My research has received approval from another department within the University of Bath
or another UK University ethics committee. Complete the checklist, together with Annex 2 or
3 and submit with evidence of the institutions approval ☐

My research involves human subjects and does not take place in an NHS context
(full consideration is required by REACH (Annex 2 or 3 and Annex 4)) ✔

My research involves human subjects and takes place outside of the UK, and for which particular consideration needs to be given
(full consideration is required by REACH - Annex 2 or 3 and Annex 4)) ☐

My research involves working with children and/or vulnerable adults
(a DBS check may also be required in addition to the above) ✔

My research involves the collection and storage (not destroyed on day of collection) of human tissue. (Full consideration from an NRES approved committee is required in ☐
addition to the above)

Where NHS REC approval is required, please provide details of who is sponsoring this project ☐

ANNEX TWO

Department for Health
Research Ethics Approval Committee for Health

ETHICAL IMPLICATIONS OF POSTGRADUATE RESEARCH PROJECT

This template should accompany the postgraduate research student application for candidature form submitted to the Board of Studies.
(Additional departmental information may be incorporated as appropriate).

Please note that this procedure is intended to help student and supervisor consider ethical implications of the proposed research project, and as such is a 'light-touch' approach. Supervisors are responsible for deciding whether a more extensive ethical review is necessary (such as submission to an NHS REC).

To be completed by Principal Investigator/Staff member

Brief Title of Project	**The assessment of the physical fitness, physical activity levels and biological maturation of school children.**
Names of Principal/Other Investigators	**Miss Corinne Yorston** **Dr. Sean Cumming**

SECTION 1: COMPLETION FOR ALL RESEARCH

Are there ethical implications concerned with the following general issues? If yes, please provide details below	
1. Data storage (eg Confidentiality, availability, length of storage, etc)	All data will be anonymised with participants being assigned a numeric ID. Data will be stored in a secure location at the University of Bath and electronic versions of the data will be password protected. Data will be kept for five years following the completion of the study.
2. Are you free to publish the results? eg Are there any restrictions raised by contractual issues?	Yes
3. Effect on/damage to the environment eg Hazardous waste may be produced; water or air might be polluted; injurious pathogens might be released; damage to ecological systems/habitats.	No

Specific Issues		
4. Does the research involve human participants in any way? (Please note if you are processing personal data you need to tick 'Yes'.)	No	Complete only Section 1
	Yes **X**	Complete Sections 1 and 2

5. Does the research involve animals in any way?	No **X**	Complete only Section 1
	Yes	Complete Sections 1 and 3

Demonstration of Ethical Considerations *Please outline the ethical issues which will need to be managed during the course of the activity.*
The participants will be recruited from primary and secondary schools within the South West of England. Written consent will be obtained from the Head Teacher of each school, who will act in *loco parentis* (see Appendix Two). Parents will be informed about the research by a letter and asked to provide passive consent with the option of their child opting out of the study (see Appendix Three). Verbal consent will be obtained from the participants, who will have the option to opt out of the research at any point. Biological maturity will be assessed using the non-invasive Khamis-Roche protocol which involves measures of participant height, weight, and age, and self-reported parent height. Participants will complete a brief demographic questionnaire with information pertaining to date of birth, gender, ethnicity, and self-reported parent height. Participants will be asked to record self-reported parent height as part of a class activity prior to the testing. Participants will also complete the Physical Activity Questionnaire for Adolescents, a brief 8 items scale designed for adolescents that reflects the participant's involvement in physical activity (see Appendix Four). A battery of simple anthropometric and physical fitness tests will be undertaken by the participants, entailing height, weight, linear speed, agility, power, momentum, upper body strength and balance (see Appendix One). All measurements will be carried out by myself and a team of trained sports scientists, all of whom will have successfully completed a disclosure and barring service check (formally CRB checks). The participants will experience no more discomfort than they are used to when participating in traditional a physical educational lesson. All measures of weight will be taken using a digital scale with a handheld display screen. Accordingly, participants will not know or be told what their weight is. Participants will be able to opt not to perform any of the tests that they do not wish to participate in. All data will be kept confidential and anonymous with no names appearing on either hard or electronic copies of the data. All hard copies of data being stored in a locked filling cabinet at The University of Bath and electronic data being stored on a password protected computer.

	Yes	**No**
1. Does the study involve participants who are particularly vulnerable or unable to give informed consent? (eg children, people with learning disabilities)	X	
2. Will the study require the co-operation of a gatekeeper for initial access to the groups or individuals to be recruited? (eg students at school, members of self-help group, residents of a nursing home)	X	
3. Will it be necessary for participants to take part in the study without their knowledge and consent at the time? (eg covert observation of people in non-public places)		X
4. Will the study involve discussion of sensitive topics? (eg sexual activity, drug use)		X
5. Are drugs, placebos or other substances (eg food substances, vitamins) to be administered to the study participants and/or will the study involve invasive, intrusive or potentially harmful procedures of any kind?		X
6. Will blood or tissue samples be obtained from participants? *Note: If the answer to this question is 'yes' you will need to be aware of obligations under the Human Tissue Act, see further information at* http://www.bath.ac.uk/internal/ethics/committee/HTA.html		X

7. Is pain or more than very mild discomfort likely to result from the study?		X
8. Could the study induce psychological stress or anxiety or cause harm or negative consequences beyond the risks encountered in normal life?		X
9. Will the study involve prolonged or repetitive testing?		X
10. Will financial inducements (or other expenses and compensation for time) be offered to participants?		X
11. Will the study involve recruitment of patients through the NHS? Note: If the answer to this question is 'yes' you will need to submit an application to the NHS through IRAS, see: http://www.nres.npsa.nhs.uk/applications/integrated-research-application-system/		X

SECTION 2: FOR COMPLETION IF YOUR RESEARCH INVOLVES HUMAN PARTICIPANTS

If any of the answers to these questions are 'yes', please confirm in the space below how the ethical issues will be managed during the course of the activity.

Compulsory question for consideration by all disciplines:

	Yes	**No**
Will the study involve obtaining or processing personal data relating to living individuals, (eg involve recording interviews with subjects even if the findings will subsequently be made anonymous)? *Note: If the answer to this question is 'yes' you will need to ensure that the provisions of the Data Protection Act are complied with. In particular you will need to seek advice to ensure that the subjects provide sufficient consent and that the personal data will be properly stored, for an appropriate period of time). Information is available from the University Data Protection Website and dataprotection-queries@lists.bath.ac.uk*	X	

Departments may amend the following list to include topics of particular relevance to their discipline(s).

Section 2: Demonstration of Ethical Considerations

Please complete this section if any of the answers to the above questions are 'yes'.

Participants' anthropometric and physical fitness measurements will be taken. All measurements will be taken by myself and a team of trained sports scientists from The University of Bath. Anyone involved in the study will all have successfully completed a disclosure and barring service check (formally CRB checks). Participants' data will be kept confidential and anonymous, with all names removed and participants recorded as a number.

The study involves children aged 9-16. Written consent will be obtained from the Head Teacher of each school, who will act in *loco parentis*. Parents will be informed about the research by letter, with the option for their child to opt out of the study. Verbal consent will be obtained from the participants, who will have the option to opt out of the research at any point.

Access to the schools' facilities will be required, however all testing will take place during normal physical education periods of usual school operative hours. The class teachers will be present during the data collection. Prior to carrying out any research within the school, knowledge of the schools individual minor injury procedures will be obtained and taken into full consideration during the study.

For those children who are unable to participate or who have indicated that they do not wish to participate in the study, a separate activity will be run by the physical education staff from the school.

SECTION 3: FOR COMPLETION IF YOUR RESEARCH INVOLVES ANIMALS

	Yes	**No**	**In progress**
1. Has the project been submitted to and approved by the Ethical Review Committee for the purposes of Home Office approval under the Animals (Scientific Procedures) Act 1986?			
2. If the research is outside the scope of the Animals (Scientific Procedures) Act 1986 is it controlled by any other UK legislation? If so, please give details below.			
3. If the research is not controlled by UK legislation have the ethical implications of the project been considered by the Ethical Review Committee? *http://www.bath.ac.uk/research/docs/nonlicencedthicareviewformfinalmay2010-2.doc*			

Section 3: Demonstration of Ethical Considerations
This section is available for submission of further details relevant to Section 3.

Declarations

I confirm that the statements in Sections 1-3 describe the ethical issues that will need to be managed during the course of this research activity.

Principal Investigator/ Supervisor/Project Supervisor	**Signature:** [redacted] **Date: 18/01/2015**
Second reader(PhD/DHealth/ MPhil/MD only)(normally <u>external</u> to the project team)	[redacted] **Signature:** **Date: 23/01/2015**
Researcher/Student	[redacted] **Signature:** **Date: 18/01/2015**

Please return this form to the Secretary for the Research Ethics Approval Committee for Health (REACH). (Issues will be monitored for incorporation into an annual departmental report to be submitted to the University Ethics Committee.)

ANNEX FOUR – Application form for full submission for research ethics approval

Department for Health
Research Ethics Approval Committee for Health

Title of study	**The assessment of the physical fitness, physical activity levels and biological maturation of school children.**
Chief investigator **(for research student projects, put research supervisors name here)** **(for undergraduate projects, put project supervisors name here)**	Name: Sean Cumming e-mail: S.Cumming@bath.ac.uk Telephone: 01225386251
Other investigators **(for research student projects, put students name here)** **(for undergraduate projects, put student(s) name here)**	Name: Corinne Yorston e-mail: c.yorston@bath.ac.uk Telephone: [redacted]
Source of funding for the study	Graduate School URS / School-Humanities
Proposed dates of study	January 2015 – January 2017
Research question	The purpose of this study is to determine the contributions of physical activity and biological maturation to the physical fitness performance of school children aged 9-16 using a standardised fitness testing battery. This study will also attempt to provide fitness data for the general paediatric population, in order to ascertain benchmark results for the speed, agility, power, momentum, strength and balance of children and adolescents.
Background (less than 100 words)	There is limited information surrounding the physical fitness performance of the ‘normal’ paediatric population. Whilst most elite sporting pathways and talent identification protocols use a battery of tests to ascertain whether an athlete has the necessary physical attributes to perform in their chosen sport, this provides information on a specific,

	elite population. Further, variance in fitness may also reflect individual differences in children's activity levels and biological maturation. With the absence of a populace from which to provide benchmarks against, there is a difficulty for practitioners working with paediatric populations to fully analyse fitness performance or changes in youth, or assess the success of various fitness interventions. This research aims to provide physical performance data for the average population of school children aged 9-16. Influence of maturity status, relative age, and physical activity will also be considered
Methods (less than 300 words)	A cross sectional sample of approximately 1000 school children, aged 9-16 years of age of both sexes will be asked to participate in the study. Written consent will be obtained from the Head Teacher of each school, who will act in *loco parentis*. Parents will be informed about the research by post and asked to provide passive consent with the option of their child opting out of the study. Verbal consent will be obtained from the participants, who will have the option to opt out of the research at any point. Prior to carrying out any research within the school, knowledge of the schools individual minor injury procedures will be obtained and taken into full consideration during the study. Each participant will perform a physical testing protocol which will include anthropometrical measurements of height, sitting height and weight. The physical tests will entail the 10m, 20m and 30m sprint; momentum test, hand grip strength; a stork balance test; 505 agility test; and a vertical jump with and without arms. The participant's height and seated height will be measured on an individual basis with a fixed stadiometer to the nearest 0.1cm and their weight will be measured with a calibrated electronic scale to the nearest 0.1kg. Biological maturity will be assessed using the non-invasive Khamis-Roche protocol. The Khamis-Roche protocol requires the decimal age, height and weight of the player as well as the midparent height [(mother's height + father's height)/2] to determine maturity. Biological parent's heights will be requested at the start of the study. The participants linear speed and agility will be measured using an electronic light gate timing system (best of three attempts) and their lower limb explosive power with vertical jump height (best of three attempts). Momentum will be determined from the participant's 8-12m average velocity x participant's body mass. An indication of strength will be obtained with the hand grip dynamometer (best of three attempts on both hands). Balance will assessed using the Y Balance Test on both legs (See Appendix One – Description of Physical Tests).

	Anthropometric and physical performance characteristics will be measured by myself and a trained team of sports scientists The testing battery will be performed indoors as part of a physical education class following normal guidelines and test descriptions. Physical activity levels for each participant will be assessed using a Physical Activity Questionnaire for Adolescents, which will be distributed at the initial stages whilst requesting parental height.
Sample size (or equivalent qualitative approach)	▪ Approximately 500-1500 school children of both male and female sex, aged between 9-16 years of age.
Proposed Analysis	Since this study is cross sectional in nature, the investigators will use methods to examine the associations between maturity, chronological age, anthropometric and physical performance variables. This will include simple descriptive analyses, correlations, regressions, and curve estimations, but may also extend to multivariate logistic regression and multivariate analysis of variance (MANOVA).
Potential risks to volunteers	▪ None
Potential for pain/discomfort	▪ The participant will experience no more discomfort than they are used to when participating in their sport.
Benefits to participants	▪ The information obtained in this study will provide schoolteachers, youth sports organisations, National Governing Bodies and other practitioners that work with young children guidance on normative data for the various physical fitness capabilities throughout childhood and adolescence. The data will provide a reference from which to compare the physical performance of young people throughout the country. ▪ The participants will have the opportunity to participate in a series of fitness tests through a research study which will gain a better understanding of science and its application in relation to physical education and health. ▪ Schools will receive their own set of results which will be anomalous, as well as receiving the average results across all schools for the various tests, again which will be kept anomalous. They will benefit from obtaining this information as this will supplement and better inform the practise carried out in the school and will allow for useful within-school comparisons to be made across classes within year groups and between year groups.
How will participants be recruited?	▪ The children will be recruited from primary and secondary schools local to the study, within the South West of England.

	▪ Upon acceptance, Head Teacher consent and passive parental consent, and following subsequent liaising with the school, the children will participate in the study at a convenient time for both myself and the school.
Exclusion/inclusion criteria	▪ The study will aim to include participants from all ethnicity and socio-economic class. ▪ Only those participants that are physically fit or able to perform all tests maximally will take part. ▪ In instances where a participant is unable to participate in a specific task (e.g., wheel chair user for counter movement jump) a separate more appropriate fitness test will be offered as an alternative (i.e., hand grip test). ▪ For those children who are unable to participate or who have indicated that they do not wish to participate in the study, a separate activity will be run by the physical education staff from the school.
How will participants consent be taken?	▪ The Head Teacher of the school will act in *loco parentis* ▪ Passive parental consent will be obtained for each participant with the option to opt out of the research. ▪ The participant will also have the opportunity to opt out of the research at any point during the study.
How will confidentiality be ensured?	▪ Hard copies of data will be stored in a locked filing cabinet at The University of Bath. ▪ Electronic data will be stored on password protected computers at The University of Bath. ▪ All data will be retained for 5 years following completion of the study. ▪ Names will not appear on either hard copies or electronic data. ▪ Any information provided to the participating schools will remain anonymous.

Attach the following (where relevant):

1. Participant information sheet
2. Consent Form
3. Health history questionnaire
4. Poster/promotional material
5. Copy of questionnaire/ proposed data collection tool (questionnaire; interview schedule/ observation chart/ data record sheet/ participant record sheet)

Signed by: Principal Investigator or Student Supervisor

[redacted]

________________________________ Date: 18/01/2015_______________

Signed by: Student or other researchers

[redacted] Date: ____18/01/2015________

University of Bath **Research Student Progression Form PGR11**

CHANGE OF THESIS TITLE

This form is to be used only when the topic of the thesis remains substantially the same. If there is a substantive change to the area of research, a new candidature form and abstract should be completed.

THE COMPLETED FORM SHOULD BE PASSED TO THE DOCTORAL COLLEGE

1. General details of the student's current registration

Full name: Corinne		**Student number:** 010282717/2	
Dept/Sch: Department for Health		**Mode of study** *(please circle)*: Part-Time	
Supervisor(s): Dr. Sean Cumming (Lead); Dr. Grant Trewartha			
Start date of registration: 01/04/14	**Current end date of registration: 31/03/21**	**Main funding source** URSA -HUM	**Degree for which registered: Doctor of Philosophy**

2. Specific details relating to this request

Current thesis title: THE ASSESSMENT OF THE PHYSICAL FITNESS, BIOLOGICAL MATURATION AND PHYSICAL ACTIVITY LEVELS OF SCHOOL CHILDREN
New thesis title: **The influence of growth, maturation and relative age on the physical fitness of adolescent schoolchildren**

3. Supervisor's comments

I support this change. For some reason the term physical activity, had not been removed from the initial title submission. The title that Corinne is proposing does not deviate from what she has been working on from the start of the project and through her transfer.

Dr Sean Cumming 29/03/21

Signed[redacted]..**Date 29/03/2021**..
Student

Signed **Date**29/03/2021
Director of Studies

Form PGR11 – July 13

Physical Test Information Sheet For Assistants

The assessment of biological maturation and physical fitness of school children.

During the study, the following physical fitness tests will be carried out:

Physical Assessment of: **Test Performed:**

Muscular Power **Countermovement Jump – With and Without Arms**

The participant's muscular power will be indirectly assessed by their vertical jump performance. The countermovement jump can be used to assess stretch-shortening functioning of the lower limbs. The jump test will be performed with and without the assistance of arms. This will allow for assessment of lower limb muscular power, as well contribution and coordination of upper body.

Protocol: Following a standardised jump warm up the participant stands on the jump mat in a comfortable position that will allow them to perform a maximal jump. Following a standardised countdown the participants aim to jump as high as possible, landing on the jump mat with a cushioned landing. The participants must not 'flick' their heels or raise their knees as they jump. Each participant performs three jumps without the use of their arms and three with the use of their arms for assistance. Between each jump a complete recovery must be allowed (15 seconds or more).

Speed **10m Acceleration and 20m / 30m Maximum Velocity Speed Tests**

The sprint tests over 10m, 20m and 30m will provide information on the participant's ability to accelerate as well as their maximum velocity.

Protocol: The electronic timing gates will be set up at 0m, 10m, 20m and 30m according to the standardised protocol. Following a standardised speed warm up, participants will perform 3 sprints maximally through the timing gates. The participant starts with their dominant foot on the start cone, 1m behind the 0m first timing gate. The participants are then to start when they are ready, running maximally through all sets of gates, slowing down in a deceleration zone after the 30m line.

Agility **505-Agility Test**

The 505-agility test will assess the participant's ability to change body direction and position rapidly in the performance of a 5m sprint with a 180º turn of both legs, followed by a 5m reacceleration.

Protocol: Electronic timing gates will be set up 5m from a designated turning point. Following completion of a standardised speed and agility warm up, the participants assume a starting position 10m from the timing gates. Participants must accelerate as quickly as possible from the start line through the timing gates, performing a 180º cut on the turn line and sprint back through the timing gates as quickly as possible. Each participant will perform four maximal effort sprints with two turns on each leg.

Balance

Y Balance Test

The Y Balance Test assesses neuromuscular control in the form of balance and postural stability by measuring single leg dynamic movements in three directions. As well as testing for balance and joint stability in the lower limb, this test also requires involvement of lower limb coordination, flexibility and strength.

Protocol: Each participant should perform a practise of each movement prior to testing. The test is then performed without shoes on. The participant stands on one leg on the designated start line. Maintaining a single leg stance, reach with the free limb in the anterior, posteromedial and posterolateral directions in relation to the stance foot. The distance obtained by measurement of the big toes of the reach leg is recorded. The participant must perform three trials of each direction on each leg. The measurement cannot be taken if the participant fails to maintain a unilateral stance, fails to maintain reach foot in contact with the line or fails to return the reach foot to the starting position under control.

Upper Body Strength **Hand Grip Dynamometer**

The participant's upper body muscular strength will be assessed through the hand grip strength.

Protocol: Following completion of a standardised upper body warm up, the participant will perform three measurements of hang grip strength assessment on the dynamometer on both arms. The participant is in a standing position with arms at the side and elbows slightly bent. The participant must grip the dynamometer and squeeze with as much force as possible. The assessment will be carried out on both dominant and non-dominant arms, with three trials on each. Complete recovery of at least 30 seconds should be allowed between trials.

Momentum **8-12m Average Velocity x Body Mass**

The participant's momentum will be assessed by measurement of the average velocity between 8-12m of a linear sprint, with subsequent multiplication of the participant's body mass.

Protocol: The electronic timing gates will be set up at 0m, 8m and 12m according to the standardised protocol (this test will be carried out at the same time as the 30m linear speed sprint). Following a standardised speed warm up, participants will perform 3 sprints maximally through the timing gates. The participant starts with their dominant foot on the start cone, 1m behind the 0m first timing gate. The participants are then to start when they are ready, running maximally through all sets of gates, slowing down in a deceleration zone after the 30m line. The average velocity between 8m-12m is determined and multiplied by the participant's body mass in order to determine momentum.

WARM UP PROTOCOL FOR ASSISTANTS

Speed: (In two lines or a straight line)

- Jog @ 50% 30m
- Jog @ 75% 30m
- Ankling 10m
- High knees 10m
- Knee drive hamstring kick 10m
- Bum Flicks 10m
- Hamstring Kicks
- Sprint @ 90%
- Sprint @ 100% x2

Agility:

- Jog @ 50% 20m
- Jog @ 75% 20m
- Ankling 10m
- High knees 10m
- Knee drive hamstring kick 10m
- Bum Flicks 10m
- Hamstring Kicks
- Lateral Side Steps 10m
- Sprint @ 90% with turn at 10m and sprint back
- Sprint @ 100% with turn at 10m and sprint back

CMJ:

- Squats x 10
- Jumps @ 50% x 4
- Jumps @ 100% x 4 with arms
- Jumps @ 100% x 4 without arms

Y Balance

- 4 x practise runs each direction each leg

Hand Grip:

- 3 x practise attempts on each arm

Further Information
If you have any queries regarding this study please contact:
Corinne Yorston
The Dept. for Health
The University of Bath
Claverton Down
Bath BA2 7AY
[redacted]
[redacted]*uk*

THE ASSESSMENT OF THE PHYSICAL FITNESS, PHYCICAL ACTIVITY AND BIOLOGICAL MATURATION OF SCHOOL CHILDREN.

SPORT AND EXERCISE SCIENCE

Department for Health

On behalf of the students attending ____________________, I fully understand what is involved in taking part in this study. Any questions about the study or the students' participation in it have been answered to my satisfaction. I have been informed that the students are free to withdraw their consent and discontinue participation at any time. If they do decide to withdraw from the study, it has been made clear that it will not have any undesirable consequences. It has been made clear to me that all the data will be kept strictly anonymous and confidentially will be maintained throughout. Should I feel that these regulations are being infringed or that the interest of the students are being ignored, neglected, or denied, I should inform Dr. Gordon Taylor, Head of the Research Ethics Approval Committee for Health who will undertake to investigate my complaint.

Signature of Head Teacher: ....

Name Printed:

Date: ....

Corinne Yorston
The Department for Health
University of Bath
Email: c.yorston@bath.ac.uk
Contact number: [redacted]

Further Information
If you have any queries regarding this study please contact:
Corinne Yorston
The Dept. for Health
The University of Bath
Claverton Down
Bath BA2 7AY
[redacted]
[redacted]*uk*

THE ASSESSMENT OF THE PHYSICAL FITNESS, PHYICAL ACTIVITY AND BIOLOGICAL MATURATION OF SCHOOL CHILDREN.

SPORT AND EXERCISE SCIENCE

Department for Health

Dear Parent,

Your son/daughter has been invited to take part in a research study conducted by my colleagues and I from the University of Bath. I am currently studying a PhD at The Department for Health, The University of Bath, and this research will form part of my PhD study. The study will be conducted during a physical education class of normal school operating hours, thus will require no further time commitment outside of usual school hours. Participation in this study is optional and there is absolutely no obligation for your son/daughter to take part. Thus, I would like to give you the chance to see what is involved before both you and your child decide whether you would be happy for them to take part.

The purpose of this study
Physical fitness is very important for the health of children and adolescents, with schools, sports clubs, and sporting organisations working with younger athletes aiming to develop aspects of physical fitness and performance. At present however, there are no standards upon which to determine if a child is more or less fit than would be expected for their age and development. As such it is very difficult to tell whether a child is achieving the levels required for healthy physical development.

Thus, this research aims to provide physical performance data for a population of schoolchildren, taking into account individual differences in maturation status, age and physical activity level. This information will greatly improve the knowledge for those people working with young people in sport, fitness and health.

What would your child have to do?
A convenient time to carry out the fitness testing will be determined by your child's school and thus the study will take place either within a normal school physical education class, or at a more convenient time for the school. The fitness testing

will be carried out by myself, with the aid of fully trained University of Bath Sports and Exercise Science students, all of whom will have successfully completed a disclosure and barring service check (formally CRB checks). The study will involve your child completing five very simple fitness tests. These will entail a 30m sprint test to measure speed and momentum; an agility test; a hand grip strength test to measure upper body strength; a balance test; and a vertical jump test to measure lower limb explosive power. Alongside the fitness tests, simple measurements of height and weight will be recorded. Measures of weight will be taken individually using a scale with a remote display. As such students will not know or be told their own weight. The children will be given full instruction on how to perform the tests and will have the opportunity to ask questions should they need additional clarification.

Throughout the testing, education and the enjoyment of the children will be at the forefront. Those participating will be given information on physical fitness, performance testing and will be informed about the importance of physical fitness for health. It will also give those involved the chance to see the link between research and sport in action.

Confidentiality

Every effort will be made to preserve the confidentiality of the participant including the following:

- To ensure anonymity, all participants will be assigned an ID number which will be used throughout the study.
- All data and information collected on each participant will be anonymous and kept in a locked file cabinet in the personal possession of the researcher.
- The researcher and the members of the researcher's committee will all have successfully completed a disclosure and barring service check (formally CRB checks).

It is your decision if you would like your child to participate in this research study. If you are happy for your child to participate, you do not need to do anything. However, if you would prefer that your child ***does not*** take part, please may you contact me to let me know. You can do this either by **returning the opt-out form** enclosed with this letter to your child's form tutor or by **contacting me directly** on the contact details below. If either you or your child decides to opt-out at a later date, this is perfectly acceptable.

Further Information

If you have any queries regarding the present study please contact Miss. Corinne Yorston (Tel: [redacted] Email:c.yorston@bath.ac.uk) or Dr. Sean Cumming (Tel: 01225 386251; Email: S.Cumming@bath.ac.uk).

Yours sincerely,

[redacted]

Corinne Yorston

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University of Bath Research Project

THE ASSESSMENT OF THE PHYSICAL FITNESS, PHYSICAL ACTIVITY AND BIOLOGICAL MATURATION OF SCHOOL CHILDREN AGES 9-16 YEARS.

PARENTAL OPT OUT FORM

Please complete and return if you would prefer your child ***NOT*** to take part in this research.

I would prefer my child …………………………………………………..…… (name) in class ……..…. not to take part in the research.

Please sign below:

Signature: ______________________________ **Date:** ____________________________

SCHOOLS PARTICIPATION PROPOSAL

The assessment of the physical fitness, physical activity levels and biological maturation of school children.

Aim

This research study is being carried out by myself Corinne Yorston, with support from my supervisor Dr. Sean Cumming, from The Department of Health, The University of Bath. It aims to produce standard testing results of young children and adolescents that can be used throughout the country for talent identification, general fitness, and health guidelines and for athletic development programmes. The study aims to develop an inaugral testing battery of basic physical fitness components of school children, in order to identify 'normal' results for youths aged 9-16 years of age. Identifying this information will greatly improve the knowledge for those people working with young people in sport, fitness, and health in many ways, namely:

(i) It can provide schoolteachers, youth sports organisations, National Governing Bodies and any other practitioners that work with young children guidance on where their children are compared to normative data.

(ii) It will allow for a comparison between those children that do limited physical activity, those that do regular physical activity and then those that do elite sport.

(iii) Those young people that excel on one and/or several areas of fitness can be more easily identified. This can aid with earlier talent identification into suitable sports and could help progress athletes along sporting pathways.

(iv) It can provide schoolteachers, youth sports organisations, National Governing Bodies and any other practitioners that work with young children a reference for which to compare any fitness tests they carry out against.

(v) Those young people way below the averages can be more easily identified and helped to improve for both health and fitness reasons.

Plan of Work

- A date and time to carry out testing that is convenient for the school will be established. Ideally this will be in school hours (PE time, lunch etc) as this will increase reliability of results.
- The school Headteacher will act as *in loco parentis* and will provide consent for student participation.
- A letter offering the chance to opt out of the study will be sent to each family.
- The child will be sent a quick physical activity questionnaire for completion prior to testing, parental heights and weights will also be asked for at this point.
- A group of helpers and I will visit each school, only one testing visit per child is required.
- We can test a maximum of approximately 40 children at a time. Testing of 40 children would take approximately 90 minutes – 2 hours.
- The testing battery will be: 1. Heights & Weights 2. Balance Test 3. Speed Tests (Acceleration & Maximum Velocity & Momentum) 4. Agility Test 5. Jump Test 6. Strength Test
- The session will of course involve the children completing the tests. However, throughout the session the children will also be educated on the importance

of health and fitness, as well as aspects around research, further education, and university.

- If there are any individuals that are unable to take part due to injury or illness or have opted out of being involved, they can watch and learn, or alternatively the teacher for the class could occupy them on other things.
- The session itself will be enjoyable as well as educational for the children. Questions and information seeking will be encouraged, alongside children being given the opportunity to push themselves and challenge themselves against others.

<u>What Results Will Be Produced</u>

All results produced will be treated as confidential.
Overall:

- Average testing results for each fitness performance tests for children aged 9-16 years. These results will be grouped by:
    - Chronological Age (9.00-9.99 years of age; 10.00-10.99; etc)
    - Biological Age – taking into account stage of growth and maturation. This will be established by the non-invasive Khamis-Roche method of assessing maturity, an equation based calculation using parental heights, child decimal age, height and weight.
- Developmental trajectories for each performance test will be produced. These plot performance score by age, in order to look at a change of performance as age increases

Individual Participating Schools will receive:

- Individual school's results pack for their children's performances
- A document comparing their own schools performances compared to other schools performances (confidential) – to determine where they fit compared to the average
- A fully comprehensive information pack on the physical fitness testing battery procedures and how the school can administer them themselves, including:
    - Information on what speed, balance, power and agility are
    - Information on growth and maturation in young children and how these can influence physical performance
    - What each physical performance test was and how it was done
    - Alternative tests that could be performed in schools for each physical test including more basic tests, those that require less equipment
- Potentially, information may also be provided on the steps subsequent to good testing results for an individual i.e. how they can progress, which sports could be considered etc.

<u>What Do We Need From You and Your School</u>

- Agreement if you would like your school to be involved in this study
- Parental permission for each child to be obtained, as well as parental heights and weights (to be obtained closer to study)
- A convenient date and times to be established for me to visit your school and carry out the fitness tests on the children. Depending on numbers, this could be multiply classes (or year groups) together, or different age groups/classes back to back sessions, or different age groups/classes on different days. Weekends as well as weekdays are fine for independent schools.

- An appropriate facility to perform the testing – ideally a school hall in case of poor weather. Although all tests can be carried outside also. The area needs to be at least 40m in length.

Summary

This research study aims to establish fitness performance data that has not as of yet been obtained in this country. The day itself will be fun and educational for the children involved, allowing them to partake in various fitness tests and learn about how to improve in their fitness, the links between University research and performance amongst many other things. The information will be treated as confidential, however the schools that take part will gain detailed information in the performances of their own children and how these compared to the other schools' averages, as well as information on the tests, how they can be administered by the school in the future, how results can be improved and what the data means.

Further Information
If you have any queries regarding this study please contact:
Corinne Yorston
The Dept. for Health
The University of Bath
Claverton Down
Bath BA2 7AY
[redacted]
c.yorston@bath.ac.uk

THE ASSESSMENT OF THE PHYSICAL FITNESS, PHYICAL ACTIVITY AND BIOLOGICAL MATURATION OF SCHOOL CHILDREN.

TEACHER INFORMATION SHEET

SPORT AND EXERCISE SCIENCE

Department for Health

Aim

This research study is being carried out by myself Corinne Yorston, with support from my supervisor Dr. Sean Cumming, from The Department of Health, The University of Bath. It aims to produce benchmark athletic fitness data of young children and adolescents that can be used throughout the country for general fitness and health guidelines and for athletic development and talent identification programmes. The study aims to develop an inaugural testing battery of basic athletic physical fitness components of school children, in order to identify 'normal' results for youths aged 9-16 years of age. Identifying this information will greatly improve the knowledge for those people working with young people in sport, fitness and health in many ways, namely:

(vi) It can provide schoolteachers, youth sports organisations, National Governing Bodies and any other practitioners that work with young children guidance on where their children are compared to normative data.
(vii) It will allow for a comparison between those children that do limited physical activity, those that do regular physical activity and then those that partake in elite sport.
(viii) Those young people that excel on one and/or several areas of fitness can be more easily identified. This can aid with earlier talent identification into suitable sports and could help progress athletes along sporting pathways.
(ix) It can provide schoolteachers, youth sports organisations, National Governing Bodies and any other practitioners that work with young children a reference for which to compare any fitness tests they carry out against.
(x) Physical fitness testing routinely takes place in elite sports clubs, however there is a lack of this being carried out in the general population of children and adolescents.

What Happens?

- A date and time to carry out testing that is convenient for the school will be established. Ideally this will be in school hours (PE time, lunch etc) as this will increase reliability of results, however after school is also fine.
- The school Head teacher will act as *in loco parentis* and will provide consent for student participation. A simple form will be emailed to you which the Head teacher must sing providing consent for testing.
- A letter offering the chance to opt out of the study will be sent to each family.
- The child will be sent a short physical activity questionnaire for completion prior to testing, parental heights and weights will also be asked for at this point. This information is important.
- A group of helpers and I will visit each school, only one visit is required.
- We can test a maximum of approximately 30 children at a time. Testing of 30 children would take approximately 1 hour.
- The testing session will involve carrying out: 1. Heights & Weights 2. Balance Test 3. Speed Tests (Acceleration & Maximum Velocity & Momentum) 4. Agility Test 5. Jump Test 6. Strength Test
- The session will of course involve the children completing the tests. However, throughout the session the children will also be educated on the importance of health and fitness, as well as aspects around research, further education and university.
- If there are any individuals that are unable to take part due to injury or illness, or have opted out of being involved they can watch and learn, or alternatively the teacher for the class could occupy them on other things.
- The session itself will be enjoyable as well as educational for the children. Questions and information seeking will be encouraged, alongside children being given the opportunity to push themselves and challenge themselves against others.

What Results Will Be Produced?

All results produced will be treated as confidential.
Overall:

- Average testing results for each fitness performance tests for children aged 9-16 years. These results will be grouped by:
    - Chronological Age (9.00-9.99 years of age; 10.00-10.99; etc)
    - Biological Age – considering stage of growth and maturation. This will be established by the non-invasive Khamis-Roche method of assessing maturity, an equation-based calculation using parental heights, child decimal age, height and weight.
- Developmental trajectories for each performance test will be produced. These plot performance score by age, in order to look at a change of performance as age increases.

Individual Participating Schools will receive:

- Individual school's results pack for their children's performances
- A document comparing their own schools' performances compared to other schools performances (confidential) – to determine where they fit compared to the average
- A fully comprehensive information pack on the physical fitness testing battery procedures and how the school can administer them themselves, including:

  - Information on what speed, strength, balance, power and agility mean.
  - Information on growth and maturation in young children and how these can influence physical performance.
  - What each physical performance test was and how it was done
  - Alternative tests that could be performed in schools for each physical test including more basic tests, those that require less equipment.
- Potentially, information may also be provided on the steps subsequent to good testing results for an individual i.e., how they can progress, which sports could be considered etc.

<u>What Do We Need From You and Your School?</u>

- Agreement if you would like your school to be involved in this study.
- A convenient date and times to be established for me to visit your school and carry out the fitness tests on the children. Depending on numbers, this could be multiple classes (or year groups) together, or different age groups/classes back-to-back sessions, or different age groups/classes on different days. Weekends as well as weekdays are fine for independent schools.
- An appropriate facility to perform the testing – ideally a school hall in case of poor weather. Although all tests can be carried outside also. The area needs to be at least 40m in length.
- I will then email you the Head Teacher consent for to be singed, the parental opt out forms to be given to the parents, and the short questionnaire for each child (where they will also need to obtain their parents heights).

<u>Summary</u>

This research study aims to establish fitness performance data that has not as of yet been obtained in this country. The day itself will be fun and educational for the children involved, allowing them to partake in various fitness tests and learn about how to improve in their fitness, the links between University research and performance amongst many other things. The information will be treated as confidential, however the schools that take part will gain detailed information in the performances of their own children and how these compared to the other schools' averages, as well as information on the tests, how they can be administered by the school in the future, how results can be improved and what the data means.

Further Information
If you have any queries regarding this study please contact:
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The University of Bath
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Bath BA2 7AY
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c.yorston@bath.ac.uk

THE ASSESSMENT OF THE PHYSICAL FITNESS, PHYICAL ACTIVITY AND BIOLOGICAL MATURATION OF SCHOOL CHILDREN.

PARENTAL HEIGHT COLLECTION INFORMATION SHEET

SPORT AND EXERCISE SCIENCE

Dear student and parent / guardian,

In the last term prior to the summer holidays, you took part in a study with the University of Bath, where myself and a few other members of Team Bath staff came to XXX and fitness tested you. We measured your speed, agility, jump power, upper body strength and balance, as well as measuring your heights and weights.

In order for your results to be used as part of this important research project we really need for you to provide us with the heights of both your parents as well as your date of birth. Remember, all information is confidential but it is crucial for me to be able to gain the information I need. Please could you fill in your Dads height, your Mums height and your date of birth in the spaces below and return the slip to xxx:

Fathers Height: ………………

Mothers Height: ………………

Date of Birth: ….………………

Please could you complete the information above and return to XXX as soon as possible.

Thank you so much for your help with this, I really do appreciate it.

Many thanks,

Corinne Yorston
The Department for Health
University of Bath
Email: c.yorston@bath.ac.uk
Contact number: [redacted]

RESULT OUTPUTS FOR SCHOOLS

THE UNIVERSITY OF BATH

SPORT AND EXERCISE SCIENCE. THE DEPARTMENT OF HEALTH

Corinne Yorston ASCC MSc

YOUTH ATHLETIC PHYSICAL FITNESS TESTING

SCHOOL	
YEAR GROUP	Year 6

FITNESS TEST		Overall Average: Your Result	Overall Average: All School Result	Male Average: Your Result	Male Average: All School Result	Female Average: Your Result	Female Average: All School Result
Acceleration (s)		1.87	1.84	1.80	1.81	1.92	1.86
Measures speed over 8m							
Maximum Velocity (20m) (s)		4.09	4.01	3.91	3.93	4.21	4.07
Maximum Velocity (30m) (s)		6.06	5.92	5.72	5.75	6.29	6.03
Measures speed over 20m & 30m							
Agility (s)	*Right*	3.35	3.25	3.24	3.19	3.41	3.29
	Left	3.40	3.28	3.29	3.22	3.48	3.32
	Right & Left	3.44	3.33	3.32	3.26	3.54	3.38
Measures speed and ability to change direction quickly							
Power (cm)	*Without Arms*	20.63	22.01	22.68	22.52	19.43	21.67
	With Arms	22.79	24.13	24.90	25.03	21.69	23.50
Measures ability to produce force quickly; both total body power (with arms) and lower body power (without arms)							
Upper Body Strength (kg)	*Right*	18.73	17.89	19.25	19.22	18.29	16.96
	Left	17.85	18.57	18.92	20.17	16.93	17.46
	Right & Left	18.29	18.23	19.08	19.69	17.61	17.21
Measures upper body strength							
Balance (cm)	*Right*	194.65	197.41	193.90	194.31	197.60	199.40
	Left	188.33	190.81	189.00	188.75	190.50	192.08
	Right & Left	190.46	193.49	191.45	191.53	192.41	194.69
Measures unilateral balance and postural control							

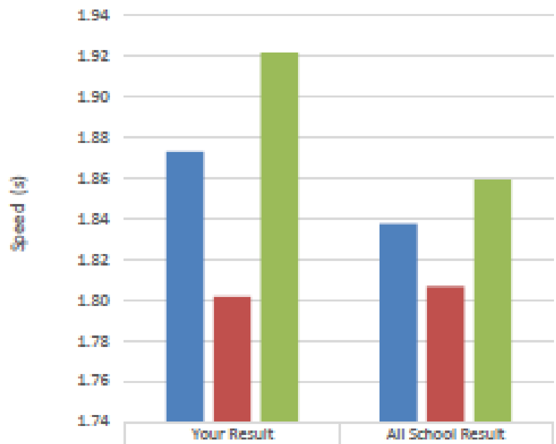
THE UNIVERSITY OF BATH

SPORT AND EXERCISE SCIENCE. THE DEPARTMENT OF HEALTH

Corinne Yorston ASCC MSc

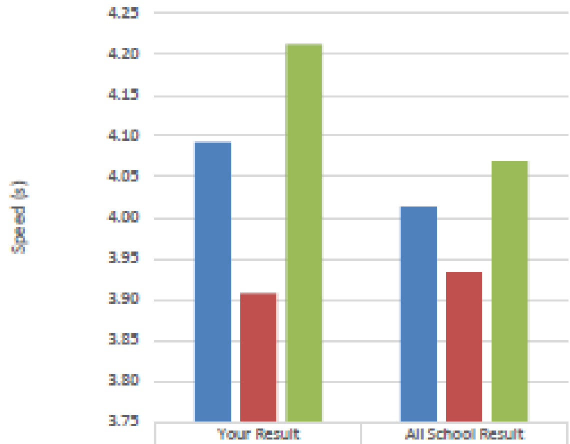
YOUTH ATHLETIC PHYSICAL FITNESS TESTING

ACCELERATION



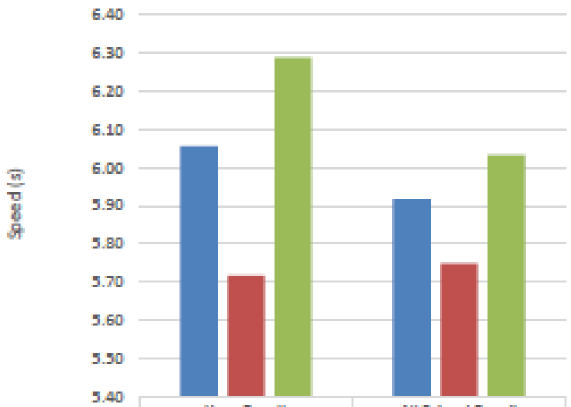
	Your Result	All School Result
Overall Average	1.87	1.84
Male Average	1.80	1.81
Female Average	1.92	1.86

MAXIMUM VELOCITY (20m)



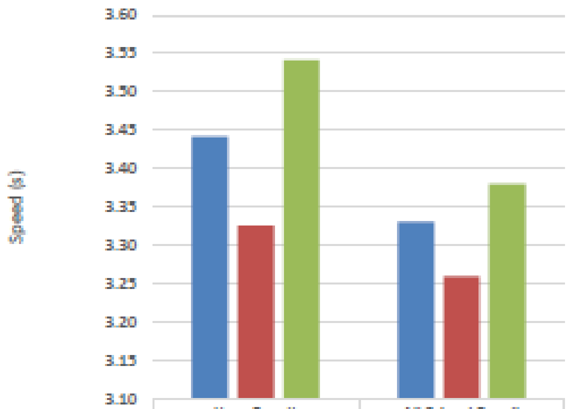
	Your Result	All School Result
Overall Average	4.09	4.01
Male Average	3.91	3.93
Female Average	4.21	4.07

MAXIMUM VELOCITY (30m)



	Your Result	All School Result
Overall Average	6.06	5.92
Male Average	5.72	5.75
Female Average	6.29	6.03

AGILITY (Right & Left)



	Your Result	All School Result
Overall Average	3.44	3.33
Male Average	3.32	3.26
Female Average	3.54	3.38

UNIVERSITY OF BATH

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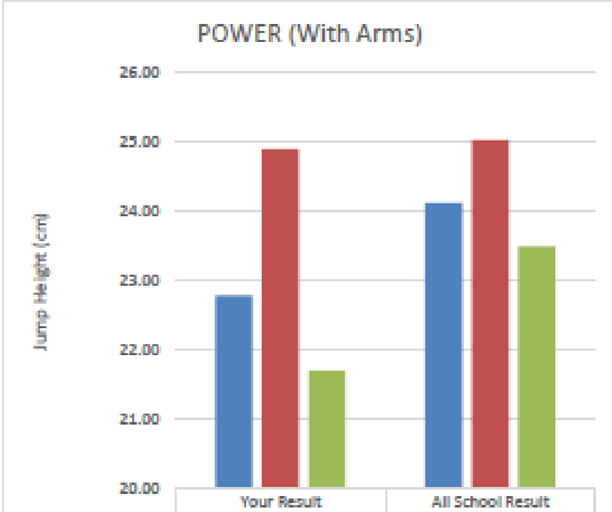
SPORT AND EXERCISE SCIENCE. THE DEPARTMENT OF HEALTH

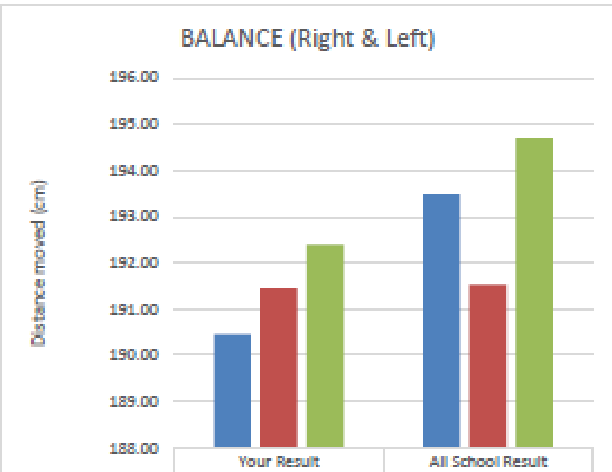
Corinne Yorston ASCC MSc

YOUTH ATHLETIC PHYSICAL FITNESS TESTING

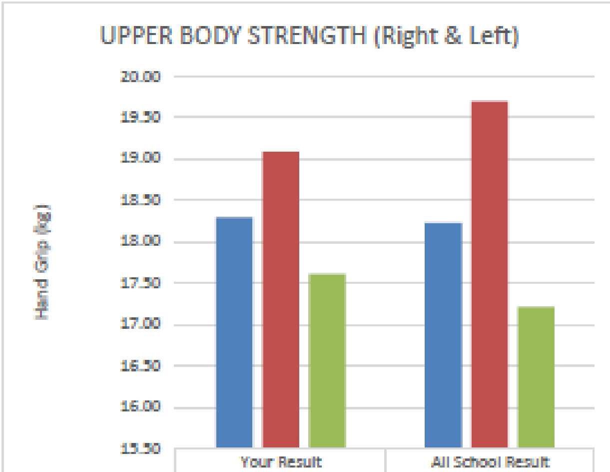
	Your Result	All School Result
Overall Average	20.63	22.01
Male Average	22.68	22.52
Female Average	19.43	21.67



	Your Result	All School Result
Overall Average	22.79	24.13
Male Average	24.90	25.03
Female Average	21.69	23.50



	Your Result	All School Result
Overall Average	190.46	193.49
Male Average	191.45	191.53
Female Average	192.41	194.69



	Your Result	All School Result
Overall Average	18.29	18.23
Male Average	19.08	19.69
Female Average	17.61	17.21