Performance of the Athletic Ability Assessment in Adolescent Academy Football players

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Abstract

LTAD models suggest boys aged 12-16 years should focus on strength, power, speed, agility, and sport-specific skill development. Consequently, implementing movement quality training interventions with football players around PHV will lessen the effects of adolescent awkwardness. Therefore, the aim of this thesis was to a) Assess the intra- and inter-rater reliability of the AAA and its scoring methods among academy football populations and b) explore the effects of maturation on AMC in academy youth footballers, using the AAA. The participants were part of a Category 1 football academy and aged U12-16 during the 2020-21 season. Each movement of the AAA was completed for a total of five repetitions in frontal and sagittal planes on both left and right leg, which were marked using video footage. In study one the intra-rater reliability, was assessed by the lead researcher assessing 59 participants, with a test-retest conducted after 7 days. To determine the inter-tester reliability of the AAA scores, five other testers scored all participants from the video footage. In study two each movement was scored across three areas using a three-point scale. Each specific area was associated to a numeric value, to objectify the athletes movement competency. Each key area score was summated to produce a single total movement score ranging from 3 to 9. The results from study one showed that the AAA is a reliable assessment tool to be used within English football academies. The inter-rater reliability was 0.975, whereas the intra-rater reliability in this study was substantial (0.714). The results from study two, showed that AAA performance of the Double Lunge, SL RDL and hop and stick improves with biological maturity, thus is most likely due to increases in strength which occur during male adolescence. However, the circa-groups were significantly worse at performing the OH squat.

1 Literature Review

1.1 Human Development

1.1.1 Defining Human Development

Throughout childhood to adolescence there are a number of hormonal, psychological and physiological changes. The childhood phase progresses from the age of 2 to 12 years old and is typically called ‘infancy’. During this phase, skeletal maturity is usually at its greatest (30 $cm.year^{-1}$) this rate then plateaus (5.5 $cm.year^{-1}$) until the start of puberty (Lloyd *et al*., 2011). After the childhood phase, is the onset of the adolescence phase, this consists of physical and psychological changes, involving puberty, which typically occurs from 12 to 18 years of age. During this period, there is significant growth in body stature and mass (adolescent growth spurt), due to increases in growth hormone and sex steroid (Rogol *et al*., 2000) with both males (age 12-14 years) and females (11-13 years). As a result of this, speed (Philippaerts *et al.,* 2006), strength (Lillegard *et al*., 1997; Vrijens, 1978), aerobic endurance (Naughton *et al*., 2000) muscle mass (Beunen, 1997) and muscular power (Blansksby *et al*., 1984) are increased. Therefore, it is necessary, for practitioners to understand phases of human development leading to such changes, so that appropriate training interventions can be implemented.

1.1.2 Motor Skill Development

Fundamental movement skills are an organised series of basic movements requiring the combined movement patterns of two or more body segments e.g. Running, throwing, kicking and jumping (Gallahue & Donnelly, 2003). Fundamental movement skills are viewed as the building blocks for sport-specific movement patterns (Gallahue, Ozmun, & Goodway, 2011). These building blocks help build a sufficiently diverse motor repertoire that will allow for later learning of skilled actions that can be flexibly tailored to specific movement contexts. Importantly, the motor patterns developed during this period will provide the basis for later motor skilfulness (Clark and Metcalfe 2002). Clark and Metcalfe (2002) described fundamental movement skills as the base camp at which children begin the climb up the mountain of motor development, with these fundamental skills essential for ensuring that correct movement patterns are mastered to ensure safe and effective performance of more complex sports movements.

A common misconception is that children naturally develop competency of fundamental movement skills (Stodden *et al.,* 2008). However, fundamental movement skills need to be taught and practiced to in order for children to gain mastery of these skills (Payne & Isaacs, 2002), through practice, encouragement, feedback and instruction (Gallahue *et al*., 2011). This is supported by the Stodden *et al.,* (2008) model, which proposes that children's physical activity levels may drive their fundamental movement skill competency, as increased physical activity results in more opportunities to promote neuromuscular development, which then increases fundamental movement skill competency (Fisher *et al.,* 2005). During childhood, the brain has high 'plasticity' as neurons undergo maturation and synaptic pruning takes place (Gogtay *et al.,* 2004 and Myer *et al.,* 2015). The brain's neuroplasticity has been suggested to underpin the acquisition and retention of motor skill learning. Additionally, after the fundamental movement skills have been established, motor skill development becomes influenced more by cultural, family, and social constraints (Clark and Metcalfe 2002).

1.2 Frameworks, Models and Principals of Youth Athletic Development

Long term athletic development (LTAD) is explained as planned and progressive development of an individual athlete to help them reach their full potential (Balyi, Way and Higgs, 2013). LTAD focusses on what is best for the individual throughout life and not for short-term success. It consists of applying the appropriate training depending on the stage of human development and is in important for preparing adolescents for professional careers in football (Pichardo *et al.,* 2018). Early LTAD models were originally classified based on chronological age, which is calculated as a single time point away from the date of birth. However, research has shown that chronological age is not a good indicator to base athlete development models on (Balyi & Hamilton, 2004. There are many extraneous factors (degree of maturation, anatomical, neurological, hormonal, and musculoskeletal changes in structure) that must be included within any physical programme (Malina, Bouchard, & Bar-Or, 2004; Tihanyi, 1990). The Balyi and Hamilton (2004) LTAD model (See Figure 1) was designed, using objective physiological assessment tools (peak height velocity (PHV) and peak weight velocity), to identify maturation differences and apply the relevant training protocols. This model allows for the individualisation of training programmes, accounting for varying stages of maturation, age, sex, and training history (Balyi & Hamilton, 2004).

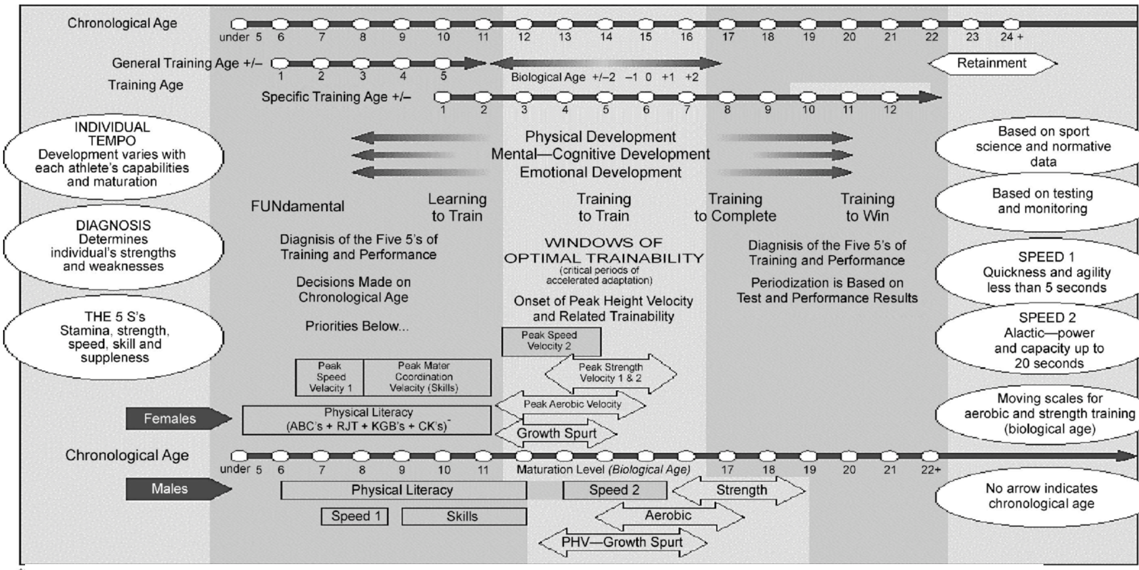

Figure 1. Balyi and Hamilton (2004) Long Term Athlete Development Model

However, due to the existence of periods of naturally occurring accelerated adaptation, the model suggests there is a "window of opportunity" during the developmental years, suggesting children and adolescents are more sensitive to training induced adaptations during these periods (Balyi & Hamilton, 2004). Failure to utilise this window of opportunity will limit the individual's full athletic potential (Balyi & Hamilton, 2004). Although, a large number of National Governing Bodies (NGB's) have implemented the LTAD model a significant lack of research exists to validate the model's effectiveness (Ford *et al*., 2011). Such suggestions have been largely criticised due to a lack of evidence and suggestions that this window closes, when in fact they remain open. (Ford *et al.,* 2011, Fischer., 2006). Furthermore, such observations lack scientific rigour and have been largely based on observations (Lloyd *et al.,* 2016). The Balyi & Hamilton (2004) model suggests that, during periods of natural adaptation, exposing athletes to a given stimulus will prevent reaching a ceiling' effect on performance (Lloyd *et al*., 2011). However, conflicting research suggests, natural growth and development will surpass any training stimulus. Bacquet *et al.,* (2003) examined the effects of training on VO_{2max} in youths aged 13-18, finding little difference in development as a result of training compared to that of maturation alone.

From this, Lloyd & Oliver (2012) designed the Youth Physical Development (YPD) model (See Figure 2). The YPD model proposes that the primary focus for boys aged 12-16 years should be on strength, power, speed, agility, and sport-specific skill development, while fundamental movement skills, such as jumping, landing and kicking should be present within any athlete development program, for any athlete, of any age (Lloyd & Oliver, 2012). Additionally, it has been suggested that muscular strength is critical for successful fundamental movement skill development (Behringer *et al.,* 2011). A review of motor competency, by Cattuzzo *et al.,* (2016) showed children and adolescents demonstrated strong positive association between fundamental movement competency and muscular strength. Consequently, it is reasonable to suggest that developing levels of muscular strength should be a priority of any athlete development program, as strength would appear to underpin all other fitness components (Lloyd & Oliver 2012). Developing muscular strength should also be included in youth strength and conditioning programs, not only for performance enhancement but also for reducing the risk of sport-related injuries (Faigenbaum *et al.,* 2009). In 2011, the National Athletic Trainers' Association recommended that 50% of overuse injuries in youth sports could be preventable with appropriate strength development (Valovich-McLeod *et al.,* 2011). As such, a focus should be placed on developing the ability to competently perform the fundamental movements that underpin advanced gym-based exercises (athletic movement competency).

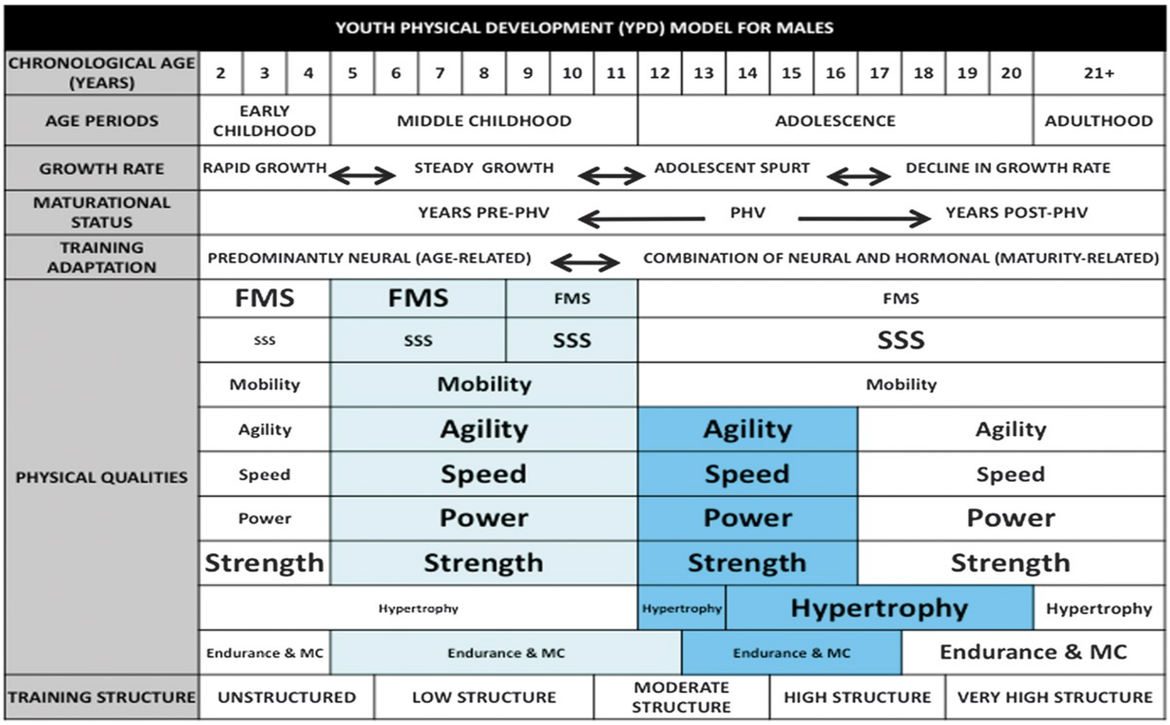

Figure 2. The Youth Physical Development (YDP) Model (Lloyd & Oliver, 2012)

1.3 The Elite Player Performance Plan

The Elite Player Performance Plan (EPPP) was developed between the English premier league and football league clubs in 2012, with the aim of producing more homegrown players (Premier League, 2011). The EPPP aims to develop the physical, technical, tactical and psychological capabilities of the academy players through a long-term strategy and multi-discipline approach. The plan consists of non-negotiable stipulations around staffing, facilities, coaching hours, and games programme, with the aim to increase the coaching hours for players who joined the system at 9 and exited at 21, from 3,760 hours to 8,500 hours (Premier League, 2011). Furthermore, the EPPP recommends appointing specialist staff to contribute towards the multi-disciplinary approach. Specifically, the appointment of sport science staff enables the implementation of maturation measurement, monitoring, and individual physical and biomechanical analysis to enhance player development and reduce injury risk (Premier League, 2011). Despite this, recent research has demonstrated a linear relationship between injury risk and growth ((Johnson *et al.,* 2022). Therefore, a better understanding of how growth affects individuals is needed, to help reduce injury risk and improve physical development.

1.4 Athletic Movement Competency

1.4.1 Introduction to Athletic Movement Competency

Athletic movement competency (AMC) is defined as the ability to competently perform the basic movement patterns which underpin advanced resistance training techniques (Lundgren *et al.,* 2014). Greater movement competency in youth is related to increased physical activity, participation in sport, and athletic success (Hulteen *et al.,* 2018 and Lai *et al.,* 2014). Young adolescent football players possess lower lean body mass and lower maximal strength in comparison to adult players (le gall *et al.,* 2010). Consequently, there is often a transitional period for young players whereby physical development is emphasised within their training, so they can compete with more mature athletes (Rogers 2020). Moreover, competency in foundational resistance training skills were found to be positively associated with muscular fitness, perceived strength, resistance training self-efficacy and motivation for resistance training in boys (mean age 14.1 years) (Smith *et al.,* 2018). Therefore, competencies of basic weightlifting movements, such as the squat, hinge and lunge should be critical aspects of any LTAD model (Balyi 2001) in order to adequately prepare athletes to safely and effectively participate in resistance training. Ultimately, AMC can lay the foundations among young players so that more advanced strength training can be introduced at senior level (Rogers, 2020).

Furthermore, movement competency does not occur in children as a result of natural development, but it is a process that is learned through coaching and opportunities (Hulteen *et al.,* 2018). However, if fundamental movement skills are not learnt, then individuals may encounter proficiency barriers when trying to learn AMC. This is largely explained by neuromuscular maturation, which appears to account for development of AMC. As skeletal maturation only accounted for a small (6.1%) percentage of variance in AMC in children aged 3-6 years (Freitas *et al.,* 2018).

During puberty, an increase in testosterone and the development of the neuromuscular system improves muscular contraction in the lower body (Kraemer *et al.,* 1989, Lloyd and Buchanan 2001). Thus, resulting in improved AMC, from improved muscular contraction, motor control and muscle bulk. However, it has been suggested that relative strength has more influence on motor competency than maturity (Pichardo *et al.,* 2019).

1.4.2 Relevance to Youth Football

The assessment of AMC can help identify deficiencies and technical flaws when performing movement patterns (Myer *et al.,* 2014). Exploring AMC throughout adolescence and the transitions made during academy football such as 'adolescent awkwardness' (described as delays or regressions in sensorimotor function relative to rapid growth spurts (Quatman-Yates *et al.,* 2012)) and PHV will help practitioners develop performance benchmarks and implement appropriate training strategies to improve the physical development of young academy players (Rogers 2020). Suggesting rapid changes in limb length and body mass impair proprioceptive and movement ability, Ryan *et al.,* (2018). Consequently, implementing movement quality training interventions with football players around PHV to lessen the effects of adolescent awkwardness. However, limited, and conflicting research has explored the effects of maturation on AMC in youth soccer players. Ryan *et al.,* (2018) reported no significant differences between maturation groups in relation to Functional Movement Screen (FMS) scores while Lloyd *et al.,* (2015) reported those post-PHV performed the FMS significantly better. However, the differing results could be due to the poor scoring methods of the FMS and inappropriateness for athletic populations. Additionally, these studies used different methods to assess biological maturation and conducted testing at different times within the season. Which may explain the differing results. Therefore, future research using more appropriate screening methods is needed to assess the effects of maturation on AMC.

1.5 Movement Assessment Protocols

Screening has commonly been used for identifying movement dysfunctions associated with injury, rather than assessing the ability to perform foundational movement patterns. Such screening protocols more specific to athletic populations, for example; the Conditioning Specific Movement Tasks (CSMT), Movement Competency Screen (MCS), Resistance Training Skills Testing Battery (RTSB), the MovementSCREEN, Athlete Introductory Movement Screen (AIMS) and the Athletic Ability Assessment (AAA). Further details of these screening methods and the assessment protocols can be seen in Appendix 1.

1.5.1 The Functional Movement Screen

A common method of screening in sport, in more recent times, is the FMS. The FMS aims to provide a reliable tool to objectively measure functional movement patterns that are modifiable and indicative of an elevated likelihood of sustaining musculoskeletal injury. The FMS classifies seven movements (overhead squat; in-line lunge; hurdle-step; rotary stability test; trunk-stability push-up; shoulder mobility test; active straight-leg raise) into one of three performance levels (3 = performs movement without compensation; 2 = performs movement with compensation; 1 = cannot perform movement). Several studies have explored the association or lack thereof between movement and physical performance using the FMS (Hartigan *et al.,* 2014, Lloyd *et al.,* 2015, Lockie *et al.,* 2015). The FMS was originally developed as a screening tool to determine if someone is safe to exercise (Gamble 2013) and does not account for sporting demands, such as dynamic movements like jumping and landing. Furthermore, the rigid scoring system means a wide range of movement abilities can be scored the same, explaining its poor ability to identify meaningful change in movement quality (Frost *et al.,* 2012). Thus, leading sports performance practitioners have been found to prefer using their own movement assessment screen(s) in place of the FMS (McKeown & Ball 2013).

Consequently, more specific screening tools, capable of assessing and tracking movement competency are needed.

1.5.2 Conditioning Specific Movement Tasks and Movement Competency Screen

The CSMT (Parsonage *et al.,* 2014) and MCS (Milbank 2016) adopt a similar protocol to the FMS but incorporate movements more specific to those used in rugby conditioning (i.e., sprinting, jumping, landing, and lifting), (Parsonage *et al.,* 2014). The CSMT consists of an overhead squat, Romanian deadlift, single leg squat, double leg-single leg landing, 40m sprint, Counter Movement Jump (CMJ), Yo-Yo intermittent recovery test level 1. The MCS consists of squat, lunge, twist, bend, pull, push-up, and single leg squat. These tasks were specifically aligned to the *training to train* phase of the LTAD model presented by Balyi and Hamilton (2004). Thus, it maybe better suited to older or more skilled adolescents and senior athletes entering or training in a high-performance program. Notably, Reid and colleagues (Reid *et al.,* 2015) recently concluded that some tasks in the MCS were too difficult for an adolescent netball cohort with limited to no resistance training background. Furthermore, tasks are scored on a 4-point scale (similar to FMS on each of the tasks which ranged from 0 to 3 points and total score range from 0 – 18).

The use of the FMS scoring system means the MCS and CSMT can only deem athletes as competent or not competent. Using this scoring method limits the ability of the CSMT and MCS to track small changes in athletic movement competency (AMC) over time or discriminate between individual subjects, as a wide range of movement abilities can be scored the same (Frost *et al.,* 2012). Further research has shown weak associations between the total MCS score and injury risk and even presented untrue results of asymmetry (Inovero *et al.,* 2016 and Milbank 2016). Therefore, the validity of the MCS is questionable. However, it has been suggested that the reliability of the MCS was higher through analysis of digital recording (Milbank 2016).

1.5.3 Resistance Training Skills Testing Battery

The Resistance Training Skills Battery (Lubans *et al.,* 2014) was designed to i) evaluate the efficacy of resistance training programmes and ii) track, monitor and provide feedback on

AMC over time (Lubans *et al.,* 2014). Therefore, it has the ability to detect small improvements in both individual skills and overall skill competency (Lubans *et al.,* 2014). The protocol consists of body weight squat, push-up, lunge, suspended row, standing overhead press, and front support with chest touches. The assessment requires two sets of four repetitions for each task with the score being based on the best repetition. Rather than using the criteria to guide score (similar to the FMS), the score is the sum of the criteria met, receiving one point for each. Although this allows movement to be tracked in a more continuous nature, it lacks the ability to identify improvements due to its yes or no criteria. Furthermore, it was designed for and with the constraints of a school setting in mind and therefore requires minimal equipment and can easily be conducted by educators. Thus, it may not account for sporting demands and sport specific skills, such as jumping, landing and unilateral force absorption.

1.5.4 The MovementSCREEN

The MovementSCREEN (Bennett *et al.,* 2019) is an electronic-based, video-recorded tool used to track changes in movement quality that occur in response to individualised exercise interventions (Bennett *et al.,* 2019). It consists of a squat, lunge, deadlift with bent over row, single leg squat, overhead reach, thoracic rotation, four-point with opposite arm/leg lift, push up, and active straight leg raise. Similarly, to the FMS, CSMT and MCS each movement contains specific criteria and are scored as a 'yes' or 'no' response. The quality of each individual movement is scored using a 100-point sliding scale (with a score of 100 being suggestive of perfect movement). To create a final movement quality score for each movement, the score is weighted against a sum of the component items to provide an overall score out of 100 (100 being the highest achievable score). The sliding scale used in this assessment tool allows for greater sensitivity in scoring and tracking changes in movement quality. However, similar to the previous screening tools, the use of a yes or no criteria may mean it possesses similar limitations. Furthermore, the MovementSCREEN was designed for those working in gym based environments, therefore, it may not account for the more dynamic, sporting demands such as running and jumping.

1.5.5 The Athletic Ability Assessment

Recently the Athletic Ability Assessment (McKeown *et al.,* 2014) was designed to reflect the key movements which underpin advanced gym programmes. It consists of Overhead Squat, Inline Lunge and a Single Leg Romanian Deadlift which are videoed and marked retrospectively. The AAA is aimed towards athletes travelling along the performance sport pathway and require increased movement competency as they transition to higher sport demands (McKeown *et al.,* 2014). Rather than using a yes or no criteria, individual movements are scored on three criteria per movement over 3-tiered system (e.g. good, inconsistent, or poor-form), task scores range from 3-9, adding the score from each area to obtain a total movement score. Thus, making the scoring system more sensitive to changes in AMC (Rogers 2020). Studies have demonstrated the validity and reliability in its scoring system (McKeown *et al.,* 2014). To date, no studies have explored it use in adolescent academy football players, with all previous research having been conducted in Australian rules football (Rogers 2020). Saw *et al.,* (2017) demonstrated the upper limb was the second-most common body region of injuries in Australian football, in comparison to Hawkins (2001) where upper limb injuries only accounted for 3% of injuries in soccer. Furthermore, the match demands in Australian rules youth football (Jennings *et al.,* 2023) was lower than that seen in youth soccer (Reynolds *et al.,* 2021). Therefore, it is possible that the demands of the Australian rules football account for the results shown (Rogers *et al.,* 2020). There is potential for the AAA to be used in other sports settings and AAA data on other populations e.g. academy football players, this would be of use to practitioners and researchers. However, prior to this there is a need to understand Performance of the AAA in adolescent academy football players.

1.6 Growth and Maturation

Growth, in relation to the body, refers to the increase in size of the body or its parts, whereas maturation refers to the progression towards full grown adult height, this is different between individuals and can also be different for tissues (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al.,* 2014). The growth and maturation of children is a complex process, consisting of anatomical and physiological changes, which is influenced by gene, hormones, nutrients and the environments in which the individual lives (Bar-Or, 2004).

1.6.1 Chronological Versus Biological Age

Chronological age is the number of years and days (at a precise time-point) an individual is from their date of birth (Hannon *et al.,* 2020). Within English football academies players are usually categorised and compete within chronological age-groups e.g. U12, U13, U14, U15, U16, U18 (Wrigley *et al.,* 2012). However, biological maturation and chronological age can differ within individuals, as the timing, rate and rate of change of biological maturation differs between individuals (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al.,* 2014, 2016). For example, an early maturing player will be biologically advanced compared to their peers in the same chronological age group. Similarly, a late maturing player will be biologically behind their peers in the same chronological age group (Figure 3) (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al.,* 2014, 2016).

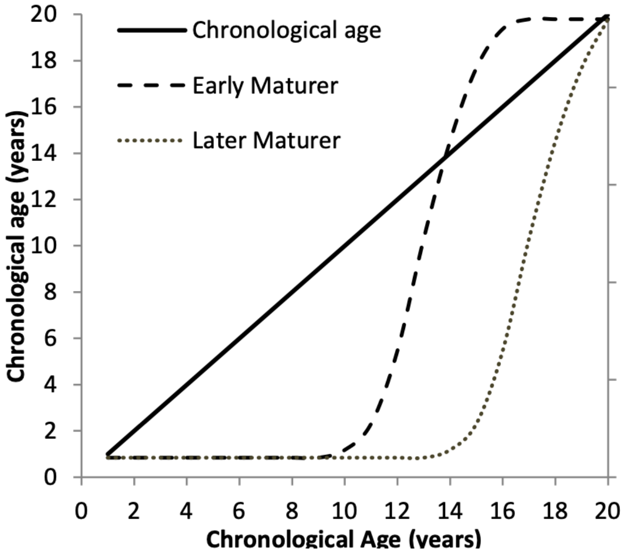

Figure 3. Differences in developmental trends of chronological age and biological maturation of early- and late-maturing boys (Oliver *et al.,* 2014).

Research suggests a bias may exist towards *early* or *on time* matures within football academies (Coelho-e-Silva, 2017, Malina *et al.,* 2000; Carling, Le Gall and Malina, 2012). Thus, due to those possessing superior athletic qualities compared to *Late* maturing individuals, such as speed and strength. Thus, meaning accurate measures of growth and maturation are needed in order to limit bias towards early maturing players. Researchers have also noted the importance of considering biological maturation when developing appropriate training programs to optimize training adaptation and minimize injury risk among children/academy players (Lloyd and Oliver 2012).

1.6.2 Methods of Assessment of Maturation

There are multiple methods available to assess maturity status, the level of maturity at a given age and the timing. These methods can be classified as either invasive or non-invasive, the relative strengths and limitations of these assessment measures will be discussed.

1.6.2.1 Invasive Methods – Sexual Maturation

Sexual maturation through puberty, is the development towards fully functional reproductive capability (Tanner, 1962). Biological development in males takes place during childhood to adulthood and is characterised by changes in primary (testes and penis) and secondary (e.g. pubic and facial hair) sexual characteristics from development of the reproductive system (Malina *et al.,* 2004). This method of assessing maturation is not commonly used with youth athletes, due to the invasive and unethical nature (Lloyd *et al.,* 2014). Furthermore, this method is only capable of assessing maturation around puberty. Assessment of pubertal stage involves classifying the status of sexual characteristics, from characteristic from stage 1 (prepubescent or immature) to 5 (pubescent or mature) typically known as the 'Tanner stages' (Tanner, 1962, Malina *et al.,* 2004). Self-assessments have also been researched, as a way around the invasive nature of this approach. Studies validated this method (Matsudo and Matsudo, 1994; Leone and Comtois, 2007). However, individuals are likely to under or overestimate their status (Leone and Comtois, 2007).

1.6.2.2 Sexual Maturation in relation to performance

Assessment of pubertal stage (sexual maturation), has been previously researched in youth players across Europe (Ital, Portugal, Denmark and England) (Malina *et al.,* 2005, Malina *et al.,* 2007 Forbes *et al.,* 2009, Hansen *et al.,* 1999, Figueiredo *et al.,* 2011, Figueiredo *et al.,* 2009 Sproviero *et al.,* 2002). These studies demonstrated a strong relationship with maturity and physical performance. As 13-15 year old boys who were advanced in sexual maturity were significantly better at performing physical tasks, with stage of pubic hair positively correlating with sprinting, jumping and aerobic performance (Malina *et al*., 2004). Finally, none of the studies reported measurement reliability, suggesting such information is difficult to obtain.

1.6.2.3 Invasive Methods – Skeletal Maturation

Assessing skeletal maturity is a method to determine the stage of development of the skeletal, from cartilage to bone and is considered the gold standard method of assessing maturity (Malina *et al*., 2004). Typically, radiography (x-ray image) of the wrist is used to determine biological maturity. However, due to the exposure of radiation, this method is invasive and not often used within practice (Lloyd *et al*., 2014, Malina *et al*., 2015, Tanner, 1962; Malina, Bouchard and Bar-Or, 2004). Furthermore, using radiography requires special equipment and trained practitioner who is capable of analysing the imagery, Such equipment and expertise can be costly. To determine the stage of development of the skeletal, there methods are used; the Fels method (Roche, Chumlea and Thissen, 1988), Tanner-Whitehouse methods (TW1, TW2 and TW3) (Tanner *et al*., 1975, 1983, 2001) and the Greulich-Pyle method (Greulich and Pyle, 1999). These methods were intended for different populations and aren't as accurate when used on youth athletes (Malina *et al.,* 2007; 2017). Consequently, due to the expensive and potentially inaccurate nature of this method it's not commonly used.

1.6.3. Non-Invasive Methods – Somatic Maturation

Somatic maturation is the most common method used, to determine maturity, within soccer academies. Thus, lacks invasiveness, requires little training and isn't timely. (Buchheit and Mendez-Villanueva 2013; Lovell *et al*., 2015; Towlson *et al*., 2017). Somatic age is the amount or change in stature or body parts (Lloyd *et al.,* 2014). Anthropometric measurements can be obtained and subsequently used to derive several indicators of maturity including growth rate, age at PHV and percentage of predicted adult height attained. Approaches have been developed to estimate these through anthropometric measures and predictive equations. There are several commonly used methods to estimate somatic maturity which include equations by; Khamis and Roche (1994); Mirwald *et al.* (2002); and Sherar *et al.,* (2005).

1.6.3.1. The Khamis Roche Method

The Khamis Roche (1994) method uses an equation which consists of current stature, body mass and the mean parent stature (mean stature of both parents). From this the predicted height and Percentage of adult height (PAH) can be calculated. However, due to the requirement for the inclusion of both parents heights, it is not always feasible to be used. Furthermore, this method often requires self-reporting of parents heights, which can often lead to error in prediction of adult height and subsequently PAH. Furthermore, this method was developed on white Americans and has been shown to have an error rate of 2.2cm (Khamis and Roche 1994).

1.6.3.2. The Mirwald Method

The Mirwald method (Mirwald *et al.,* 2002) uses a prediction of the age that PHV occurs. The equation consists of age, body mass, stature, sitting stature and leg length. From this, the age of which PHV occurs and the maturity off set (on time, before or after PHV) can be calculated, this method has a standard error of 0.24 years Mirwald *et al*., (2002). This method is based off growth going proximal to distal, where bones in the feet and legs grow before those in the trunk. A positive of using this method is, it does not require parents height. However, the accuracy has been question when using it on different ethnicities, although those have been debunked by Buchheit and Mendez-Villanueva (2013).

2. Study 1: The Reliability of the Athletic Ability Assessment

2.1 Introduction

The assessment of athlete movement competency (AMC) in academy football has previously been used to help practitioners implement training programs to improve players physical development. Currently, the association between movement competency and injury is inconclusive (Newton *et al.,* 2017). Due to poor evidence on movement screening protocols. However, assessments of movement competency have been particularly useful during adolescence and the period of PHV (Rogers 2020), as it allows practitioners to identify movement dysfunctions due to growth as rapid changes in limb length and body mass impair proprioceptive and movement ability (Ryan *et al.,* 2018). Therefore, practitioners aim to identify those dysfunctions in order to implement movement quality training interventions and lessen the effects of adolescent awkwardness.

Specific screening protocols have been used within athletic populations, for example; the Conditioning Specific Movement Tasks (CSMT), Movement Competency Screen (MCS), Resistance Training Skills Testing Battery (RTSB), the MovementSCREEN and the Athlete Introductory Movement Screen (AIMS) (see Table 1). Several questions around the have been raised, as it has been suggested that the scoring systems used for these assessments means a wide range of movement abilities can be classified as the same score (Frost *et al.,* 2012). Further questions have been raised about the movements used within these assessment protocols, as McKeown *et al.,* (2014) recommends using movements which underpin athletic performance. Additionally, the FMS, RTSB and MovementSCREEN were designed to be used within school and gym-based environments and therefore may not be suitable to use within academy football.

The AAA was designed to reflect the key movements which underpin advanced gym programmes and has been specifically designed towards youth athletes progressing through pathways such as football academies (McKeown *et al.,* 2014). The AAA can be used to help identify deficiencies and technical flaws when performing movement patterns (Myer *et al.,* 2014). Using the AAA to explore AMC throughout adolescence and the transitions made during academy football such as 'adolescent awkwardness' (described as delays or regressions in sensorimotor function relative to rapid growth spurts (Quatman-Yates *et al.,* 2012)) and PHV will help practitioners develop performance benchmarks and implement appropriate training strategies to improve the physical development of young academy players (Rogers 2020) To date, no prior study has explored the use of the AAA in adolescent academy football players, with previous research having been conducted in Australian rules football (Rogers 2020). Whilst an additional study within professional female football demonstrated the validity and reliability of the AAA scoring system (McKeown *et al.,* 2014), however, none have assessed the reliability of this method in academy football.

The aim of this study is to assess the intra- and inter-rater reliability of the AAA and its scoring methods among academy football populations and assess changes in movement quality as players progress through adolescence and advance through academy systems.

2.2 Methods

Subjects

The participants were part of a Category 1 football academy and were aged U12-16 (n = 59) during the 2020-21 season. All subjects/participants were participating in regular football training and competition, in accordance with the regulations set out by the Premier League's Elite Payer Performance Plan (EPPP). To be included in the study, participants were injury free at the time of assessment (more than six months injury free). Ethical approval was granted by the Ethics Committee of Liverpool John Moores University.

Athletic Ability Assessment

The AAA (McKeown *et al*., 2014) consists of four movements which underpin the foundational athletic movements required to perform specific strength and conditioning exercises within team ball contact sports (Parsonage *et al*., 2014), these movements were adapted from the original AAA (McKeown *et al*., 2014). The four movements are: Overhead squat (highlights compensatory patterns through shoulder/arm/thoracic spine to cope with this position and assessing lower body mobility and strength); Double lunge (assessing hip mobility, trunk stability, strength, and motor control when decelerating); Single leg Romanian deadlift (RDL) (assessing the ability to hinge at the hips, balance and control while in single-leg stance); Single leg forward Hop & Hold (assessing the capability to reduce and stabilise forces in a unilateral environment, which is critical for change of direction) (McKeown *et al*., 2014).

Athletic Ability Assessment Protocol

All testing took place during the 2020-2021 season, at the clubs training facility, in July. All movements were completed for a total of five repetitions in both frontal and sagittal planes on both the left and right leg (10 repetitions on each leg in total), with the same camera being used for each view. A short, five- minute dynamic warm up was performed prior to assessment; this included bodyweight movements and mobility exercises (e.g. squat, lunge, leg swings and hip mobility exercises). The overhead squat was performed with a wooden dowel, held above the head. The movements were performed in a standardised order of; overhead squat, double lunge left, double lunge right, single leg Romanian deadlift left, single leg Romanian deadlift right, single leg forward hop & hold left, single leg forward hop & hold right. All movements were filmed, (Cannon XF605, Tokyo, Japan) with the camera positioned directly anterior to the

subjects and the working leg closest to the camera, with scoring being conducted retrospectively using the video analysis. One researcher (C.G.) conducted all assessments, providing a visual demonstration of each movement and verbal instructions to participants prior to completing each movement on the key areas being assessed, all participants were familiar with the testing protocol, having completed it the previous season.
No feedback was provided, while performing the assessment to reduce any potential scoring bias (Frost, *et al*., 2013).

Athletic Ability Assessment Scoring

Each movement was scored across three areas using a three-point scale (see Table 1). Each specific area was associated to a numeric value, to objectify the athletes movement competency (McKeown *et al*., 2014; Parsonage *et al*., 2014). Each key area score was summated to produce a single total movement score ranging from 3 to 9.

Assessment of Intra and inter tester reliability

To assess intra-rater reliability, the lead researcher assessed 59 participants completing the AAA via video analysis, with a test-retest conducted after 7 days. To determine the inter-tester reliability of the AAA scores, five other testers scored all participants (n = 59) from the video footage.

Raters

The testers all had at least two years' experience of movement assessment scoring. The testers were given a brief explanation of the scoring criteria for each movement and were provided with the scoring instructions (Table 1). Each tester was instructed they could watch each clip as many times and slow the video clip down as they deemed necessary before recording their score.

Statistical Analysis

All statistical analysis was completed using SPSS (Version 28 IBM SPSS Inc, Chicago, IL). For the inter reliability analysis a two-way random interclass correlation coefficients (ICC) analysis was used to determine the reliability for each movement score. The inter reliability was assessed using Kappa statistics. ICC's were interpreted according to the following criteria: high (0.90–0.99); good (0.80–0.89); fair (0.70–0.79) and poor (0.00–0.69). Kappa statistics were interpreted according to Landis and Koch (1977) slight agreement (0.01-0.20), fair agreement (0.21- 0.40), moderate agreement (0.41- 0.60), substantial agreement (0.61-0.80), and almost perfect agreement (0.81-1.00).

Table 1: Instructions provided to Academy football players when performing the Athletic Ability Assessment

Movement	Setup	Instruction
OH Squat	Participants were told to rest the dowel on their head and attain a grip width, at a right angle at the elbow. Participants are then instructed to press the dowel overhead until elbows are straight.	1. Squat to the lowest position possible. 2. Keep the dowel in line with your head. 3. Keep your arms straight.
Double Lunge	Hands on Hips, with shoes on.	1. Lunge forward and backward without stopping. 2. Ensure your knee is roughly a pound's width from the ground.
Single Leg RDL	Hands on Hips, with shoes on.	1. Lower your body in a controlled way to the lowest position possible 2. Keep a slight bend in your knee 3. Keep your back straight and head inline with your toe.

Hop and Stick	To standardised the Jump distance. Participants were asked to Lunge forward, with both knees at 90 degrees. A dowel was used to mark out the distance from the back toe to the front. Participants were then told to put their hands on their hips.	1.Standing on one leg, Hop the appropriate distance and land on the same leg. 2.Stick the landing, with a soft knee, being as controlled as possible.

2.3 Results

Table 2 presents the mean inter-rater agreement levels for each of the four movements assessed. A high degree of reliability was found between raters, with the mean ICC was .975 with a 95% confidence interval from .971 to .979 ($F(412,1652)= 39.94$, $p<.001$).

Kappa statistics showed that there was a good intra rater agreement k=.714 (95% CI, .0.27 to 1.45, P = 0.59).

Table 2: The Inter-rater reliability for each movement performed and scored in the AAA.

Movement	**Inter-Rater Reliability (ICC)**
OH Squat	0.95
Lunge (L)	0.91
Lunge (R)	0.75
SL RDL (L)	0.89
RS RDL (R)	0.90
Hop and Stick (L)	0.89
Hop and Stick (R)	0.89

2.4 Discussion

The aim of this study was to determine the intra- and inter-rater reliability of the AAA when used in youth football academies. The results from this study showed that the AAA is a reliable assessment tool to be used within English football academies. The inter-rater reliability was 0.975, which is similar to that seen in McKeown *et al.,* (2014), which was conducted in senior players Australian rules football players. The intra-rater reliability in this study was substantial (0.714), similar to McKeown *et al.,* (2014) and Rodger *et al.,* (2021).

The inter-rater reliability is of particular importance to practitioners, as it is often the case that different practitioners will rate/mark movement screenings for player's as they progress on their pathway throughout academy football. Additionally, the reliability shown in this study is better than the reliability of the FMS (Smith *et al.,* 2013). In comparison, the results of the present study show that the inter-rater reliability of the AAA was better than that seen in the RTSB, as Lubans *et al.,* (2013) reported an ICC of 0.88 with the ICC for Individual movements ranging 0.67 to 0.87. Lubans *et al.,* (2013) was also completed on adolescents (mean Age 14.3 years). Whereas the inter reliability in our study showed that the level of agreement was greatest in the OH Squat (ICC 0.95), this could be due to it being a bilateral movement and the margin for error when performing the movement is smallest. Comparatively, the lowest level of agreement was seen in the Double Lunge (R) (ICC 0.75), similar to McKeown *et al.,* (2014). Interestingly, the inter-reliability of the double lunge (L) was higher than the Lunge (R), this could be due to the right leg being the predominantly dominant leg and the left leg being the standing leg. Therefore, the movement variability could have been greater on the right leg due to spending less time on this leg. However, more research is needed to be able to conclude this.

The intra-rater reliability in this study was substantial (0.714), similar to McKeown *et al.,* (2014) and Rodger *et al.,* (2021). This finding supports that the AAA is a reliable assessment tool to be used in academy football. Neither McKeown *et al.,* (2014) and Rodger *et al.,* (2021, were conducted on adolescents, therefore, it could have been suggested that the reliability would be reduced, due to poor or inconsistent movements when scoring adolescents. However, this study has eliminated any queries around this. The reliability of any screening protocols is critical if AMC is to be compared over time, if a good level of agreement is not established, then practitioners cannot be confident in effectively tracking longitudinal changes, as changes may be due to error.

There are currently numerous screening tools used with football academies, however the reliability of these is questionable. So far, the AAA has only been researched within Australian rules football (Rodger *et al.,* 2021, Mckeown *et al.,* 2014, Woods *et al.,* 2016), and although it has been proven to be a reliable measuring tool, the same results may not be seen in English football academies. Furthermore, no study has researched the reliability of the AAA when used among adolescents.

This study is not without limitations, the participants used in this study were healthy young athletes and it is likely the variation in movement quality will be greater than more mature athletes and less than clinical practice. Therefore, the reliability shown within this study may not be transferable to different populations. Additionally, the participants performed 10 repetitions per leg (5 frontal and 5 sagittal plane), therefore it could be possible that the movement quality deteriorated towards the latter repetitions. Consequently, the reliability when assessing these repetitions could be reduced.

The findings in this study demonstrate the AAA is a reliable screening tool when used on adolescent academy football players. The inter- and intra-rater reliability within this study was similar to that in previous studies, on different cohorts. Additionally, the reliability scores in this study were better than that of other screening methods such as the FMS (Smith *et al.,* 2013) and the RTSB (Lubans *et al.,* 2013) The inter-rater reliability of the OH squat was the most reliable movement to score, which the authors suggest is due to the relatively low level of complexity of this movement, meaning there is less margin for error assessing the movement. Future studies should investigate the reliability across different experienced raters. Furthermore, practitioner should explore the relations between the AAA scores and injury risk along with the links to performance.

2.5 Practical Applications

The results from this study demonstrate that the AAA is a reliable tool to be used in a practical setting. It is recommended that stringent training takes place within the organisation, to ensure the interpretation and of the scoring criteria is standardised across raters. Furthermore, the intra-rater agreement demonstrates that AAA scores can be compared longitudinally, even if the markers change. Often the raters change due to staff turnover or transitions within academies, however, any data from previous raters remains valid and can still be used for comparisons, providing such training has taken place.

3. Study 2: The Effect of Biological Maturation on the Athletic Ability Assessment Performance in Academy Football players

3.1 Introduction

Previous literature has reported the importance of athletic movement competency for effective long term athletic development in youth athletes (Lloyd & Oliver, 2012). Greater movement competency in youth is related to increased physical activity, participation in sport, and athletic success (Hulteen *et al.,* 2018 and Lai *et al.,* 2014). Furthermore, improved neuromuscular control will increase the effectiveness during landing and cutting manoeuvres, improving physical performance and reducing the risk of injury (Sikora *et al.,* 2023). Long term athletic development (LTAD) is explained as planned and progressive development of an individual athlete to help them reach their full potential (Balyi, Way and Higgs, 2013). Therefore, competencies of basic weightlifting movements, such as the squat, hinge and lunge should be critical aspects of any LTAD model (Balyi 2001) to adequately prepare athletes to safely and effectively participate in resistance training.

Early LTAD models were originally classified based on chronological age, which is calculated as a single time point away from the date of birth. However, research has shown that chronological age is not a good indicator to base athlete development models on (Balyi & Hamilton, 2004). Chronological age is the number of years and days (at a precise time-point) an individual is from their date of birth (Hannon *et al.,* 2020). Within English football academies players are usually categorised and compete within chronological age-groups e.g. U12, U13, U14, U15, U16, U18 (Wrigley *et al.,* 2012). However, biological maturation and chronological age can differ within individuals, as the timing, rate and rate of change of biological maturation differs between individuals (Malina, Bouchard and Bar-Or, 2004; Lloyd *et al*., 2014, 2016). There are multiple methods available to assess maturity status, the level of maturity at a given age and the timing.

The Khamis Roche method (1994) is a common method used within academy football. This method uses an equation that consists of current stature, body mass and the mean parent stature (mean stature of both parents). From here the predicted height and percentage of adult height

(PAH) can be calculated. However, due to the inclusion of both parents heights, it is not always feasible to be used. Furthermore, this method often requires self-reporting of parents heights, which can often lead to error in prediction of adult height and subsequently PAH.

Another popular method is the Mirwald *et al.,* (2002) which predicts the age at which PHV occurs. The equation consists of age, body mass, stature, sitting stature and leg length. This then provides, the age at PHV and the maturity off set (On time, before or after PHV). The positive of this method, is that it does not require parents height. However, the accuracy of this equation has been questioned, particularly when used on different ethnicities (Mirwald *et al*., 2012). However, Buchheit and Mendez-Villanueva (2013) demonstrated a strong correlation between maturity off set and skeletal age.

The assessment of AMC can help identify deficiencies and technical flaws when performing movement patterns (Myer *et al.,* 2014). Exploring AMC throughout adolescence and the transitions made during academy football such as 'adolescent awkwardness' (described as delays or regressions in sensorimotor function relative to rapid growth spurts (Quatman-Yates *et al.,* 2012)) and PHV will help practitioners develop performance benchmarks and implement appropriate training strategies to improve the physical development of young academy players (Rogers 2020). To date, there is limited and conflicting research when comparing the effects of maturation on AMC in youth soccer players. Ryan *et al.,* (2018) reported no significant differences between maturation groups in relation to FMS scores while Lloyd *et al.,* (2015) reported those players post-PHV performed the FMS significantly better. However, the differing results could be due to the poor scoring methods of the FMS and inappropriateness for athletic populations. Additionally, the FMS was originally developed as a screening tool to determine if an individual is safe to exercise (Gamble 2013) and does not account for sporting demands, such as dynamic movements like jumping and landing. Recently the Athletic Ability Assessment (McKeown *et al.,* 2014) was designed to reflect the key movements which underpin advanced gym programmes and is specifically aimed towards athletes participating in performance sport pathways (McKeown *et al.,* 2014), such as football academies. Rogers *et al.,* (2021) demonstrated that those more biological mature were significantly better at performing the AAA. However, this study was carried out on Australian rules footballers and the results may not be reflected in English football academies, as the match demands in Australian rules youth football (Jennings *et al.,* 2023) was lower than that seen in youth soccer

(Reynolds *et al.,* 2021). Therefore, the aim of this study is to explore the effects of maturation on AMC in academy youth footballers, using the AAA.

3.2 Methods

Subjects

73 Male academy football players (Mean age 14.1 years) participated in this study. All players were part of a category 1 football academy and were aged U12-16 during the 2020-21 season All players were participating in regular football training and competition, in accordance with the regulations set out by the Premier League's EPPP. Athletes were injury free at time of assessment (and six months prior). These players were separated into 3 groups (pre-, circa- and post-PHV) based on biological maturation by estimating their relative proximity to PHV using anthropometric variables (Mirwald *et al.,* 2002). Descriptive statistics for each group are presented in Table 3. Ethical approval was granted by the Ethics Committee of Liverpool John Moores University.

Table 3. Descriptive statistics for each group

	Pre-PHV (n=17)	Circa-PHV (n=23)	Post-PHV (n= 19)
Age (Years)	12.4 ± 1.7	13.9 ± 1.0	15.8 ± 1.5
Height (cm)	152.6 ± 14.2	167.7 ± 7	179.7 ± 13.5
Body Mass (kg)	44.6 ± 12.9	54.1 ± 8.3	68.7 ± 12.6
Time from PHV (Years)	-1.5 ± 1.7	-0.1 ± 0.8	+2 ± 1.5

Methodology

All testing took place during the 2020-2021 season, over two separate time periods (July 2020 and January 2021). Standing height was obtained with a stadiometer (Harpenden, Seritex, Carlstadt, NJ) using the stretch stature technique. Subjects were instructed to stand fully erect and both heels, back and buttocks touching the stadiometer. The subjects head was placed in Frankfort plane, and the bar was lowered to the crown of the head, compressing the hair. The assessor placed their hands along the jaw and applied a gentle upward lift as the subject inhaled, with their heels in contact with the floor. Seated height was obtained with a stadiometer

(Harpenden, Seritex, Carlstadt, NJ) and an anthropometric box (height of 40 cm), as per ISAK guidelines (Stewart *et al.,* 2011). The anthropometric box was placed on the floor, against the back of the stadiometer. Subjects were instructed to sit as erect as possible, with their back and buttocks touching the stadiometer and their hands resting on their thighs. Furthermore, the subjects head was placed in Frankfort plane, and the bar was lowered to the crown of the head, compressing the hair. The assessor placed their hands along the jaw and applied a gentle upward lift as the subject inhaled. Body mass was measured using a portable scale (Seca 875, Chino, California), any heavy clothing was removed, and the scales were zeroed before the subjects stood on them, body mass was recorded to the nearest 0.1kg. Leg length was measured using a segmometer (Cescorf, Porto Alegre, Brazil), subjects placed their feet under an anthropometric box (height of 40 cm), with their arms hanging by the side. The assessor identified the site of the iliospinale, and the distance between the top of the box and the iliospinale was measured, with the branch of the segmometer placed on top of the box. Consequently, the height of the box (40 cm) was added on to the measurement. All measurements were recorded by the same practitioner. The AAA was completed by all players within one week of collecting anthropometric data. All AAA movements were filmed frontal and sagittal planes, using a camera and tripod, and retrospectively assessed by the same rater who had at least 2 years' experience of movement assessment scoring.

Athletic Ability Assessment Movements

The AAA consists of four movements which underpin common gym programmes in team sports, the movements were adapted from the original AAA illustrated by (McKeown *et al.*, 2014). As they reflect the foundational athletic movements required to perform specific strength and conditioning exercises within team ball contact sports (Parsonage *et al.*, 2014). These movements were, overhead squat (highlights compensatory patterns through shoulder/arm/thoracic spine to cope with this position and assessing lower body mobility and strength); double lunge (assessing hip mobility, trunk stability, strength, and motor control when decelerating); single leg RDL (assessing the ability to hinge at the hips, balance and control while in single-leg stance) and single leg forward hop & hold (assessing the capability to reduce and stabilise forces in a unilateral environment, which is critical for change of direction, McKeown *et al.*, 2014).

Athletic Ability Assessment Protocol

All the movements were completed for a total of five repetitions both the left and right leg. A short, five- minute dynamic warm up was performed prior to assessment; this included bodyweight movements and mobility exercises (e.g. squat, lunge, leg swings and hip mobility exercises). The overhead squat was performed with a wooden dowel, held above the head. The movements were performed in a standardised order of; overhead squat, double lunge left, double lunge right, single leg Romanian deadlift left, single leg Romanian deadlift right, single leg forward hop & hold left, single leg forward hop & hold right. All movements were filmed, (Cannon XF605, Tokyo, Japan) by positioning the camera anterior to the subjects, the scoring was completed after the assessment by reviewing the video footage. The same researcher carried out the assessment on all participants, giving the same instructions (Table 1) whilst also using visual demonstrations.

All participants were familiar with the testing protocol, having completed it the previous season. No feedback was provided, while performing the assessment to reduce any potential scoring bias (Frost, *et al*., 2013).

Athletic Ability Assessment Scoring

Each movement was scored across three areas using a three-point scale (see Table 4). Each specific area was associated to a numeric value, to objectify the athletes movement competency (McKeown *et al*., 2014; Parsonage *et al*., 2014). Each key area score was summated to produce a single total movement score ranging from 3 to 9.

Assessment of Biological Maturation

Biological maturation was estimated using the Mirwald method (Mirwald *et al*., (2002), where maturity offset and the age at PHV is calculated using leg length, height, seated height, body mass, and age. The subjects were then classified as pre-PHV (greater than 1-y pre-PHV), circa-PHV (within 1 y on either side of PHV), or post-PHV (greater than 1-y post-PHV). This method was selected due to its non-invasive method and practicality for use in the field (Lloyd *et al*., 2014).

Statistical Analysis

All statistical analysis was completed using SPSS (Version 28 IBM SPSS Inc, Chicago, IL). A one way ANOVA was used to determine difference between groups ability at performing each movement, with significant group effects followed up using the Tukey post hoc test. Descriptive statistics are presented as mean and standard deviation, with the significance set at $p < 0.5$.

3.3 Results

Over Head Squat

There was a significant difference between groups ($F(2,56) = 4.216$, $p = 0.020$), with movement quality, on the overhead squat significantly higher for post-PHV (7.74 ± 1.4, $p = 0.15$) ˙compared to circa-PHV (6.48 ± 1.47). There was no significant difference between the pre-PHV (6.94 ± 1.29) and post- ($p = 0.215$) or circa-PHV ($p = 0.561$) (Figure 4).

Double Lunge

There was a significant difference between groups ($F(2,56) = 10.32$, $p =0.001$), with movement quality on the double lunge (left) significantly lower for pre-PHV (5.53 ± 0.1.23, $p = 0.001$) and circa-PHV (6.22 ± 1.54, $p = 0.10$) compared to post-PHV (7.42 ± 0.90). There was no significant difference between pre- and circa-PHV ($p = 0.22$ (Figure 5).

There was significant difference between groups ($F(2,56) = 11.057$, $p = 0.001$), movement quality on the double lunge (Right) was significantly lower for pre-PHV (5.59 ± 1.18, $p = 0.001$) and circa-PHV (5.91 ± 1.28, $p = 0.001$) compared to post-PHV (7.32 ± 1.11). There was no significant difference between pre- and circa-PHV ($p = 0.67$) (Figure 6).

Single Leg RDL

There was a significant difference between groups determined by a one way ANOVA ($F(2,56) = 6.89$, $P = 0.002$). A Tukey post hoc test revealed that movement quality on the single leg RDL (Left) was better for post-PHV (7.26 ± 0.80, $p = 0.001$) compared to pre-PHV (5.71 ±

1.57). There was no significant difference between circa-PHV (6.43 ± 1.30) and post- (P = 0.95) or pre-PHV (p = 0.76) (Figure 7).

There was a significant difference between groups as determined by a One-way ANOVA ($F(2,56) = 12.34$, $P < 0.001$). A Tukey post hoc test revealed that movement quality, on the Single Leg RDL (Right) was significantly lower for pre-PHV (5.44 ± 0.96, p = <0.001) and circa-PHV (6.13 ± 1.06, p = 0.006) compared to post-PHV (7.16 ± 1.07). There was no significant difference between pre- and circa-PHV (p = 0.109) (Figure 8).

Hop & Stick

There was a significant difference between groups and determined by a One-way ANOVA ($F(2,56) = 6.96$, $p = 0.002$). A Tukey post hoc test revealed that movement quality, on the hop and stick (Left) was significantly lower for pre-PHV (5.94 ± 1.19, p = 0.002) and circa-PHV (6.35 ± 1.23, p = 0.026) compared to post-PHV (7.26 ± 0.80). There was no significant difference between pre- and circa-PHV (p = 0.485) (Figure 9).

There was a significant difference between groups and determined by a One-way ANOVA ($F(2,56) = 3.48$, $p = 0.038$). A Tukey post hoc test revealed that movement quality, on the hop and stick (Right) was significantly higher for post-PHV (7 ± 1.11, p = 0.37) compared to pre-PHV (5.94 ± 1.39). There was no significant difference between circa-PHV (6.25 ± 1.25) and post- (P = 1.46) or pre-PHV (p = 0.70) (Figure 10).

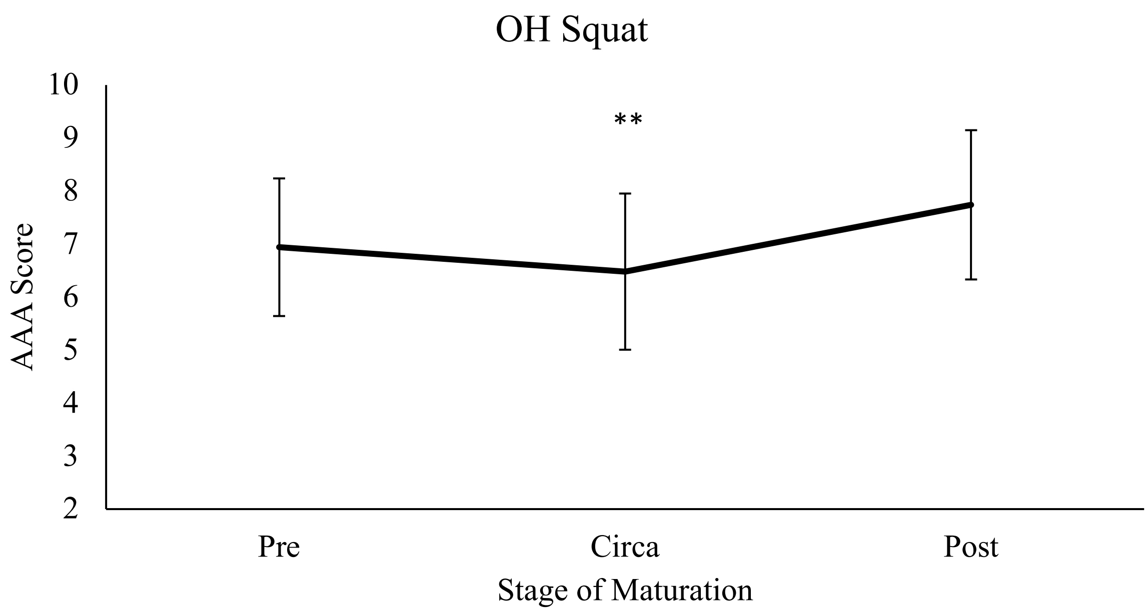

Figure 4: Between group differences for OH Squat (Mean + SD). ** Significant difference between circa- and post-PHV

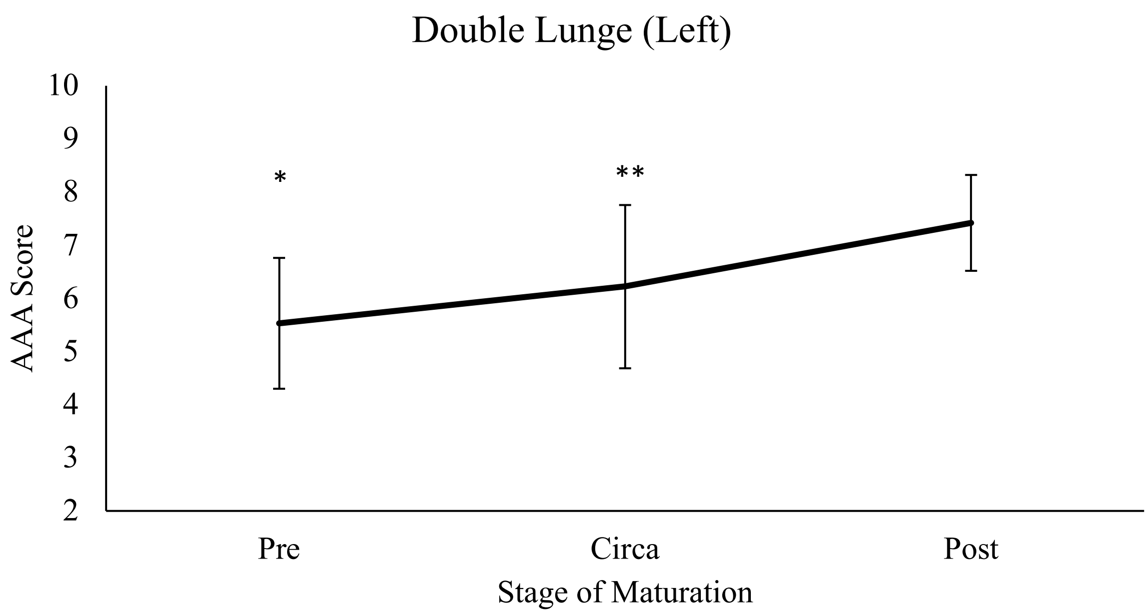

Figure 5: Between group differences for Double Lunge (Left) (Mean + SD). * Significant difference between pre- and post-PHV ** Significant difference between circa- and post-PHV

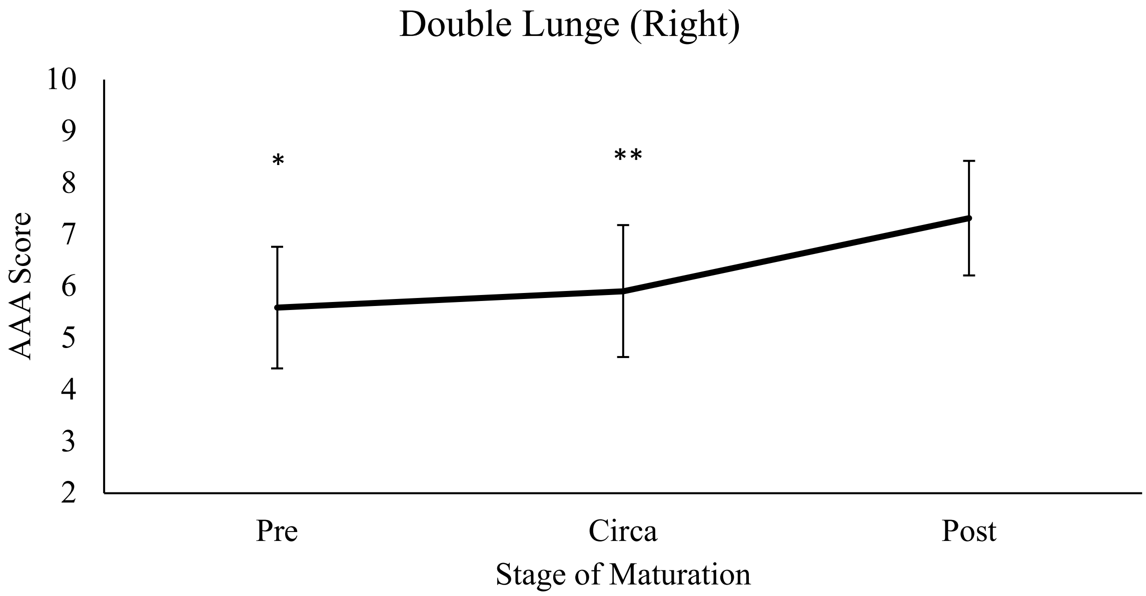

Figure 6: Between group differences for Double Lunge (Right) (Mean + SD). * Significant difference between pre- and post-PHV ** Significant difference between circa- and post-PHV

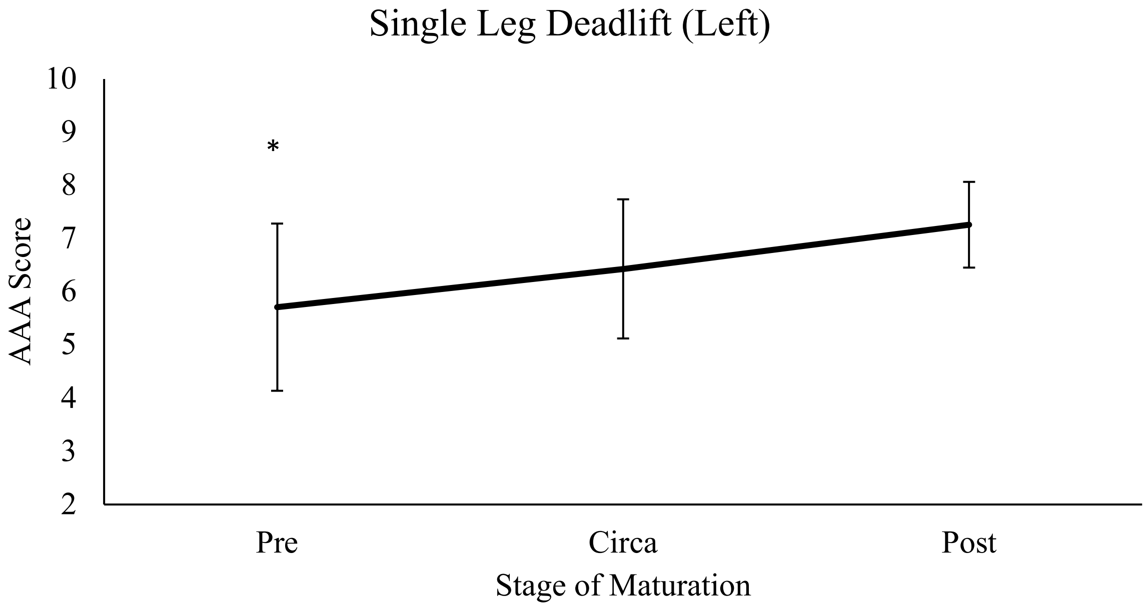

Figure 7 Figure 7: Between group differences for Single Leg Deadlift (Left) (Mean + SD). * Significant difference between pre- and post-PHV.

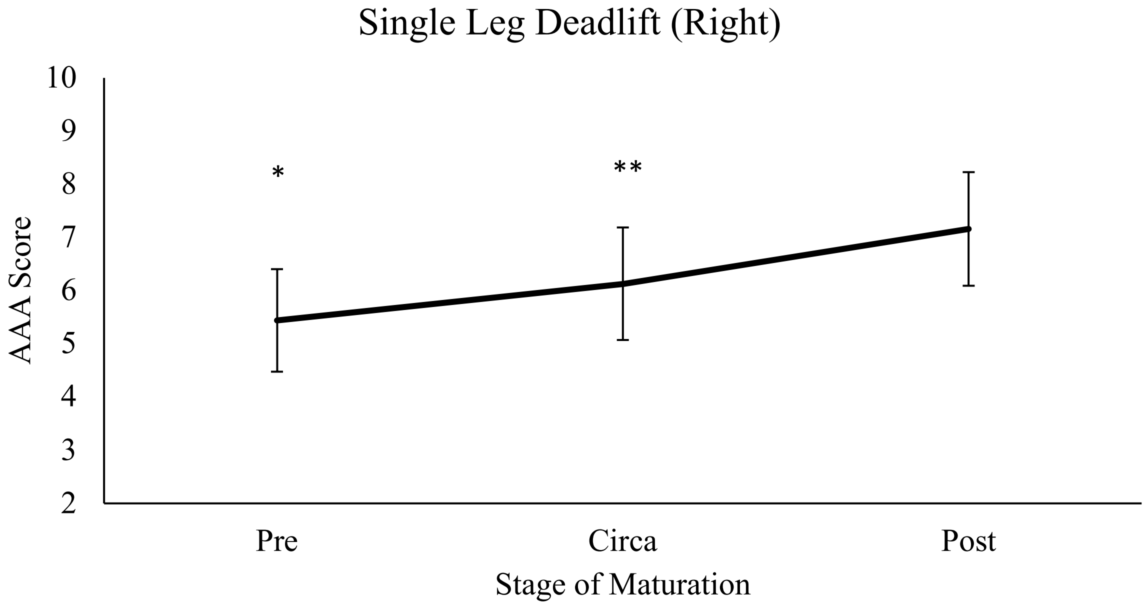

Figure 8: Between group differences for Single Leg Deadlift (Right) (Mean + SD). * Significant difference between pre- and post-PHV. ** Significant difference between circa- and post-PHV.

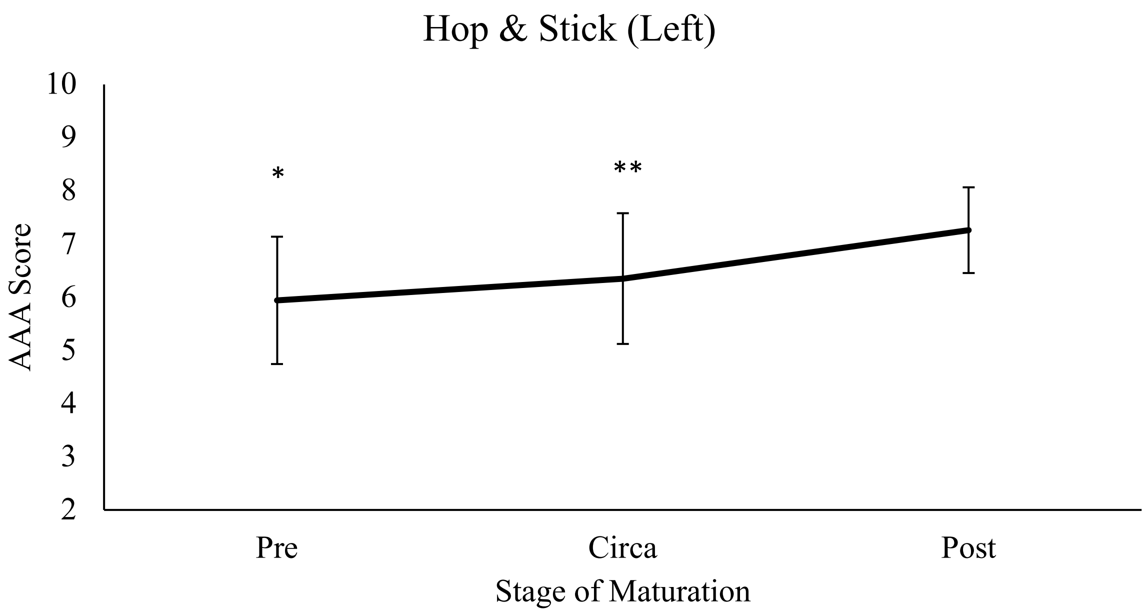

Figure 9: Between group differences for Hop & Stick (Left) (Mean + SD). * Significant difference between pre- and post-PHV. ** Significant difference between circa- and post-PHV.

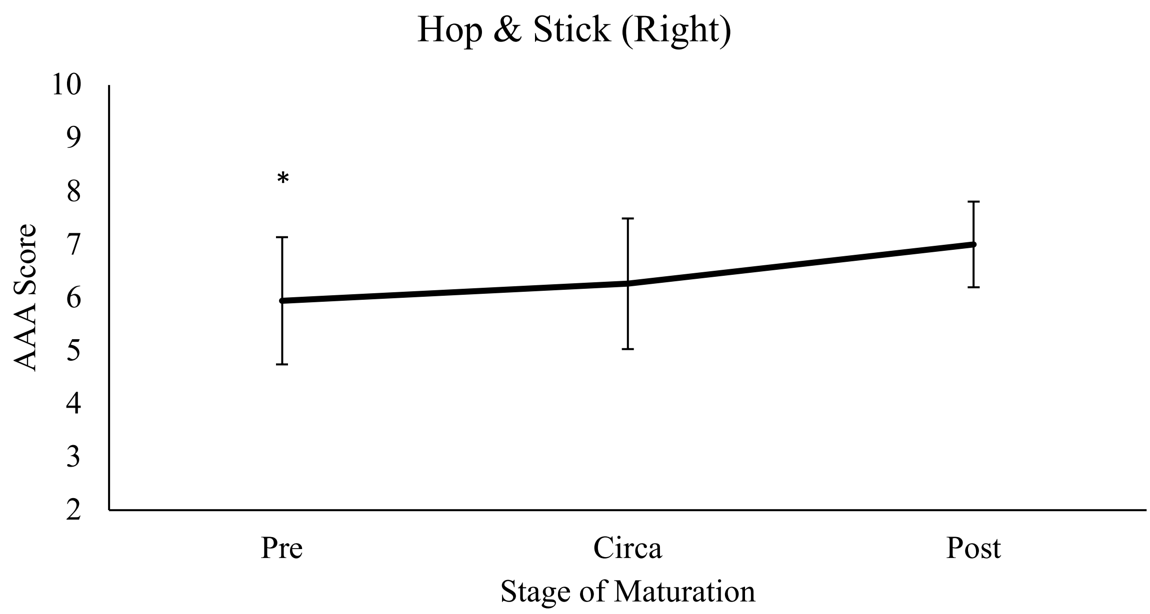

Figure 10: Between group differences for Hop & Stick (Left) (Mean + SD). * Significant difference between pre- and post-PHV.

3.4 Discussion

The aim of this study is to explore the effects of maturation on AMC in academy youth footballers, using the AAA. The results from this study, show that AAA performance of the Double Lunge, SL RDL and hop and stick improves with biological maturity, thus is most likely due to increases in strength which occur during male adolescence (Carron *et al.,* 1974). However, the circa- groups were significantly worse at performing the OH squat. This is the first study to analyse the effects of biological maturation on AAA performance in football players. Previous studies have been conducted in Australian rules football, predominantly on senior cohorts.

Although there were significant differences between pre- and circa- groups when compared to post-, they did not differ between each other. Thus, suggesting a stagnation in AMC during the period of PHV, which could potentially be explained by adolescent awkwardness, which is described as delays or regressions in sensorimotor function relative to rapid growth spurts (Quatman-Yates *et al*., 2012). Suggesting rapid changes in limb length and body mass impair proprioceptive and movement ability. Consequently, changes in limb length and impaired proprioceptive ability could explain why little differences were seen between the pre- and circa- groups. However, similarly to Rodgers (2021) the OH squat showed the circa- group to be significantly worse compared to both pre- and post-groups. It is possible that a reduction in mobility as a result of PHV could explain these results as the OH Squat is highly dependent on joint mobility rather than muscular strength (Rodgers 2021). During PHV joint stiffness and flexibility is impaired (Ford *et al.,* 2010) which could explain the reduction in OH Squat ability during PHV.

Interestingly, there was no significant difference between the circa- and post group when performing the SL RDL (left). However, there was a significant difference between these groups when performing the SL RDL (right). Further asymmetries were found during the hop and stick, as there was no significant difference between circa- and post- groups on the right, compared to the left. This was predominately due to the post- group being better on the left compared to the right. Therefore, it could be suggested that the right leg is the predominantly dominant leg and therefore, the left leg is used more for standing. Consequently, this may have led to improve balance and control on the left side. However, future research is needed to understand any asymmetries between groups, as this wasn't the main aim of this study.

The results from this study show that practitioners should consider maturation status when comparing AMC. Failure to consider maturation status could result in miss judgment of AMC of late maturing players. Consequently, leading to inappropriate exercise selection when programming.

This study is not without limitations, most notably the method used to determine stage of maturation. The Mirwald (Mirwald *et al.,* (2002) method was used due to inaccurate or poor availability of additional data such as parents height. Therefore, this method was the best available. This method has been questioned when used with some ethnicities and has been shown to under or over predict years from PHV by around one year (Moore *et al.,* 2015). Therefore, it is possible that the stage of maturation may have been wrongly predicted.

In conclusion, the results from this study suggest that practitioners should monitor AMC changes in relation to maturation status. Using the results of this study, it can be suggested that strength and conditioning programs should focus on flexibility, proprioceptive and movement competency during PHV as these seem to be impaired or delayed during this period. However, there are some considerations to be made, as this study used the Mirwald method (Mirwald *et* *al*., (2002) to calculate maturation status which has been questioned when used on different ethnicities (Mirwald *et al*., 2012). Future studies should explore the effects of maturation on AMC using multiple methods to calculate maturation status, to determine the differences between each method.

3.5 Practical Applications

Using the findings in this thesis, the AAA can be used in conjunction with other monitoring tools to monitor players throughout their adolescence. This study demonstrated the circa-groups were significantly worse at performing the OH squat, which we hypothesised was due to reduced mobility. Therefore, practitioners can use the AAA with maturation monitoring tools to highlight players with increased risk of growth-related injuries. For example, if a player is circa PHV, has significant growth and reduced OH squat performance, then their programme could be adjusted accordingly. Furthermore, the AAA can be used for exercise selection, if a player is circa PHV and has decreased OH squat performance, then mobility exercises could be prescribed. Consequently, if a player is post PHV and has improved double lunge performance then strength-based exercises could be prescribed.

Table 4: The modified AAA used to assess athletic movement competency as adapted from McKeown *et al*. (2014).

Movement	Assessment Point	3	2	1
Overhead Squat	Upper Quadrant	Perfect hands above head and feet	Hands above head and feet	Unable to achieve position
	Triple Flexion and squat depth	Squat to parallel	Near Parallel/Parallel with compensatory	Unable to achieve position
	Hip Control	Perfect Alignment throughout & Heels down, neutral spine	slight loss of control, slight elevated heels, Valgus & Hip Flexion.	Excessive deviation
Double Lunge	Hip Knee, ankle	Perfect Alignment (90-90) Heels down	Slight Deviation, heels up, valgus, under/over 90-90	Poor alignment, excessive heels up & valgus
	Hip Control	Perfect Control/Neutral hip position	Slight deviation, flexion/Extension	Excessive Flexion/Extension
	Take off Control	Perfect control	Jerking	Excessive Deviation
Single led RDL	Hip Control frontal	Full Control no deviation	Slight loss of control, Excessive Flexion/Extension on SL Stance	No control excessive deviation
	Hip control Sagittal	No Rotation	Slight Rotation at end range	Excessive rotation
	Hip Range	Achieves Parallel	Near parallel	Unable to reach near parallel

Single leg forward Hop & Hold	Hip/Knee/Ankle Alignment	Perfect alignment	Inconsistent/Minor misalignment (Valgus, varus, Heels up etc)	Poor Alignment
	Balance/Control	Landing with perfect control and balance	Sticks Landing but unbalanced. Adjustments using other body parts (Leaning etc)	No balance or control on landing
	Power Position	Lands in Single Leg power position/quarter squat after every rep	Inability to land in power position on some but not all reps OR makes adjustments post landing to attain power position	Excessive hip/knee/ankle flexion. Poor positioning to reproduce force.

Appendix 1 Summary of Athletic Movement Competency Screening Methods

Protocol name (Abbreviation) Reference	**Objectives / Population and Key aspects of the study.**	**Scoring Method**	**Movements assessed**
The Functional Movement Screen (FMS) (Cook *et al.,* 2006)	To predict injury risk by assessing mobility and stability capability on multiple joint segments of the body. Indicate preparedness or readiness to commence exercise and identify individuals who have developed movement dysfunction. Designed for Healthy and active general population.	0 = pain anywhere in the body during the movement. 1 = unable to complete the movement pattern or is unable to adopt the position to perform the movement. 2 = able to complete the movement but with compensation in some way 3 = movement correctly performed without any compensation. Specific criteria: yes/no Movement Score: 1-3 Combined Score 7-21	Overhead squat; in-line lunge; hurdle-step; rotary stability test; trunk-stability push-up; shoulder mobility test; active straight-leg raise

Condition Specific Movement Task (CSMT) (Parsonage *et al*., 2014)	To assesses movement quality of gym-based conditioning tasks. Evaluating an athlete's preparedness train in Elite Rugby Union. Originally was in adolescent rugby union players (U16 years). Also used to asses preparedness to progress into the next stage of their development.	Tasks scored on a 4-point scale (similar to FMS on each of the tasks which ranged from 0 to 3 points and total score range from 0 - 18. Specific criteria: yes/no Movement Score: 1-3 Combined Score	Overhead squat (OH Squat) Romanian deadlift (RDL), single leg squat (SL squat),double leg-single leg landing (DL-SL landing), 40m sprint, CMJ. Yo-Yo intermittent recovery test level 1 (IR1).
Movement competency screen (MCS) (Kritz, 2012)	To assesses movement quality and dysfunction specific to athletic populations. To assist in the level of exercise selection and loading parameters (e.g. body weight or ready for external resistance)	Perform 6 repetitions of each bilateral task and 12 repetitions of each unilateral movement task (i.e. three facing the sagittal plane and three facing the frontal plane). Individual movements scored on multiple criteria per movement over 3-tiered system, tasks scores range from 1–3, total score range 7 – 21	Squat, lunge,twist, bend, pull, push-up, and single leg squat

	Athletic populations entering or engaged in structured physical preparation training.	Specific criteria: yes/no Movement Score: 1-3	
Resistance Training Skills battery (RTSB) (Lubans *et al*., 2014)	The RTSB was designed to evaluate the efficacy of school- and community-based resistance training programs and to support children's understanding broader understanding of physical fitness concepts. Study used a general secondary school cohort of 44 boys and 19 girls (mean age = 14.5 ± 1.1 years), participants were assessed twice, 7- days apart for the initial reliability assessment.	Assessment requires 2 sets of 4 repetitions for each task. 4 or 5 performance criteria's for each task are rated as pass/fail and points added together to give an overall score in each task. Scores based on the best repetition (i.e. the repetition in which the participant satisfied the highest number of performance criteria was used to represent the score for that task). Tasks summed to create a resistance training skill quotient (RTSQ) with a possible range of 0–56. Specific criteria: Pass or Fail Composite score: 0 – 56	body weight squat, push-up, lunge, suspended row, standing overhead press, and front support with chest touches

MovementSCREEN (Bennett *et al.,* 2019)	An electronic-based, video-recorded movement quality assessment tool guides individualised exercise interventions; providing a clear starting point from which an individual can commence gym-based resistance exercise. Designed for those working in gym based environments.	Each testing session was video recorded where one camera recorded the sagittal plane of movement and one the frontal plane from the anterior aspect. Each individual movement is scored using a 100-point sliding scale with associated cues (with a score of 100 being indicative of perfect movement quality). To create a final movement quality score for each movement, the subjective score is weighted against the sum of the component items to provide an overall score out of 100 (100 being the highest achievable score). For unilateral movements, each side is scored sepa- rately, and a mean score of the two sides is provided	Squat, lunge, deadlift with bent over row, single leg squat, overhead reach, thoracic rotation, four-point with opposite arm/leg lift, push up, and active straight leg raise.

		Specific criteria: yes/no Overall movement quality: 0 – 100 Movement score: 0 – 100 Composite score: 0 – 100	
Athletic Ability Assessment (AAA) (McKeown *et al*., 2014)	To assess movements specific for athletic populations to determine preparedness to progress into the next stage of their development. Aimed for athletes travelling along the performance sport pathway (LTAD) and require increased movement competency as they transition to higher sport demands. Original presentation assessed national level female football players (n=17); movements scored by the primary researcher in real-time and via video on two separate occasions.	Movements scored on 3 criteria per movement over 3-tiered system (e.g. good, inconsistent, or poor-form), task scores range from 3-9. Movement score: 3 – 9 Composite score: 21 – 63	Overhead Squat, Inline Lunge, Single Leg Romanian Deadlift

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