

**UNIVERSITY of
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**Methods to assess maximal strength in elite adolescent
soccer players: A narrative systematic review.**

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Declaration

I hereby declare that all work included in this thesis is my own, and the document was composed by myself under the supervision of Dr James Dugdale and Prof. Angus Hunter. External advice was also sought from Dr Marco Beato and Dr Thomas Brownlee. I fully understand the severity and consequences associated with committing plagiarism. This thesis does not infringe on upon anyone's copyright claim and all references and material used in this thesis have been acknowledged in accordance with common reference practises.

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II – GENERAL ABSTRACT

Background – Maximal strength (MS) is a key physical quality for the talent development (TD) and talent identification (TI) of youth elite soccer players. This is due to strength's key role in underpinning explosive soccer actions such as sprinting and decelerating and the relationship between strength and injury occurrence. Due to the developmental nature of youth soccer, conducting MS assessments within this population requires several considerations. Nonetheless, a narrative systematic review of MS assessments has not been conducted in youth elite male and female soccer athletes.

Objectives - The aims of this narrative systematic review were to: (1) identify the tests and modalities used to assess MS in youth elite soccer players; (2) identify how chronological and biological age may impact the selection of strength tests; (3) report the reliability values of included tests.

Methods – A systematic narrative review of the academic databases PubMed (MEDLINE), Scopus, Web of Science, CINHL and SPORT Discus were conducted for studies published until March 2023, using the Preferred Reporting Items of Systematic Reviews and Meta-Analyses (PRISMA) Guidelines. Studies were eligible for inclusion if they: (1) included a population younger than 18 years old (i.e, mean age of the group); (2) players were part of an elite academy or national governing body; (3) included a MS assessment, with reported absolute values; (4) was original work published in a peer-reviewed article and not as a review, in English.

Key results – This review returned 86 studies; 22 different tests were implemented with a total of 181 individual evaluations performed. The most common assessments were knee extensor strength (23% of evaluations), and knee flexor strength (22% of evaluations). Three different modalities of strength assessment were identified, maximal voluntary contractions (MVC), maximal voluntary isometric contractions (MVIC) and dynamic free weight (DFW) assessment. The most popular modality was MVC assessments which were assessed in 40 studies (47%) with the majority evaluations performed being isokinetic dynamometry (55% of all evaluations). The

implementation of DFW tests were generally employed in older populations (15 years and above). Thirteen studies reported reliability (15%), all of which reported acceptable reliability. However, only the Isometric Mid-Thigh Pull (IMTP) (ICC = 0.93 – 0.98) and NHE (ICC = 0.84-0.96) were shown to have good to excellent within-session reliability within athletes aged less than 15 years old.

Conclusions – The broad range of different testing within this review highlights the variety of strength assessments available to practitioners. It is important to determine factors such as maturity status, technical competency and outcome goals when designing a testing battery for youth elite athletes. Given the lack technical proficiency that may exist in younger athletes and athletes experiencing rapid growth, it should be advised that practitioners conduct their own reliability assessments within their environment.

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V – LIST OF ABBREVIATIONS

1RM	– 1 repetition maximum
3RM	– 3 repetition maximum
5RM	– 5 repetition maximum
BS	– Back Squat
CMJ	– Counter movement jumps
CV	– Coefficient of variation
DFW	– Dynamic free weight
HHD	– Hand-held dynamometer
HSR	– High speed running
ICC	– Intraclass correlation coefficient
IKD	– Isokinetic dynamometry
IMTP	– Isometric mid-thigh pull
KG	– Kilogram
LTAD	– Long term athletic development
MVC	– Maximal voluntary contraction
MVIC	– Maximal voluntary isometric contraction
N	- Newtons
PHV	- Peak height velocity
PRISMA	– Preferred reporting items for systematic reviews and meta-analyses.
PT	– Peak torque
R	– Pearson's r correlation coefficient
RFESS	– Rear foot elevated split squat
TD	– Talent Development
TI	– Talent identification

1 – INTRODUCTION

1.1 - Background

With over 5 billion fans worldwide (The Football Landscape – The Vision 2020-2023 | FIFA Publications), football is broadly considered the most popular sport in the world. Football clubs in Europe's top leagues typically generate over 500 million euros annually (Annual Review of Football Finance 2022 | Deloitte UK) and the revenue of these clubs is positively linked with their competitive success (Sakinc et al, 2017). Therefore, to maximise their on-field success, investment in performance and player development is a key priority for professional football clubs. One strategy used by football clubs to maximise the potential of long-term success are systematic talent development (TD) programmes, typically in the form of youth academies (Williams et al, 2020a). Within these systems, young footballers are recruited to the club with the aim to develop first team footballers. These players are trained from a young age to fit the club's philosophy and style of play from a physical, technical, and tactical perspective (P. R. Ford et al, 2020). This approach has been successful in producing talent within the top leagues in Europe. In England, players such as Phil Foden, Marcus Rashford, and Bukayo Saka are all academy graduates playing in their respective first team in the Premier League and representing their country, internationally. Football clubs may also sell their academy players to generate revenue (P. R. Ford et al, 2020). It has been reported that SL Benfica in Spain have made over 379 million euros in academy player sales since 2015, with a single sale of João Félix worth 126 million euros (Richard, 2024). Professional clubs see their academies as a source of income and have the goal of producing players for their first team (Gavião et al, 2023; Sæbø & Hvattum, 2018). Accordingly, football clubs may prioritise the identification and development of talent within their academies to maximise financial and competitive success.

Talent identification (TI) is recognised as the process of identifying individuals with the potential to become elite senior players (Unnithan et al, 2012). Football coaches and scouts' expert opinions are important during the identification of talent. Whether a scout or coach believes a

player possesses the ability or potential to play for a club's academy has been identified as an intuitive feeling based on multiple factors including a player's technical ability, game understanding, and social behaviours such as motivation (Williams et al, 2020b). In recent years, objective information, such as match-play statistics, cognitive and physical profiling have been utilised within the talent identification process (Baláková et al, 2015; Ghar et al, 2021; Yunus et al, 2024). This approach allows clubs to create profiling systems that reduce bias and the reliance of opinion in TI. During their review of TI and TD in soccer between 2000 and 2020, Williams and colleagues (2020) concluded that players who successfully progressed from youth academies to senior professionals displayed a physical advantage in fitness, weight, and speed. Consequently, it may be deemed as important for players to have physical profiles that can cope with the ever-increasing demands of elite football match play and the high chronic workloads experienced across a season (Barnes, 2014). To establish a physical profile of a young footballer requires players to perform a battery of tests that assess the broad range of characteristics associated with soccer performance, such as linear sprint speed, change of direction, strength, power, flexibility, and balance (Hulse et al, 2013a). Scores may then be compared to create benchmarks and identify high performing individuals or areas for development (Rebello et al, 2013). As part of the physical profiling process, chronological age and biological maturity are also considered, given the substantial changes to individual physiology experienced throughout adolescence (Patel et al, 2019). This information can influence coach decision-making around performance evaluation, (de)selection, and recruitment, adding further context to TI and TD in youth soccer.

A club's TD programme is a holistic environment with the aim to nurture and develop football talents so that players reach their highest potential (Vaeyens et al, 2012). These environments are multi-disciplinary and aim to develop a player's technical, tactical, physical, and psychological capabilities (Williams et al, 2020a). Within professional academy programmes, it is the primary role of sport scientists and Strength and conditioning (S&C) coaches to enhance

the physical capabilities of players (McQuilliam et al, 2022a). During childhood, a practitioner may focus on broad range of gross, fundamental motor skills aiming to develop players with high a competency of physical literacy both on and off the pitch (Sommi et al, 2018). As a player progresses towards and through adolescence, the developmental focus typically changes to increase capacity of the body systems associated with actions such as sprint speed, change of direction, MS, and intermittent running performance (P. Ford et al, 2011a; Lloyd & Oliver, 2012). Physical training is often designed and delivered within a multidisciplinary football programme, as well as being supplemented via dedicated pitch-based and off-field S&C. Throughout this process, practitioners assess and monitor physical qualities of their players to gauge fitness levels, track developmental progress, or in an attempt to minimise injury risk (Asimakidis, Mukandi, et al, 2024; Pena-González et al, 2019; Sherwood et al, 2021).

Strength assessments form a prominent component of S&C training and injury prevention in football. Assessments of maximal or relative force are often integrated as part of a multidimensional assessment battery used by coaches and practitioners working in football. Strength can be defined as the maximal amount of force the body is able to exert against an external object (Moritani & DeVries, 1979; Suchomel et al, 2016) and may serve as an underpinning physical quality to a variety of sporting movements. During actions prevalent in soccer training and competition such as sprinting, jumping, decelerating, and contesting duels, the amount of force produced during these actions may be limited because of MS (McBride et al, 2009; Taber et al, 2016). Consequently, assessing and monitoring strength as part of a systematic TD programme may be extremely valuable.

When considering young, developing soccer players and the vast physiological and neural development experienced throughout adolescence, there are many variables that may be problematic when assessing MS. For example, limited motor competence, specificity of movement, and considerations pertinent to reliability are but three considerations that may be

considered when assessing muscular strength in adolescent players. To date, no systematic reviews exist within published literature that report strength assessments employed when assessing muscular strength within this group.

1.2 General Aims of Review

The aim of this thesis is to summarize the current body of evidence of strength assessments used in male and female junior-elite soccer players to better understand the commonly used tests within research. Furthermore, this thesis aims to determine the strengths and limitations of the assessment utilised highlight areas of further research with regards to this sample. Findings from this thesis aim to develop the understanding of use of MS assessments in junior-elite soccer players and ultimately aid practitioners when selecting methods of strength assessment within their own applied practice

2 - LITERATURE REVIEW

2.1 – Talent development

Professional football academies may recruit players from as young as 8 years old (Larkin & Reeves, 2018). It is proposed that a greater amount of time exposed to a holistic talent development programme increases the chances of producing players who transition into professional senior football (Vaeyens et al, 2008; Wrigley et al, 2014). To support the development of young players throughout their academy journey, National Federations and Governing Bodies have developed performance strategies to provide objective guidance to clubs and practitioners. For example, in 2012 the English Premier League introduced the Elite Player Performance Plan (EPPP) with the aim to improve the quantity of home-grown professional footballers by English clubs (Cooper, 2021). Following the implementation of the EPPP, age groups within academies are split into 3 categories; Foundation Phase (U5–U11); Youth Development Phase (U12-U16) and Professional Development Stage (U17-U21). This allows multidisciplinary support for young players to be tailored to their developmental stage (Williams et al, 2020a). Researchers in the field of youth physical development suggest that a long-term approach to talent development should be adopted, focussing on developing a broad technical and physical base in younger players before progressing to specific skills later in their development (P. Ford et al, 2011; Lloyd & Oliver, 2012; Williams et al, 2020a).

These systematic performance strategies outline that during foundation phases, coaches play a significant role on the technical development of players, less focus is placed on tactical awareness, and technical skills are developed in a fun environment whilst driving enjoyment. During developmental phases, players practise applying their technical ability within different tactical roles and systems. Finally, during professional development phases, players are taught to apply specific principles and tactics to outmanoeuvre and beat opposition (Cooper, 2021). Physical development follows a similar pattern of general to specific motor qualities throughout

different phases of these systematic performance strategies. Whilst most physical qualities can be trained throughout childhood and adolescence, it is recommended that practitioners focus on introducing fundamentals of movement in the younger ages with the aim to broad skill base (P. Ford et al, 2011a). This is deemed to be a longitudinal approach to athletic development which may support athletes develop 'building blocks' for fundamental movements and allow for training and development of physical qualities in a structured and progressive manner (Lloyd & Oliver, 2012). Early and ongoing engagement with training and monitoring of physical qualities remains consensus amongst scientists, coaches, and practitioners working with this population.

Effective TD programmes for academy players are multi-disciplinary in nature (Kelly et al, 2022), Williams et al, 2020b). Whilst technical and tactical mastery is key for a player to succeed in professional football, physical, psychological, and sociological traits are understood to contribute to selection and high-performance in player development (S. Gil et al, 2007; S. M. Gil et al, 2007; Lago-Peñas et al, 2011; Razali Abdullah et al, 2016; van Yperen, 2009). In football, multi-disciplinary teams typically consist of sport scientists, S&C coaches, nutritionists, psychologists and technical analysts (Raya-Castellano & Uriondo, 2017). These support roles work in a holistic manner to improve the physical ability, recovery strategies, tactical understanding and mental capabilities of players (Dean et al, 2022; McQuilliam et al, 2022a; North et al, 2022). To this end, support staff have become integral to maximise the development of young football players ensuring that they are able to cope with the broad and ever-increasing demands of academy and professional football (Barnes et al, 2014; Harper et al, 2019).

In recent years, an increase in the utilisation and importance placed on data and analytics in senior professional football has been observed, with the aim to create strategies to gain a competitive advantage in recruitment and training practises (Memmert & Raabe, 2018; Pantzalis & Tjortjis, 2020; Seidenschwarz et al, 2020). Through partnerships with football technology and analytic companies such as Catapult Sports and VALD Performance, testing and monitoring

equipment is now routinely used to assess the physical qualities of players and produce in-depth reports on players' physiological load and performance during training and matches (McMahon et al, 2018; J. Reynolds et al, 2021). This demonstrates the transition to more of a systematic approach to holistic player development and placing a greater importance of supplementary sciences than previously observed. These practises have also been utilised within academy football to improve the TD process. Consequently, academy staff are required to have a broader knowledge base in the various areas of TD and be versed in testing, monitoring, and presentation of data to support this process for young soccer players.

2.2 – Demands of soccer match play

The implementation of global positioning systems (GPS) technology in soccer has led to a greater understanding of the physical demand placed on players in training and matches (Clemente et al, 2019). A coach understanding of the physical demands of the match play is important to effectively inform the TD process (J. Reynolds et al, 2021). Football match play is an intermittent, aerobic activity, interspersed with periods of anaerobic actions, such as sprinting, jumping, jostling, accelerating, and decelerating (Datson et al, 2014; Stølen et al, 2005). Whilst the primary source of energy delivery during match play is aerobic glycolysis (Mohr et al, 2005), the importance of anaerobic actions should not be underestimated as they often influence match outcome. As a linear sprint is the most common action before goal scoring (Faude et al, 2012) and covering an opponent's attack, pressing, exploiting space and overlapping make up large parts of the distance players cover at high speed during a match (Wonwoo et al, 2023). Research suggests that total distances covered throughout a match may vary between positions and groups (Foot, 2019). However, it is typically seen that professional male players generally cover between 10 and 13 km across a competitive match (Allen et al, 2023a). Of this distance, male soccer players may cover ~750m of high-speed running (>19.8 km/h) and ~200m of sprint distance (>25.2 km/h) (Gualtieri et al, 2023a). Research into match demands of elite female

soccer players, found women usually cover 9.5 – 11.5 km during competitive fixtures (Bradley et al, 2014; Datson et al, 2017). Due to the lower peak speed in female soccer players compared to males, high speed and sprint thresholds are typically set as 15.6 km/h and 20km/h respectively (Bradley et al, 2014; Gualtieri et al, 2023a). At these thresholds elite female soccer players typically perform 1000m of high-speed running and 270m of sprinting (Gualtieri et al, 2023a).

When examining position-specific differences in both male and female soccer, wide positions (such as wide midfielders and full-backs) and attacking players (such as centre forwards and wingers) cover higher distances of high-speed running and sprinting compared to central players (Bradley et al, 2009; Datson et al, 2014; Gualtieri et al, 2023a). The tactical formation a team adopts does not seem to have a large effect on the total distance players run during a match (Bradley et al, 2011). However, there does seem to be variation amongst the distance covered at high-speed. When implementing a 4-5-1 formation, players performed less high-speed running when their team were in possession and more when they were out of possession, compared to when implementing a 4-4-2 and 4-3-3 formation (Bradley et al, 2011). Contextual evaluation shows that most of a central defender's high-speed running is accumulated out of possession in defensive actions such as covering a ball played in behind the defensive line, whilst a centre forward covers most of their high-speed running distance driving towards goal or whilst pressing the opposition players whilst out of possession (Bradley & Ade, 2018). These differences in positional demands are important to understand for practitioners as they may dictate how players are trained specific to their roles match demands.

In recent years, professional football has seen an increase in its physical demands (Allen et al, 2023b). Evidence suggests a change in tactical play whereby teams utilise more transitional moments to create scoring opportunities (Allen et al, 2023a; Sarmiento et al, 2018) and press higher up the pitch (Harper, Sandford, et al, 2021), results in a higher frequency of high-speed and explosive actions (Bortnik et al, 2022). When examining Europe's top male leagues over the

past 20–years, a ~30% increase in high-speed running and a ~50% increase in sprint distance covered during a match has been reported (Allen et al, 2023a; Gualtieri et al, 2023b; Lago-Peñas et al, 2022). It is therefore important for practitioners to design training to expose players to periods of match intensity (Ravé et al, 2020), with sufficient explosive and high-speed actions (Aiello et al, 2023; Malone et al, 2018). It is proposed that the physical demands of football will continue to increase over the coming years (Harper, Sandford, et al, 2021). Therefore, both the current and future physiological demands of soccer should be considered when designing TD programmes. This may lead to an increased emphasis on physical testing and strength training to improve the physical capabilities of academy players to ensure they are prepared for ever increasing demands of senior football.

2.3 – Strength training

Strength can be defined as the ability of the neuromuscular system to produce force against external resistance (Suchomel et al, 2016). Strength is an important physical component of a professional football athlete because it underpins sporting actions such as jumping and sprinting (Comfort et al, 2014). Newton’s 2nd law of motion ($F = m \cdot a$) (Olenick et al, 1986) dictates that the rate of change in motion is proportional to the force that is applied. Because the amount of force applied throughout an action is not consistent, the total force produced throughout the movement can be calculated, this is referred to as impulse (McBride et al, 2011). Impulse and change in velocity are directly proportional to one another meaning the greater the force, the greater the change in velocity of a movement (Schilling et al, 2008). Within football, it is important to produce large amounts of force relative to body weight for improved performance when sprinting, jumping, and jostling opposition during duels (Wagner et al, 2023). There is a direct relationship between the amount of force that can be produced during an action and the time taken to produce force, this is commonly referred to as the force-velocity curve (Rahmani et al,

2001). Force production can be separated into 3 categories, MS, explosive strength and strength endurance (James, et al, 2023). MS can be described as the peak amount of force an individual can produce (Cronin et al, 2000a), whilst the ability to produce maximal force as quickly as possible, is referred to as explosive strength (James, et al, 2023). MS is measured as the maximal load lifted or peak force produced during a movement (Heggelund et al, 2013; Takarada & Nozaki, 2021) and explosive strength is measured as the rate of change in force and is calculated by dividing the change in force by the rate of time, it is also interchangeably referred to as rate of force development (Maffiuletti et al, 2016). The lower amount of peak force produced during explosive strength efforts compared with MS efforts are due to the time constraints placed on the task (Taber et al, 2016). MS tasks require a longer duration to achieve peak force, due to an increasing number of myosin-actin cross bridges that form throughout the sustained contraction (Squire, 2019). Increasing an athlete's MS capacity has been shown to also improve their rate of force development (Cronin et al, 2000b). This is achieved through raising the overall peak force an athlete can produce, thus increasing the ability to produce force at different velocities (Taber et al, 2016). Unlike maximal and explosive strength, strength endurance is defined as the ability to repeatedly produce force with minimal loss of force production (Nelson et al, 2005). Like explosive strength, strength endurance performance is related to MS (Naclerio et al, 2009a). An individual with a lower MS is required to work at a higher intensity relative to a stronger athlete asked to produce the same quantity of force (Naclerio et al, 2009b). This may have detrimental energetic effects throughout extended bouts of performance, such as soccer. Whilst strength endurance and rate of force development are two separate qualities that are key for sporting actions in soccer (Hoff & Helgerud, 2004; Wong et al, 2010), MS typically underpins the expression of these qualities. Subsequently, the pursuit of higher levels of MS through strength training may be considered within soccer TD programmes, as practitioners aim to support players' power production and sprint speed abilities (Taber et al, 2016), alongside their ability to express

repeated anaerobic qualities within training and competition (Marios & Tokmakidis, 2006; Styles et al, 2016; Wing et al, 2020).

Strength development is regularly referenced in long-term athletic development (LTAD) and youth physical development (YPD) models as a key training modality (Balyi, n.d.; Lloyd & Oliver, 2012). These models suggests that strength training is not only safe through childhood and adolescence but also improves the long-term athletic capability of those who partake in structured resistance training programmes (Behringer et al, 2011a; Dahab & McCambridge, 2009). Strength training, both in isolation and when combined with other styles of training such as plyometric training, has been shown can reduce the risk of sports related injuries (Faigenbaum & Myer, 2010; Hanlon et al, 2020; Maffulli et al, 2015), increase physical performance (Granacher et al, 2018; Harries et al, 2012; Lesinski et al, 2016), and improve motor skills (Behringer et al, 2011b) in youth athletes.

The LTAD model suggests that there are periods of sensitivity throughout adolescence whereby specific physical qualities can be maximised, this could be however, too simplistic of an approach to youth physical training (P. Ford et al, 2011b). Instead, it is suggested that athletes should be exposed to a safe volume and intensity of all physical qualities, including strength training, throughout adolescence with an increased focus on exercises performed with a higher intensity and complexity, sport specific skills and endurance as they reach adulthood (Lloyd & Oliver, 2012).

Whilst comprehensive assessment and monitoring practices often occur in senior professional training environments, the increasing professionalisation in football and emphasis on TD has resulted in these practices stemming into youth football (Williams et al, 2020a). Therefore, strength assessments may be used in in academy systems to monitor physical development across chronological and biological age groups and prepare young players for transition to senior football.

2.4 – Strength assessments in soccer

Due to the importance of anaerobic actions in outcomes of football matches (Little & Williams, 2005; Oliver et al, 2009), assessing strength is an important to objectively measure progress of youth athletes and tailor S&C programmes (J. M. Taylor et al, 2022). When selecting tests to assess MS, it should first be determined to what extent MS underpins the selected skill, strength is task specific and therefore the amount of force required to perform a task successfully, varies between tasks (Little & Williams, 2005; Oliver et al, 2009). Testing should assess the physical underpinnings of a specific soccer action and as such, the selected test should assess the biomechanical properties related to this action. This provides identification of function and abilities of the targeted movements and muscles in relation to the sport, with the aim to enhance performance and minimise potential injury (Hulse et al, 2013b; A. J. Walker et al, 2019). Due to the importance of sprinting, turning and jumping in football, paired with the fact that resultant of the high running volumes and velocities required during competitive football, injuries are typically muscular, affecting the hamstrings, quadriceps, calves, and adductors (Ekstrand et al, 2011a), previous literature of strength testing within a soccer environment assessed the lower body musculature (Dodd & Newans, 2018; Hulse et al, 2013b; A. J. Walker et al, 2019; S. Walker & Turner, 2009). Factors such as training age, maturation and match scheduling are considerations which may affect the nature of the strength testing that is performed (Carling et al, 2015; Le Gall et al, 2007; R. M. Malina et al, 2021). Some tests are not appropriate for younger athletes due to their undeveloped movement skills and stage of physical development. Furthermore, it may not be viable to perform testing with older athletes year-round. Strength testing can be extremely taxing on the neuromuscular system and as such results in high levels of fatigue, during the competitive season tapering strategies are implemented to reduce fatigue closer to match days (Oliva-Lozano et al, 2022). Despite the advancement in the S&C field over the past two decades, there may be some resistance to strength training and testing in professional soccer from players and staff. As such conducting regular strength testing within a

competitive season may be challenging for S&C coaches. Strength testing therefore should be implemented in different forms to best suit constraints of the individual, environment and the multi-disciplinary team.

There are many factors which can be modified when performing strength testing. It's possible to assess strength at a particular joint or test over multiple joints with multiple muscle groups recruited (Gentil et al, 2015). Single joint assessments are helpful in isolating specific muscles, consequently highlighting a weakness that may not be identifiable in a multi-joint assessment. However, multi-joint strength assessments have a higher crossover to performance due to their biomechanical similarity to sporting actions (Brigatto et al, 2020). Dynamic strength exercises assess an exercise which includes an eccentric, isometric and a concentric phase (Mirkov et al, 2004). These tests can be performed using resistance machines or free weights. Dynamic free weight (DFW) strength assessments using a repetition maximum assessment, require a relatively high level of skill to perform, as the exercises require stabilisation of load combined with dynamic movements maintaining correct centre of mass throughout (Šarabon & Kozinc, 2020). Despite the time-consuming nature of these assessments, they are often seen as the gold standard of strength testing and potentially offer the highest transfer of dynamic sporting actions (Warneke, et al, 2023). These tests require movement proficiency to demonstrate an athlete's true strength capabilities. Novice lifters will underperform in DFW testing relative to their true strength because they are limited by an ability to perform the required skill. For instance, a trap-bar loaded jump has a low technical requirement, whilst an olympic clean has a higher technical skill requirement (MacKenzie et al, 2014). Both exercises tell us about an athlete's explosive strength capability, however an athlete with high explosive strength ability who isn't proficient in an olympic clean may be outperformed by a technically proficient athlete who possesses lower levels of explosive strength. In trained athletes DFW strength testing commonly uses the same exercises included within an athlete's S&C programme and therefore reduces the learning effect and familiarisation of performing the test (James, et al, 2023). This form of testing is simple to

administer and requires the same equipment used within a S&C programme so is therefore very cost effective. It has been shown to be safe in adults and children and if the athlete is competent, is a highly reliable form of strength testing (Faigenbaum, 2000). Using machines to assess an athlete's dynamic strength ability requires lower levels of skill to execute and as such has a lower learning effect and can be implemented safely and effectively with novice lifters (Fagher et al, 2016). However, it's transfer to sporting actions compared with DFW exercises is likely lower (Warneke, Wagner, et al, 2023). Whilst dynamic strength testing offers a high transfer to sporting performance, assessing eccentric, isometric and concentric strength can offer a great insight into an athlete's force producing capability.

Eccentric muscle actions are lengthening of a muscle under contraction, they can be highly fatiguing and result in higher levels of muscle damage when compared to isometric and concentric muscle actions (Proske & Morgan, 2001). During the deceleration action, the lower limbs 'absorb' kinetic energy by contracting the knee and hip extensor muscles eccentrically to reduce momentum and stop as quickly as stably as possible (Harper, Jordan, et al, 2021). Therefore, eccentric torque is essential to perform deceleration and change of direction actions. Furthermore, low eccentric hamstring strength has shown to be a risk factor for future hamstring injuries in elite soccer players, due to the peak eccentric force they experience during the touch down phase of sprinting (Vicens-Bordas et al, 2020). Isometric muscle actions occur as the muscle contracts, but its length remains constant resulting in no gross joint movements. Isometric muscle actions regulate force output through constant input from the sensorimotor system (Haff et al, 2005). Isometric contractions can be separated into two forms. Holding isometric muscle action which is maintaining the position against an inertial load and pushing isometric muscle contractions whereby force is applied against an immovable object. The neuronal control of a holding isometric seems to be like that of an eccentric muscle action, whilst a pushing isometric muscle seems more closely related to a concentric action (Schaefer & Bittmann, 2017a). This may explain why holding isometrics are more fatiguing than pushing

isometrics and therefore have shorter time to exhaustion (Oranchuk et al, 2021). Maximal voluntary isometric contractions (MVIC) are almost always a pushing isometric to assess the peak force an individual can produce. They have been shown to be fatigue sensitive and as such practitioners often implement MVIC testing to assess a player's state of fatigue and therefore along with other variables determine their readiness to train (Naughton et al, 2023). MVICs create very little fatigue, they can be executed within a weekly micro-cycle with little risk of physically overloading players, furthermore they require low technical competency to execute, meaning players technical competency shouldn't affect outputs (Schaefer & Bittmann, 2017b). MVIC has been seen as a feasible alternative to dynamic testing, however, there are several issues with this assumption. MVIC peak force is specific to the joint angle assessed. During a squat MVIC test, peak force increased as joint angles increased, due to a higher mechanical advantage to produce force (Folland et al, 2005), this can lead to standardisation issues with testing protocols. This variation in angle specific peak force may not translate to dynamic sporting actions, as a high peak force in one position may be limited in another, whilst dynamic strength testing assesses strength through a full range of motion and therefore more closely relates to sporting actions. It has been shown that studies reporting positive correlation coefficients between dynamic 1RM testing and MVIC were invalid due to statistical errors beyond the accepted limit between protocols and outcomes (Weakley, et al, 2023). Because of the physiological differences between the dynamic and isometric force production, testing of these qualities should be viewed as separate entities and evaluated as such. A concentric muscle action is where distal and proximal muscle attachments move towards one another during contraction (Padulo et al, 2013). The forces generated are propulsive forces that result in kinetic movement of the body. Whilst dynamic strength training comprises eccentric and isometric components of movements, a large emphasis sits upon enhancing concentric force production through increased motor unit recruitment and rate coding of motor-neurons (Del Vecchio et al, 2019). Through training, increases in maximal concentric strength and rate of force development of lower limb extensor

muscles correlate with improvements in jumping and sprinting performance (Bridgeman et al, 2018; Kadlubowski et al, 2021). However, solely pursuing increases in concentric rate of force development to enhance sporting performance is a limited approach to S&C. This is because during dynamic sporting actions concentric muscle actions do not occur without the inclusion of eccentric and isometric actions (Fukashiro et al, 2006). For example, during a jump there is an initial hip dip, which eccentrically lengthens the glutes and quads. This lengthening triggers a stretch reflex which enhances the amount of concentric force produced and therefore the jump height (Sheppard et al, 2008). The ability of an athlete to quickly produce eccentric force, utilising the stretch shortening cycle to produce high amounts concentric force quickly is key for sporting performance (Walshe et al, 1998). Therefore, whilst concentric strength assessments provide useful information into an athlete's force producing capabilities, they do not show the full extent of an athlete's performance capabilities.

Different forms of strength require unique equipment to perform, the costs associated with the equipment varies between tests. Free weight and resistance machine testing is financially efficient as the equipment utilised within testing is often the same equipment that is used within the training cycle. However, certain laboratory-based tests require can expensive equipment and sometimes carry recurring revenue costs for software licences that some make it inaccessible for some organisations. Tests such as the isokinetic dynamometers for maximal voluntary contractions during knee extension and flexion, require unique piece of apparatus that is not highly accessible. Whilst the cost has reduced for equipment like force plates and dynamometers which can be used to assess MVIC, these too can be out with the budget of some football clubs. There are cheaper alternatives available that can be used in place of these pieces of equipment. A sphygomometer has been shown to be a reliable measure of assessing hip adduction at a lower cost (Delahunt et al, 2011; O' Connor et al, 2023). Low-cost strain gauges can also be utilised in place expensive dynamometer to assess an IMTP MVIC (Romero-Franco

et al, 2017). A cost-benefit analysis should be performed by a clubs' performance staff to determine the addition of new equipment to a testing battery.

2.5 – Considerations of testing the youth athlete

It is recommended to use assessments to help support the long-term athletic development of youth (Romero-Franco et al, 2017). When used appropriately, assessment can help coaches understand how a child is developing, evaluate how effective a program has been and to individualize future interventions (Lloyd & Oliver, 2012; Read et al, 2019).

It is important to select tests that are shown to be valid and reliable within a youth population (Paul & Nassis, 2015). Reliability is the reproducibility of a measure's outcomes between repetitions in an individual (Artero et al, 2011; Grgic et al, 2020a). A low reliability results in larger errors in testing data, meaning that the assumptions drawn from testing can be inaccurate (Grgic et al, 2020b). Whilst strength assessments are typically reliable when performed within a youth population (Artero et al, 2011; Wollin et al, 2016a), increased between-day variation has been observed in younger athletes on some occasions (Weakley et al, 2017). There are various factors that can affect testing reliability, such as the measurement device, athlete intent and the athlete's ability to perform the required exercise (Paul & Nassis, 2015a). Gross motor skills develop rapidly throughout childhood and continue to develop through adolescence (Rosengren et al, 2003). Technical motor skills are improved along with physical strength through engagement of neuromuscular training and sport participation (Myer et al, 2013), therefore younger athletes with low training ages may struggle to perform physical tests that require a high level of motor skill. When performing tests with younger athletes it is also important to consider learning effect, a young athlete exposed to a new skill may develop their technical competency quickly, showing seemingly sharp increases in performance, which are through technical improvements of testing as appose to increases in physical ability (Costa et al, 2023). Repetition maximum strength testing using free-weights has in the past been considered unsafe and in-

appropriate for youth athletes, however there is now a consensus between leading professionals that if the athlete is familiar with the exercise and demonstrates good technical competency, it can be performed safely (Lloyd et al, 2016). These assessments do require a higher level of technical competency, therefore resistance machines and MVIC assessments may offer alternative valid and reliable measure for younger athletes.

Biological maturation should also be considered when assessing MS. Throughout adolescence children experience a period of rapid growth and development that impacts a range of physiological and biological systems (Patel et al, 2019). Growth is the change in size of body parts or the body as a whole and occurs gradually throughout childhood with a sharp spurt of growth during adolescence (Cumming et al, 2017). This rapid increase growth is referred to as the adolescent growth spurt and is closely related to the biological maturation of the reproductive and skeletal system (Soliman et al, 2014). The timing of biological maturation is different for each individual meaning some experience it at a younger age than others (Sullivan et al, 2023a), these early maturing individuals can often experience a higher rate of growth from their take-off age to their peak height velocity (PHV) age however overall growth from take-off age to full height is similar for early, on-time and late maturing individuals (Tsutsui et al, 2022). Females generally start their growth spurt between the ages of 8-10 years, with peak growth velocity being 7-9 cm/year between the ages of 11-13 (Malina et al, 2021). Males, however, are usually 10-12 years of age when they start their period of rapid growth, with peak growth velocity being 8-10 cm/year and occurring later, often 13-15 years of age (R. M. Malina et al, 2015). During, and immediately following this rapid growth, there is a change in body proportions which can cause a temporary decrease in neuromuscular control and function, commonly referred to as 'adolescent awkwardness' (Quatman-Yates et al, 2012) and occurs mostly in boys (BeunenEUNEN & MalinaALINA, 1988). This phenomenon can negatively influence a coach's acute perception of

footballing ability, observing players to exhibit periods of lower technical and physical performance (Hill et al, 2020). Due to this, consideration should be given to athletes experiencing periods of rapid growth, which can be defined as annual gains in 7cm or more in stature (Johnson et al, 2022). Rapid growth rates could result in a temporary drop in neuromuscular coordination and potentially lead to underperforming during physical testing with high technical requirements. Despite large growth rates potentially causing a temporary reduction in coordination, biological maturation has an overall positive impact on young athletes' physical capacities (Albaladejo-Saura et al, 2021). Adolescent females may demonstrate improvements in skill-based activities, whilst males often show steep increases in tasks that require muscular strength (Brown et al, 2017). A higher biological maturity is linked with greater linear speed (Sinkovic et al, 2023), change of direction speed (Fernandez-Fernandez et al, 2023), jump height (Yapici et al, 2022), muscle mass (Almeida-Neto et al, 2020) and muscular strength (Pena-González et al, 2019). In male adolescents, the greatest increase in speed occurs before PHV and both strength and power follow PHV (Brown et al, 2017; Roemmich & Rogol, 1995). Early maturing individuals possess greater physical qualities than their on-time and late maturing peers (Bacil et al, 2015; Hoyt et al, 2020). It is therefore important that athletes are compared to their peers through their biological age rather than their chronological age as this provides a fair comparison for a biologically younger player's physical ability and development (Cumming et al, 2017). Because of a temporary physical advantage, earlier maturing players are often rated more highly than their later maturing peers by coaches and recruiters (Hill et al, 2020). This can then lead to a systematic selection bias towards earlier maturing players (Bolckmans et al, 2022). Maturity timing is therefore an important factor for consideration for TI and TD in youth soccer.

MS assessments are important for development of athletic qualities in elite youth soccer players. There are many assessments that can be selected by practitioners. Whilst previous research has investigated the reliability, sensitivity and validity of testing performed in soccer, this research outlined field-based assessments and included an adult population (Paul & Nassis, 2015b). A

recent survey of practitioners working with elite male soccer players was conducted to determine assessments currently implemented within this population (Asimakidis, Bishop, et al, 2024). They found that 85% of the respondents assesses strength and the most common assessments were an isometric midthigh pull (35%) and an isometric adductor squeeze (34%) (Asimakidis, Bishop, et al, 2024). Whilst this prevalent in current male elite soccer practise, there is potentially a discrepancy within youth elite soccer research.

Aims

This literature review adopts the research question of what strength assessments are commonly used within elite youth soccer research and what considerations are given to the chosen methods. By use of a systematic narrative review, a variety of quantitative literature can be evaluated to ascertain which factors lend themselves to test selection and a tests limitation. This undertaking will endeavour to highlight what assessments are best placed to aid practitioners with their own testing processes.

- (1) Identify tests and modalities used to assess MS in youth elite soccer players.
- (2) Identify how chronological and biological age may impact the selection strength tests.
- (3) Report the reliability values of included tests.

3 – METHODS

3.1 Overview of methods

The primary objective of this review is to investigate the chosen MS assessments and the nature of said assessments within research of youth elite soccer players. Following guidelines on current definitions of different reviews within the field sport and exercise science, it was

determined that a systematic review would not be appropriate for this research question (Green et al, 2008; Tod, 2019). A systematic review uses a structured method to identify, screen, appraise and summarise the findings of studies to answer a specific research question, which does not satisfy the criteria for the chosen aim (Green & Higgins, 2008).

A scoping review was also considered for this review, whilst they can be used to map the depth and breadth of a topic (Munn et al, 2018). Scoping reviews are often used as a precursor to determine the necessity of a systematic review (Todd, 2019). It uses reproducible methods to provide readers with a clear overview of the main concepts of a topic, highlighting the different types of evidence available and uncovers gaps in the current body of literature (Mak et al, 2022). Whilst the protocols of a scoping review satisfy a majority the requirement of this reviews aims, it's key that this review provides practical implications that effect practise. Drawing on the authors expertise in the field of strength and conditioning to relate the implications of research to the real-world practise and critically appraise the implications of different testing modalities within the different facets of youth TI and TD. Therefore, going beyond the extent of a scoping review (Munn et al, 2018; Todd, 2019).

To adequately evaluate the broad range of research and provide a sufficient analysis of the methods used to assess MS , a narrative review, following a strict systematic approach was conducted (Fardilha & Allen, 2020; Furley & Goldschmied, 2021). Explicit and reproducible methods were used to systematically search a large quantity of research and critically appraise, and synthesise the findings (Gopalakrishnan & Ganeshkumar, 2013). A narrative review draws from primary research using informed expertise to provide an authoritative argument, enhance knowledge and determine area for further research on a topic (Furley & Goldschmied, 2021; Greenhalgh et al, 2018). Whilst narrative reviews can be considered less robust than systematic reviews, when carried out correctly they can provide a high level of academic rigour and a highly critically reflective approach to a specific aim (Furley & Goldschmied, 2021; Greenhalgh et al, ; Tod, 2019). The research question in this review was constructed using a variation of the PICO model

(Richardson et al, 1995). The PICO model is one of the most used frameworks to formulate research questions, define review criteria and create search strategies (Eriksen & Frandsen, 2018). Mnemonics frameworks such as PICO are tools to help researchers frame their research question and can be adjusted to suit an individual's need (Tod, 2019). Due to the scope of this review, intervention and comparison were combined in the framing of the question, due to the comparison within the research question being the assessments themselves and the evaluation of the subjects and appose to the effectiveness of an interventions effect on different groups. Study design and study setting were added. Adopting the methodological guidelines of a systematic review, this narrative review ensures reproducibility and reduces bias (Fardilha & Allen, 2020; Furley & Goldschmied, 2021; Tod, 2019).

3.2 Literature search

Following a meeting with a supervisory guidance to discuss appropriate methodology and understanding of the research question, the construction of appropriate search strings was created using Boolean operators (Sayers, 2008). By use of a systematic approach the literature review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRIMISA) guidelines (**Figure 1**), the review methods were established prior to the conduct of the review (Page et al, 2021).

For this review an assessment risk of the risk of bias was not performed due to the inaccuracy that can derive from judging the quality of observational studies. Where intervention studies are concerned, this review does not evaluate the effectiveness of any given intervention and therefore uses these studies in an observational way to ascertain the test performed and the characteristics of the athletes (Lang & Kleijnen, 2010).

It is recommended that a variety of relevant databases should be used for a literature search to reduce the risk of excluding relevant research papers (Ewald et al, 2022). Therefore, searches of Pubmed (MEDLINE), Scopus, Web of Science, CINHL and SPORTDiscus were conducted, these

databases have been used in previous systematic reviews in the field of sport and exercise science (Tod, 2019). The search was conducted on August 14th, 2021.

A second search was conducted on March 14th, 2023, with date restrictions set to the first search date. The second search was conducted to identify papers published in the period after the first search was conducted and the analysis of results performed. A manual search was also performed of the following peer-reviewed academic journals: Journal of Sport Sciences, British Journal of Sports Medicine, European Journal of Sports Science, and Journal of S&C Research. Bibliographies of the returned articles were also searched for additional citations (Tod, 2019).

3.2.1 Creating search syntax:

Two members of the research team (SH & JD) participated in devising the search syntax for the current review. The aim was to create a broad range of search terms to identify as many relevant studies as possible, that assessed MS in youth elite soccer players adopting the PICO method (Methley et al, 2014; Tod, 2019).

3.2.2 Population

Due to the differing use of *soccer* and *football* in the naming of the sport, previous reviews have highlighted the importance of including both terms, using an “OR” Boolean logic operating to creating two strings with both terms, increasing the yield return of studies (Low et al, 2019).

Research into elite youth soccer players shows discrepancy in the age ranges investigated. Whilst several reviews in youth elite soccer consider under-18 years of age to be appropriate (Abarghoueinejad et al, 2021), under-19 (Murr et al, 2018) and under-21 (Verstappen et al, 2021) have also been deemed a suitable age ceiling. Therefore, creating search terms “child” or “teenager” may not identify the full range of population. The terms “youth” OR “elite” OR “talent” OR “junior*” OR “adolescent*” OR “young” were included in the search syntax, adopted from Murr et al (2018) and Abarghoueinejad et al (2021). Furthermore, “academy” was included to encompass the elite professional academies and “paediatric” to further broaden the terms.

3.2.3 Intervention / comparison

Due to the observational nature of the included research, the interest of this review is with the comparison of selected tests and variables surrounding their selection and implementation. Therefore, it is crucial to create strings that identify various forms of testing. “Assessment” OR “measure” OR “evaluat*” were highlighted in other reviews as key terms (Murr et al, 2018), whilst “test” and “analysis” were also included in the current review.

3.2.4 Outcome

The outcome of this assessment is the highest muscular force an individual can produce (Taber et al, 2016). Whilst searching other reviews to ascertain common search terms, it seems apparent that literature varies on terms used when assessing MS. Whilst “strength” has been used a broad term previously (Lawton et al, n.d.), other reviews used more specific terms such “repetition max”, “RM” and “1RM” (Grgic et al, 2020b). In the current review terms from both reviews were adopted and “force” was included to encapsulate methods of maximal voluntary contraction (J. L. Taylor & Gandevia, 2008).

3.2.5 Search Syntax

(“soccer” OR “football”)

AND

(“youth” OR “elite” OR “talent” OR “junior*” OR “adolescent*” OR “academy” OR “paediatric”)

AND

(“assessment” OR “test” OR “measure” OR “analysis” OR “evaluat*”)

AND

(“strength” OR “force” OR “repetition max*” OR “RM” OR “1RM”.

3.2.6 Inclusion / exclusion criteria

The PICO method was used within the creation of the search syntax to determine a suitable inclusion and exclusion criteria (Methley et al, 2014). To allow appropriate selection of research papers a PICOSS criteria was created which allows for, this method incorporates study design, study setting and “other” (**Tables 1 & 2**). The study would include population of under-18 years of age (Abarghoueinejad et al, 2021; Sullivan et al, 2023a), soccer players. These players must be part of a professional academy, or national governing body organisation squad. Players must have been assessed in some form of MS with the results reported in absolute values (Taber et al, 2016). The article must be original work published in a peer-reviewed article and not as a review, in English (Aromataris & Pearson, 2014).

3.2.7 Study Screening

A two-stage screening process was followed during the manuscript selection process using a web based systematic review software (Covidence.org). Two reviewers (SH & JD), performed both title and abstract screening independently, removing all papers which failed to meet the criteria. The remaining papers were read in full by two reviewers (SH & JD) and further manuscripts that did not meet the inclusion criteria were removed. During this stage a consultation with two experts in the field (TB & MB) occurred to discuss the papers that SH & JD marked differently, to come to full agreeance regarding their inclusion. The two experts were consulted on any research currently not in the review, which may have been missed through the screening process, to which no further studies were added.

Table 1. PICOSS inclusion criteria

<i>Category</i>	<i>Criteria</i>
<i>Population</i>	Elite soccer players 18 years and younger.
<i>Intervention / Comparison</i>	Methods to assess MS
<i>Outcome</i>	Peak force, peak torque & repetition max.
<i>Study design</i>	Cross-sectional, longitudinal, cohort studies and randomised controlled trials.
<i>Study setting</i>	Professional soccer academies and national governing bodies.
<i>Other</i>	English Language, any geographical location.

Table 2. PICOSS exclusion criteria

<i>Category</i>	<i>Criteria</i>
<i>Population</i>	Athletes > 18 years old, or not soccer players.
<i>Outcome</i>	Variables not reported as absolute values.
<i>Other</i>	Manuscript was a review.

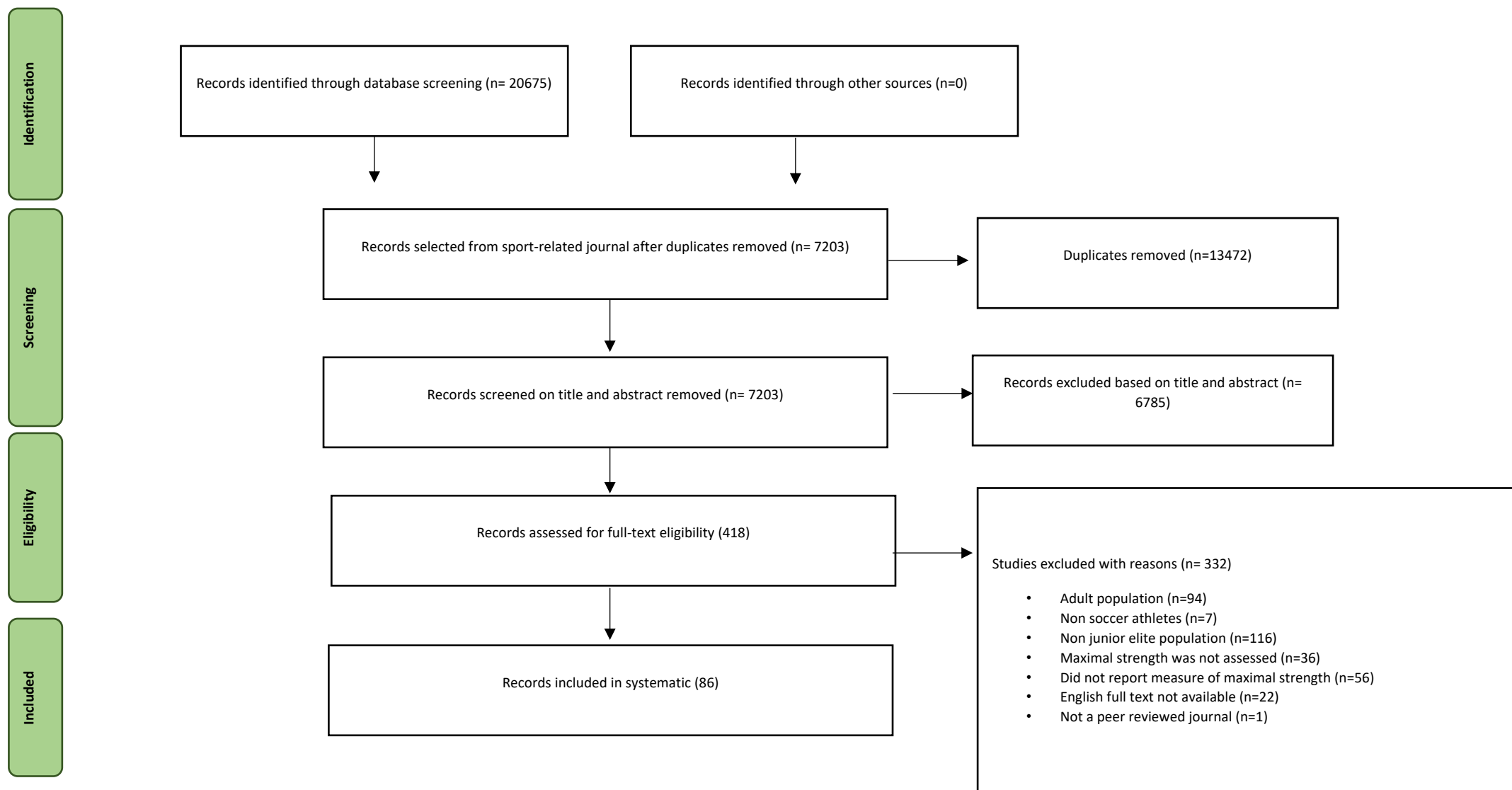


Figure 1: PRSIMA flow chart (Arder et al, 2022)

3.3 Extraction of data

To address our study aims, study characteristics were manually extracted into a custom Excel workbook (Microsoft Excel 2024, Microsoft Corporation, Redmond, Washington, USA) for all studies included in the review. The dataset included information including: (1) author names and year of publication; (2) the sample size; (3) gender; (4) age; (5) the country of origin; & playing level); (2) the experimental design of the investigation; (3) details regarding the strength assessment performed (test type, muscular contraction, & equipment used), and; (4) a summary of the main findings.

3.3.1 Quality assessment

An adapted version of the Downs and Black quality assessment scale was used to evaluate the methodological quality of studies within this review. This checklist has been used in previous systematic reviews within this subject field can be modified to meet the needs of the systematic review being performed. Questions 1-4,6-7,9-11,12,19-21 form the checklist were deemed appropriate for the aims of this review and were therefore included (**Table 3**). A 1 was given if the study met the criteria and a 0 was given if the study did not or it was unclear if the study met the criteria. Scores were summed to provide a score, 13 being the highest possible value. For question 9 if no participants were lost throughout the study, then a value of 1 was given. As for observational studies whereby no intervention was present, this was determined as the testing procedures.

1. Is the objective / aim of the study clear?
2. Are the main outcomes clearly described in the Introduction or Methods?
3. Are characteristics of the patients included in the study clearly described?
4. Are the interventions clearly defined?
6. Are the main findings of the study clearly defined?
7. Does the study estimate random variability in data for main outcomes?

9. Have characteristics of patients lost to follow-up been described?
10. Have actual probability values been reported for the main outcomes except probability < 0.001? Exact effect sizes (ES) / P-values and correlation (r) reported.
11. Is the source funding clearly available?
12. Were subjects who were asked to participate in the study representative of the entire population recruited?
19. Were the statistical tests used to assess main outcomes appropriate?
20. Was compliance with the interventions reliable?
21. Were main outcome measures used accurate? (valid and reliable)

Table 3. Quality assessments scores

ID	Study	1	2	3	4	6	7	9	10	11	12	19	20	21	Score
1	Eustace et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
2	Stern et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
3	Wong & Wong	1	1	1	1	1	0	1	1	0	1	1	1	1	11
4	Andrade et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
5	Dos'Santos et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
6	Vandendriessche et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
7	Carling et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
8	Lehnert et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
9	Lehnert et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
10	Makhlouf et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
11	Hoppe et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
12	Keiner et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
13	Iga et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
14	Hoshikawa et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
15	Bidaurreazaga-Letona et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
16	Chatra et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
17	Makhlouf et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
18	Ruivo et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
19	Hammami et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
20	Hammami et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
21	Hoshikawa et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
22	Lacombe et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13

23	DeRidder et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
24	Wing et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
25	Sander et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
26	Lehnert et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
27	Forbes et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
28	Brownlee et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
29	Morris et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
30	Herdy et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
31	McLean et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
32	Peñailillo et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
33	Lehance et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
34	Markovic et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
35	Bona et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
36	Ramirex-Campillo et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
37	Hosseini Kakhak et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
38	Grendstad et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
39	Emmonds et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
40	Ramos et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
41	Harper et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
42	Gerodimos et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
43	Wollin et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
44	Morris et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
45	Emmonds et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
46	Lehnert et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12

47	Forbes et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
48	Leat et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
49	Chrisman et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
50	Gissis et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
51	Lehnert et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
52	Enright et al.	1	1	1	1	1	1	1	1	0	1	1	1	1	12
53	Wollin et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
54	Śliwowski et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
55	Emmonds et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
56	O'Brien et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
57	Rhodes et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
58	Dragula et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11
59	Gavanda et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
60	Brännström et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
61	Thorlund et al.	1	1	1	1	1	1	1	1	0	1	1	1	1	12
62	Roth et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
63	Siddle et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
64	Martínez-Serrano et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
65	Soos et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
66	Massa et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
67	Konarski et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
68	Morris et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
69	Contreras-Díaz et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
70	Köklü et al	1	1	1	1	1	1	1	0	0	1	1	1	1	11

71	Schoffl et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
72	Jones et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
73	Kolodziej et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
74	Rhodes et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
75	Smpokos et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
76	Lesinksi et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
77	Delang et al	1	1	1	1	1	1	1	0	1	1	1	1	1	12
78	Jones et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
79	Sherwood et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
80	Sannicandro et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
81	Brogden et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
82	Drouzas et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
83	Delang et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
84	Nielson et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12
85	Horn et al	1	1	1	1	1	1	1	1	1	1	1	1	1	13
86	McQuilliam et al	1	1	1	1	1	1	1	1	0	1	1	1	1	12

4 – Results

4.1 Overview of results

Studies meeting the inclusion criteria for this review are presented in **Table 4**. In the 86 research papers included in the review there were a total of 21 different tests implemented with separate 180 evaluations performed. The most common tests were knee extension (29% of evaluations performed) and knee flexion (27% of assessments performed), whilst the least common assessments performed were the lat pull-down, barbell front squat and barbell rear foot elevated split squat (RFESS), all performed once (<1%). Of the tests, 87% assessed the lower body musculature, whilst 9% assessed the upper body musculature and 6% on the trunk muscles. There were 5425 participants tested within the selected literature, 88% were male and 12% female, with 8 studies including female participants. Reported average ages ranged from 11.3 years old to 18 years old with the mean reported age being 15.9 years old and age groups ranged from U8 to U21's. All assessments were performed by the oldest age included in this study (18 years old), except leg press, prone row and front squat. The tests performed on the youngest participants were leg extensions, leg curls and Nordic hamstring exercises, which were as young as U8's. The age ranges used by assessments are shown in **Figure 2**. Europe was the most common continent, with 55 of the 86 research articles using groups from this region. There were 6 studies from South America, 5 from Asia, 4 from North America, 4 from Oceania, 3 from Africa and 9 articles did not state a geographical location. Observational studies were the most common 55 of the 86 using a cross-sectional research design, 31 studies adopted an experimental design, however only 8 of these studies used control groups and 7 studies were longitudinal. Regarding publication date, the average publication date was 2016.7 ± 5.75 (SD), 97.7% of the studies were published in the last 20 years, whilst 44.3% were published in the last 5 years. The earliest published article was 1987.

4.1.1 Maximal voluntary contraction assessments

Studies that investigated resistance machine MVCs are summarised in **Table 5**. In total there were 40 studies that assessed resistance machine MVCs included in the current review, there were 9 separate tests with 110 individual evaluations performed. Isokinetic dynamometry peak torque was the most utilised method to assess MVC, utilised 99 (90% of MVC evaluations) times. The Nordic hamstring curl, peak torque was utilised 6 (5% of MVC evaluations) times, whilst a resistance machine 1RM was the only other evaluation included and was performed 5 (5% of MVC evaluations) times. Knee extension was the most popular, used in 29 (73%) of MVC studies whilst knee flexion was second most popular used in 25 (63%) of MVC studies. All evaluations of MVC used either concentric or eccentric assessments, of the 110 assessments, 63 (57%) tested concentric MVC whilst 47 (43%) tested eccentric MVC. There were 8 (7%) times eccentric MVC was assessed during a study without also testing concentric strength. In each of these 8 assessments each the eccentric muscular strength of the hamstrings were assessed, the NHE was used in 6 (15%) studies and isokinetic dynamometry was used in two (5%). There were 14 tests which only assessed concentric strength only, of these 14 tests, knee flexion and extension were tested together 7 (50%) times, knee extension in isolation a further 3 (21%) times and leg press once (7.1%). The lat pull-down was the only MVC assessment used to assess upper body strength, and it was performed once.

Table 4. Overview of included studies.

ID	Author	Year	Sample	Design	Classification	Assessment
1	Eustace et al	2020	17, male, 17.0±0.6, United Kingdom, EFL league 2 academy.	Cross sectional.	Observational	Knee extension and flexion.
2	Stern et al	2020	23, male, 17.6±1.2, United Kingdom, category 2 academy.	Between-subject with randomised allocation.	Experimental	Back squat and rear foot elevated split squat.
3	Wong & Wong	2009	16, male, 16.3±0.6 , China, age group national team.	Cross sectional.	Observational	Knee extension and flexion.
4	Andrade et al	2020	93, female, U13-U18 , Brazil, national level competition.	Cross sectional.	Observational	Knee extension and flexion.
5	Dos'Santos et al	2018	13, male, 16.7±0.5, United Kingdom, professional academy.	Within-subject with repeated measures.	Experimental	Mid-thigh pull and power clean
6	Vandendriessche et al	2012	78, male, (U16Futures = 15.2±0.3; U16 = 15.3±0.3; U17Futures = 16.1±0.3; U17 = 16.2±0.3), Belgium, age group national team.	Cross sectional.	Observational	Grip Strength.
7	Carling et al	2011	158, male, 13.5±0.4, France, regional academy.	Longitudinal.	Observational	Knee extension and flexion.
8	Lehnert et al	2018	20, male, 15.7±0.5, (playing country not stated), "elite".	Single group pre-post.	Experimental	Knee extension and flexion.
9	Lehnert et al	2017	18, male, 17.1±0.4, Czech Republic, first division academy.	Single group pre-post.	Experimental	Knee extension and flexion.
10	Makhlouf et al	2018	57, male, (Group 1 = 11.3±0.9; Group 2 = 11.1± 0.7; Control = 11.0±0.8), Tunisia, premier league academy.	Randomised control.	Experimental	Knee extension and Grip Strength.

11	Hoppe et al	2020	38, male, 15.6 ± 0.2, Germany, A/B-Junior Bundesliga or 1st - 4th highest adult league.	Retrospective.	Observational	Bench Press.
12	Keiner et al	2015	40, male, 16.5 ± 0.9, second division training centre.	Cross sectional.	Observational	Trunk extension and flexion.
13	Iga et al	2009	45, male, (Group 1 = 15.1 ± 1.0; Group 2 = 14.8 ± 0.9), English, professional soccer team academy.	Between subjects.	Experimental	Knee extension and flexion.
14	Hoshikawa et al	2009	26, male, 15.7 ± 0.2, Japan, first division academy.	Cross sectional.	Observational	Knee extension and flexion.
15	Bidaurreazaga-Letona et al	2019	161, male, U12-U13, (playing country not stated), professional club youth team.	Retrospective.	Observational	Grip Strength.
16	Chatra et al	2016	46, male, 16.2±1.6, Tunisia, first division club.	Cross sectional.	Observational	Knee extension and flexion.
17	Makhlouf et al	2016	57, male, 13.7±0.5, Tunisia, first division club.	Between-subject with randomised allocation.	Experimental	Bench press and Back Squat
18	Ruivo et al	2016	28, male, 16.2±1.1, China, Professional team.	Single group pre-post.	Experimental	Bench press and lat pull down
19	Hammami et al	2019	40, male, 15-17 years old, country not stated, "elite level championship".	Between-subject with randomised allocation.	Experimental	Back Squat.
20	Hammami et al	2017	29, male, U17, country not stated, professional soccer team.	Between-subject with randomised allocation.	Experimental	Back Squat.
21	Hoshikawa et al	2013	28, male, 12.3-13.1 years old, Japan, professional club academy.	Between-subject with control.	Experimental	Hip extension and flexion.
22	Lacombe et al	2019	19, male, (low volume; 17.5±0.7, high volume; 17.2±0.7), France, professional team academy.	Within-subject with counterbalance.	Experimental	Knee flexion.
23	DeRidder et al	2016	140, male, 12.7±2.1, Spain, first division club academy.	Longitudinal.	Observational	Hip extension, flexion, abduction, adduction axorotation and endorotation.

24	Wing et al	2020	15, male, 16-18 years old, England, national league scholarship squad.	Cross sectional.	Observational	Bench press and back squat.
25	Sander et al	2013	134, male, 13-18 years old, Germany, second and third tier club academy.	Between-subject with control.	Experimental	Back squat and front squat.
26	Lehnert et al	2011	45, male, 17 ± 1.2, Czech Republic, first division club.	Cross sectional.	Observational	Knee extension and flexion.
27	Forbes et al	2009	156, male, U12-U18, England, centre of excellence.	Cross sectional.	Observational	Knee extension and flexion.
28	Brownlee et al	2018	155, male U9-U21, England, premier league club academy.	Between-subject with control.	Experimental	Mid-thigh pull.
29	Morris et al	2018	293, male, U12-U19, England, professional club academy.	Cross sectional.	Observational	Mid-thigh pull.
30	Herdy et al	2018	52, male, U15-U17, Brazil, professional club academy.	Cross sectional.	Observational	Knee extension and flexion.
31	McLean et al	1993	12, male, 16.8 ± 0.7 , Australia, national junior squad.	Cross sectional.	Observational	Knee extension and flexion.
32	Peñailillo et al	2016	63, male, 12.5 ± 1.3, Chile, first division professional club academy.	Cross sectional.	Observational	Knee extension.
33	Lehance et al	2009	19, male, 15.7 ± 0.8, Belgium, first division professional club.	Cross sectional.	Observational	Knee extension and flexion.
34	Markovic et al	2018	133, male, 11-17 years old, England, tier 1 regional talent centre.	Cross sectional.	Observational	Nordic hamstring exercise.
35	Bona et al	2016	49, male, U15-U17, Brazil, first division soccer club.	Cross sectional.	Observational	Knee extension and flexion.
36	Ramirez-Campillo et al	2018	73, male, 10.9 - 15.9 years old, country not stated, professional soccer academy.	Between-subject with control.	Experimental	Back squat.
37	Hosseini Kakhak et al	2020	19, male, 15.9 ± 0.8, Iran, first division professional club.	Between-subject with randomised allocation.	Experimental	Knee extension.
38	Grendstad et al	2019	102, male, 14.0 ± 0.3, Norway, national level.	Longitudinal.	Observational	Leg Press.

39	Emmonds et al	2018	158, female, U10-U16, England, tier 1 regional talent centre.	Cross sectional.	Observational	Mid-thigh pull.
40	Ramos et al	2018	30, male, 15.97 ± 0.67, Brazil, professional club academy.	Cross sectional.	Observational	Knee extension and flexion.
41	Harper et al	2021	14, male, 16.8 ± 0.9, England, league 2 soccer academy.	Cross sectional.	Observational	Knee extension and flexion.
42	Gerodimos et al	2015	15, male, 15.0 ± 0.6, Greece, "elite".	Within-subject.	Experimental	Hip adduction and abduction.
43	Wollin et al	2015	21, male, 16.81 ± 0.54, Australia, national talent programme.	Within-subject.	Experimental	Knee flexion.
44	Morris et al	2018	112, male, 12-18 years old, England, professional soccer academy.	Longitudinal matched pairs.	Observational	Mid-thigh pull.
45	Emmonds et al	2020	113, female, U10 - U16, England, tier 1 regional talent centre.	Longitudinal.	Observational	Mid-thigh pull.
46	Lehnert et al	2014	16, male, 16.7 ± 0.7, Czech Republic, first league academy.	<i>Longitudinal</i>	Observational	Knee extension and flexion.
47	Forbes et al	2009	156, male, U12-U18, England, centre of excellence.	Cross sectional.	Observational	Knee extension and flexion.
48	Leat et al	1987	17, male, U16-U18), Canada, national.	Cross sectional.	Observational	Knee extension and flexion.
49	Chrisman et al	2012	50, 12.5, female, United States of America, premier Seattle youth soccer association.	Cross sectional.	Observational	Knee extension and flexion. Hip flexion, extension, abduction and adduction.
50	Gissis et al	2006	18, male, 16.3 ± 1.26, Greece, national age group.	Cross sectional.	Observational	Leg Press.
51	Lehnert et al	2013	16, male, 16.7 ± 0.7, Czech Republic, first league academy.	Longitudinal.	Observational	Knee extension.

52	Enright et al.	2015	15, male, 17.3 ± 1.6, England, premier league academy.	Between subjects.	Knee extension and flexion, barbell back squat.	Isokinetic dynamometer, eccentric and concentric peak torque and maximal voluntary isometric contraction. Dynamix one repetition max.
53	Wollin et al	2017	22, male, 15.53 ± 0.48, Australia, national age group.	Longitudinal.	Observational	Hip adduction.
54	Śliwowski et al	2015	24, male, U17, Poland, first division club academy.	Between subjects.	Experimental	Knee extension and flexion.
55	Emmonds et al	2017	157, female, U10-U16, England, Tier 1 regional talent centre.	Cross sectional.	Observational	Mid-thigh pull.
56	O'Brien et al	2018	58, male, 15 ± 1.9, Austria, first division club academy.	Repeated measures.	Experimental	Hip adduction.
57	Rhodes et al	2021	59, male, 17.98 ± 2.29, England, Premier league academy.	Cross sectional.	Observational	Nordic hamstring exercise.
58	Dragula et al	2017	18, male, 17.6 ± 0.8, Czech Republic, national U19 league.	Cross sectional.	Observational	Knee extension and flexion.
59	Gavanda et al	2020	47, male, 15-18 years old, Germany, first division.	Between subjects with random allocation.	Experimental	Bench press and back squat.
60	Brännström et al	2017	19, female, 15.3 ± 0.7, Sweden, first division.	Cross sectional.	Observational	Knee extension and flexion.
61	Thorlund et al.	2009	9, male, 17.6 ± 0.8, Denmark, national youth division.	One group pre - post intervention.	Experimental	Knee extension and flexion.
62	Roth et al	2016	21, male, 17.9 ± 0.7, Germany, national youth division.	Cross sectional.	Observational	Trunk extension, flexion, rotation, and lateral flexion.
63	Siddle et al	2022	16, male, 16.65 ± 0.61, not stated, "elite".	Within subjects.	Experimental	Knee extension (Flexor).
64	Martínez-Serrano et al	2022	34, male, 17.8 ± 0.8, not stated, "elite".	Between subjects.	Experimental	Knee and hip extension.
65	Soos et al	2022	81, male, 14-18 years old, Hungary, first division academy.	Cross sectional.	Observational	Hip adduction, abduction and Nordic hamstring exercise.

66	Massa et al	2022	143, male, U14, Brazil, first division academy.	Cross sectional.	Observational	Grip Strength.
67	Konarski et al	2020	31, male, 14.4 ± 0.54, Poland, first division academy.	Cross sectional.	Observational	Grip Strength.
68	Morris et al	2020	73, male, 12-18 years old, England, professional academy.	One group pre - post intervention.	Experimental	Mid-thigh pull.
69	Contreras-Díaz et al	2023	40, male, 17.02 ± 0.92, Chile, second division academy.	Cross sectional.	Observational	Hip adduction, abduction, flexion and extension.
70	Köklü et al	2022	12, male, 17.0 ± 0.6, Turkey, first division academy.	Cross sectional.	Observational	Back squat.
71	Schoffl et al	2021	111, male (63), female (48), Australia, A-League academy.	Cross sectional.	Observational	Hip adduction and abduction.
72	Jones et al	2021	146, male, U10-U18, England, first division academy.	Cross sectional.	Observational	Hip adduction, abduction and Nordic hamstring exercise.
73	Kolodziej et al	2022	56, male, 17.2±1.1, German, professional academy.	Cross sectional.	Observational	Trunk flexion, extension and lateral flexion. Hip adduction and abduction. Knee extension and flexion.
74	Rhodes et al	2022	21, male, 17.63 ±0.76, England, first division academy.	Cross sectional.	Observational	Knee extension and Nordic hamstring exercise.
75	Smpokos et al	2020	216, male, U14-U19, Greece, first division academy.	Longitudinal.	Observational	Knee extension and flexion.
76	Lesinski et al	2020	36, female, 15.3±6 0.5, German, first division academy.	Between subjects.	Experimental	Leg Press.
77	Delang et al	2020	100, male, U13-U19, United States of America, United states development group.	Cross sectional.	Observational	Hip adduction.
78	Jones et al	2020	143, male, U10-U18, England, First division academy.	Longitudinal.	Observational	Hip adduction, abduction and knee flexor.
79	Sherwood et al	2021	40, male, U16-U18, England, first division academy.	Cross sectional.	Observational	Back squat, bench press, and prone row.

80	Sannicandro et al	2022	24, male, U17, not stated, "professional team".	One group pre - post intervention.	Experimental	Nordic hamstring exercise.
81	Brogden et al	2021	67, male, 16.58 ± 0.57, English, "academy players".	One group pre - post intervention.	Experimental	Nordic hamstring exercise.
82	Drouzas et al	2020	105, male, 8-13 years old, Greece, Superleague academy.	Between subjects with random allocation and control.	Experimental	Knee extension and flexion.
83	Delang et al	2022	53, U13-U19 (14.4 ± 1.6), United States of America, Major League Soccer academy.	Longitudinal.	Observational	Hip adduction.
84	Nielson et al	2022	83, male, U13-U18, Denmark, first division academy.	Cross sectional.	Observational	Hip adduction and abduction.
85	Horn et al	2021	28, male, : 16.7 ± 1.3, England, English football league championship football academy.	Cross sectional.	Observational	Knee extension and flexion.
86	McQuilliam et al	2023	23, male, 18 ± 1, England, Soccer college.	Between Subjects with control group.	Experimental	Back squat.

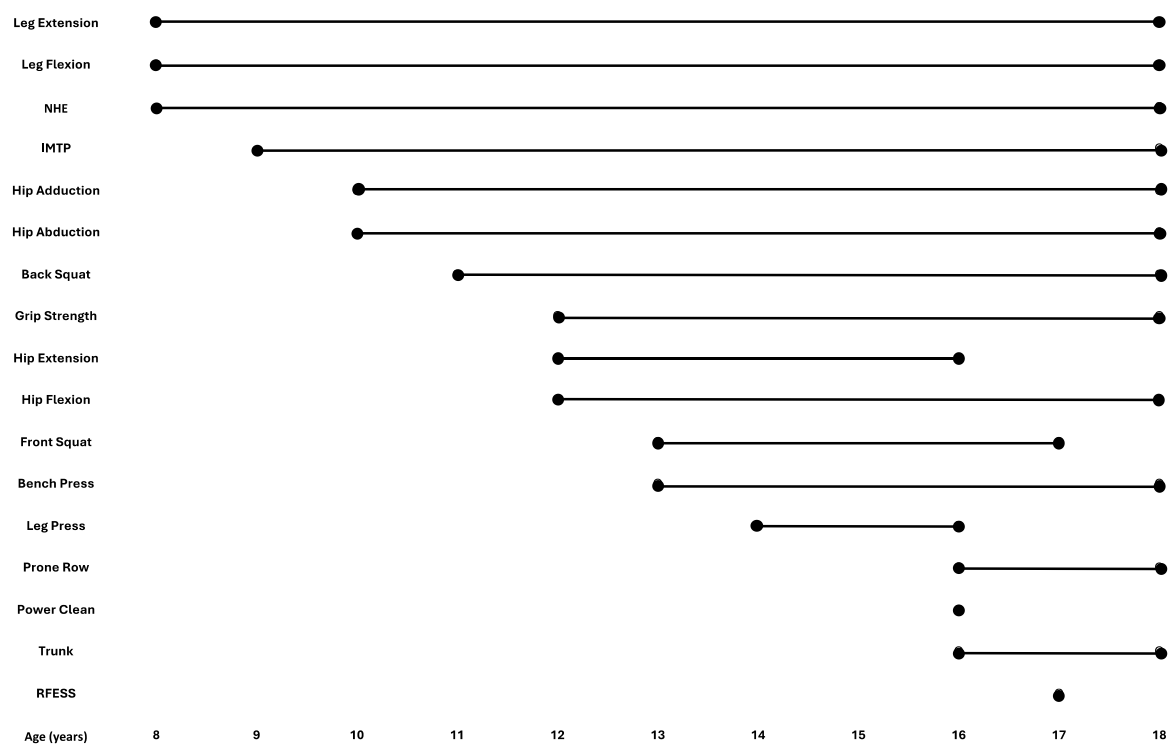


Figure 2. Shows the reported chronological age ranges rounded to the nearest year, of athletes tested for each assessment irrespective of modality.

4.1.2 Dynamic free weight assessments

The 14 studies that assessed DFW MS are included in **Table 6**. Within the 14 studies included there were 6 different tests selected, and 19 individual evaluations performed. The back squat (BS) was the most used assessment, being tested 10 (53%) times, second to this was the barbell bench press, which was assessed 5 (26%) times. The remaining assessments were all tested once (5%). Of the evaluations performed the 1RM was used 13 (70%) of the time, whilst the 3RM was implemented in 4 evaluations (31%) and 5RM in 1 (5%). An estimated 1RM using barbell velocity recorded using a linear transducer was used in two evaluations (10%) during a BS and RFESS.

Table 5. Maximal voluntary contraction assessments

ID	Author	Year	Assessment	Evaluation	Summary
1	Eustace et al	2020	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	There was no difference between youth and senior players in peak torque across all velocities tested.
3	Wong & Wong	2009	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	Peak concentric and eccentric torque produced by the quadricep was greater than the hamstring.
4	Andrade et al	2020	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	There was no asymmetry between dominant and non-dominant limbs across all age groups.
7	Carling et al	2011	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	There was no apparent change in physical attributes between those selected in early years compared to later years.
8	Lehnert et al	2018	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	Following fatigue there was not a significant decrease in peak torque force.
9	Lehnert et al	2017	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	There were no changes in peak torque in the dominant leg over the 10-week training period.
13	Iga et al	2009	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	Players who training cantered solely around the technical development of soccer skills showed asymmetry knee musculature.
14	Hoshikawa et al	2009	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	There was a greater relationship between muscle cross sectional area and torque in senior players compared to junior players.
18	Ruivo et al	2016	Lat pull-down	1 repetition max.	Athletes body composition, upper body strength and strength endurance increased following a 16-week strength programme.
21	Hoshikawa et al	2013	Hip extension and flexion.	Isokinetic dynamometer, concentric peak torque.	Training of basic core stabilisation alongside regular soccer training had no effect on trunk muscularity. It did improve hip extensor strength and vertical jump.
22	Lacombe et al	2019	Nordic hamstring exercise.	Noardboard, Peak eccentric force.	Low volume hamstring training showed similar results to high volume.
26	Lehnert et al	2011	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	Older players were stronger than younger players. Faster movement speed produced lower peak torque.
27	Forbes et al	2009	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	Peak torque increased with chronological age and pubic development scaling.

30	Herdy et al	2018	Knee extension and flexion.	Isokinetic dynamometer, concentric peak torque.	Younger players produced less force than older players. Goal keepers were stronger than outfield players.
31	McLean et al	1993	Knee extension and flexion.	Isokinetic dynamometer, concentric peak torque.	Players were stronger with their right limb and performed better on a kick drive on the right-hand side. However, when performing a chip both limbs showed similar velocity and accuracy.
32	Peñailillo et al	2016	Knee extension.	Leg extension, 1 repetition max.	There were strong correlations shown between leg strength, 20m sprint time and 15m flying sprint time.
33	Lehance et al	2009	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	U17 group produced less absolute force than senior players, however when normalised for body mass there was no difference. Players who had a previous injury showed muscular strength imbalance.
34	Markovic et al	2018	Nordic hamstring exercise.	Noardboard, Peak eccentric force.	There was a strong relationship between peak eccentric hamstring strength and sprint performance. Peak eccentric hamstring strength increased in a nonlinear fashion throughout the academy peaking at U16.
35	Bona et al	2016	Knee extension and flexion.	Isokinetic dynamometer, concentric peak torque.	U17 group exhibited higher absolute peak torque compared to the U15. No injury risks based on strength deficit were observed in either group.
37	Hosseini Kakhak et al	2020	Knee extension.	Leg extension, 1 repetition max.	Blood flow restriction use resulted in greater improvements of lower body strength and strength endurance.
38	Grendstad et al	2019	Leg Press.	Keiser, 1 repetition max.	Physical ability separated elite and non-elite junior players, not skeletal maturity.
40	Ramos et al	2018	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	Athletes showed greater H/Q symmetry in their dominant limb due to higher hamstring eccentric peak torque.
41	Harper et al	2021	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	High eccentric peak torque produced during lower velocity angles were strongly correlated with deceleration capabilities.
42	Gerodimos et al	2015	Hip abduction and adduction.	Isokinetic dynamometer, eccentric and concentric peak torque.	There were moderate to high reliability between measures of hip abduction and adduction. However, there were some disciplines when eccentric muscle action was assessed.
46	Lehnert et al	2014	Knee extension and flexion.	Isokinetic dynamometer, concentric peak torque.	There was no change in knee extensor peak torque over the period. Knee flexor peak torque increased following a

47	Forbes et al	2009	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	3-week rest period then again after a 10-week training period.
48	Leat et al	1987	Knee extension and flexion.	Isokinetic dynamometer, concentric peak torque.	The Q:H ration of the U18 and pubertal development stage 4 group was significantly lower than other groups.
51	Lehnert et al	2013	Knee extension.	Isokinetic dynamometer, concentric peak torque.	Within the testing battery utilised, elite soccer players performed better than non-soccer players.
54	Śliwowski et al	2015	Knee extension and flexion.	Isokinetic dynamometer, concentric peak torque.	There was a low to moderate relationship between jump height and leg extensor strength across a season.
57	Rhodes et al	2021	Nordic hamstring exercise.	Noardboard, Peak eccentric force.	Both groups increased peak torque of the knee extensor whilst the intervention group showed a greater increase in hamstring strength.
58	Dragula et al	2017	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque.	There was no correlation with anterior stability but there were a small to moderate correlation with posteromedial and posterolateral stability and peak eccentric force.
60	Brännström et al	2017	Knee extension and flexion.	Isokinetic dynamometer, concentric peak torque.	Relative force development during the squat jump was a better indicator of sprint performance then knee extension or flexion.
63	Siddle et al	2022	Knee flexor (hamstring)	Isokinetic dynamometer, eccentric peak torque.	There was no correlation with knee extension or flexion with peak torque and serum vitamin D levels, however there was a relationship with time to peak torque in knee extensors.
69	Contreras-Díaz et al	2023	Hip adduction, abduction, flexion and extension.	Isokinetic dynamometer, peak concentric and eccentric torque.	There were no differences to eccentric hamstring peak torque following an 8-week low volume (2x2x4) Nordic hamstring protocol.
74	Rhodes et al	2022	Knee flexor (hamstring) and Nordic hamstring exercise.	Isokinetic dynamometer and Nord board, peak eccentric torque.	There was a seemingly higher right side hip adduction and abduction in defender's vs other positions.
75	Smpokos et al	2020	Knee extension and flexion.	Isokinetic dynamometer, peak concentric and eccentric torque.	Isokinetic dynamometer results showed lower variance compared with the nord board. Whilst there is a moderate relationship between the devices.
76	Lesinski et al	2020	Leg Press.	1 repetition max.	All testing variables increased with age.

Both power training strength endurance training improved physical characteristics following the season. Power training was more effective at improving leg press

80	Sannicandro et al	2022	Nordic hamstring exercise.	N3 Easy Tech, Peak eccentric force.	strength, drop jump and linear speed whilst strength endurance training was more effective in improving trunk muscular endurance and change of direction. Peak eccentric torque decreased significantly following bouts on small, sided games.
81	Brogden et al	2021	Nordic hamstring exercise.	Noardboard, Peak eccentric force.	There were no differences in relative or absolute peak strength following the completion of a YO-YO IR1.
85	Horn et al	2021	Knee extension and flexion.	Isokinetic dynamometer, concentric and eccentric peak torque.	Peak force decreased with increasing angular velocity.

4.1.3 Maximal voluntary isometric contraction assessments

The 34 studies that assessed MVIC are represented in **Table 7**. There were 12 different tests MVIC tests selected and 55 individual evaluations. Of these 54 MVIC assessments, 20 (36%) were performed on the hip, 14 (26%) on the knee, 9 (17%) were multi-joint assessments, 7 (13%) assessments were performed on the trunk , whilst 5 (9%) MVIC evaluations were performed on the hand. There were no MVIC assessments performed on the ankle joint. Hip adduction was the most common MVIC assessment, it was assessed 10 times (19%). Knee extension and IMTP were both evaluated 8 times (15%), whilst hip abduction and knee flexion were assessed 6 times (11%) Grip strength was measured 5 (9%) times meaning it was the only upper body MVIC assessment. Moreover, both the IMTP (15%) and leg press (2%) were used to assess MVIC across multiple joints. To assess MVIC, a fixed load cell was utilised in 14 studies (42%), a portable / HHD 10 studies (29%), a force platform in 9 studies (26%) and a sphygmomanometer in one (3%). Of the 9 times a force platform was used to assess MVIC, 7 of these assessments were an IMTP and of the 10 times a handheld dynamometer (HHD) was used, grip strength was the most common assessment, being assessed 5 times. When assessing the isometric strength capabilities of the hip, adduction was assessed 10 times, abduction 6 times and flexion and extension were assessed 2 times respectively.

Table 6. Dynamic free-weight assessments

ID	Author	Year	Assessment	Evaluation	Summary
2	Stern et al	2020	Back squat and rear foot elevated split squat.	Linear transducer, predicted dynamic 1 repetition max.	Unilateral strength improved more so after unilateral strength and bilateral strength improved more so after bilateral strength training.
11	Hoppe et al	2020	Bench Press.	Dynamic 1 repetition max.	Starting players were stronger than those who were non-starters. There was no difference in strength endurance-based assessments.
17	Makhlouf et al	2016	Bench press and Back Squat.	Dynamic 1 repetition max.	There was no differences in training adaptation between the sequence of concurrent strength and endurance training.
18	Ruivo et al	2016	Bench press.	Dynamic 1 repetition max.	Athletes body composition, upper body strength and strength endurance increased following a 16-week strength programme.
24	Wing et al	2020	Bench press and back squat.	Dynamic 1 repetition max.	There were several key relationships between lower body strength/power and performance match data.
25	Sander et al	2013	Back squat and front squat.	Dynamic 1 repetition max.	Athletes who partook in strength training developed better lower body strength and sprints capability over those who didn't.
36	Ramirez-Campillo et al	2018	Back squat.	Dynamic 5 repetition max.	The optimised approach improved physical attributes to a higher degree than the fixed approach. However, the fixed approach was effective and is more practical in a large group setting.
59	Gavanda et al	2020	Bench press and back squat.	Dynamic 1 repetition max.	Block and daily undulating periodisation were equally effective for improving muscle mass, strength and performance.
70	Köklü et al	2022	Back squat.	Dynamic 1 repetition max.	Four minutes was the optimal time to elicit the highest post activation potentiation effect.
79	Sherwood et al	2021	Back squat, bench press, and prone row.	Dynamic 3 repetition max.	Age had a significant effect on the physical characteristics.
86	McQuilliam et al	2023	Back squat.	Dynamic 3 repetition max.	High intensity training produced similar results to moderate volume however also showed greater improvement in horizontal CMJ, less muscle soreness and volume.

5	Dos'Santos et al	2018	Power clean	Dynamic 1 repetition max.	There was a high inter-session reliability for the mid-thigh pull and power clean.
19	Hammami et al	2019	Back Squat	Dynamic 1 repetition max.	Eight weeks of contrast training with loads 80-90% and CMJ/sprints enhances the physical capabilities of junior elite soccer players more so than Plyometric training alone.
20	Hammami et al	2017	Back Squat	Dynamic 1 repetition max.	Eight weeks of contrast training improved the athletes improves speed, agility and lower body strength

4.1.4 Methods to assess biological maturation

Studies which assessed biological maturation of their population alongside strength are included in **Table 8**. Sixteen studies used an assessment of maturation in accordance with strength assessments. Of these sixteen studies 13 were of males and 3 of females. Two studies used a method of sexual maturity, two used a method of skeletal maturity whilst 12 used a somatic assessment of maturity. Of the studies that assessed somatic maturity, the Khamis-Roche method was implemented twice and the Mirwald assessment was used in 10 studies. Two studies within the population compared maturity timing, whilst the other 13 assessed maturity status.

4.1.5 Methods to determine reliability

Studies which assessed the reliability of strength assessments performed are included in **Table 9**. Thirteen studies in this review assessed the reliability of 18 strength assessments among elite youth soccer players. The IMTP was the most frequently evaluated, with six studies demonstrating excellent intra- and inter-session reliability across male and female athletes aged 10 to 18 years. Reported ICCs ranged from 0.93 to 0.98 for both genders. The NHE reliability was evaluated in one study, indicating high to excellent within- and between-session reliability for male athletes aged 11 to 17 years (within-session ICC = 0.84–0.96; CV = 4.61%). Hip abduction and adduction maximal voluntary contraction (MVC) IKD in one study, revealing moderate to high retest reliability, particularly at lower angular velocities (ICC = 0.71–0.91) in males with a mean age of 15.0 ± 0 years. Another study measured hip adduction MVC using a sphygmomanometer, reporting excellent within-session reliability (ICC = 0.92) in athletes averaging 15.9 years of age.

Isokinetic dynamometry assessments of knee extension and flexion in one study reported acceptable between-session CVs; however, eccentric hamstring contractions exhibited higher variability in males with a mean age of 17.3 years (CV = 1.6%–12%). Another study focused on MVC eccentric hamstring strength in 16-year-old males, finding high inter-session reliability (ICC = 0.87) despite a CV exceeding 10%. Wollin et al. and Martinez-Serrano et al. assessed MVC of the knee in males (mean ages 16.81 and 17.8 years, respectively). Both studies found high within-session reliability for MVC knee flexion (ICC = 0.87–0.98), although Martinez-Serrano et al. reported a high CV (13.35%). Additionally, Martinez-Serrano et al. evaluated MVC of the knee extensors, noting excellent within-session reliability (ICC = 0.98) and a lower CV (6.35%) compared to knee flexion. The BS, one of two free-weight exercises examined, demonstrated acceptable CV in a cohort with a mean age of 17.3 ± 1.6 years; however, specific values were not reported, and no additional statistical reliability analyses were provided. The barbell power clean was also assessed in a male population with a mean age of 16.7 ± 0.6 years, showing high inter-session reliability (ICC = 0.89).

Table 7. Maximal voluntary isometric contraction assessments

ID	Author		Assessment	Evaluation	Summary
5	Dos'Santos et al	2018	Mid-thigh pull	Maximal voluntary isometric force, peak force at incremental time points and 1 repetition max.	There was a high inter-session reliability for the mid-thigh pull and power clean.
6	Vandendriessche et al	2012	Grip strength	Hand grip dynamometer Maximal voluntary isometric contraction.	Early maturing players showed performed better on physical tests than later maturing players.
10	Makhlouf et al	2018	Knee extension and grip strength	Hand grip dynamometer maximal voluntary isometric contraction.	There were significant improvements in performance measures when participants undertook balance and agility training prior to plyometric training.
12	Keiner et al	2015	Trunk extension and flexion.	Fixed dynamometer, maximal voluntary isometric contraction.	Weak correlation between trunk strength and sprint/jump performance.
15	Bidaurrazaga-Letona et al	2019	Grip strength	Handheld dynamometer, maximal voluntary isometric contraction.	There were significant performance difference between groups despite only one year of age difference.
16	Chatra et al	2016	Knee extension and flexion.	Portable dynamometer, maximal voluntary isometric contraction.	Isometric strength of the lower body is correlated to balance.
23	DeRidder et al	2016	Hip extension, flexion, abduction, adduction axorotation and endorotation.	Handheld dynamometer, Maximal voluntary isometric contraction.	Over the three-year period decreasing hip extension strength was seemingly related to lateral ankle sprain occurrence.
28	Brownlee et al	2018	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Possible difference in peak torque between elite and non-elite population.
29	Morris et al	2018	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Age and maturation influenced absolute peak force and impulse but not relative peak force and relative impulse.
39	Emmonds et al	2018	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	The early maturing athletes showed greater strength than late maturing athletes. However, there were trivial differences between sequential maturity groups.

43	Wollin et al	2015	Knee flexion.	Load cell, maximal voluntary isometric contraction.	High reliability was exhibited with the device able to detect 11-15% differences in strength.
44	Morris et al	2018	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Elite population of youth footballers improved physical qualities over non elite across a full season. The physical quality which improved most varied based on stage of PHV.
45	Emmonds et al	2020	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	All players relative strength improved across the season whereas other physical qualities worsened
49	Chrisman et al	2012	Knee extension and flexion. Hip flexion, extension, abduction and adduction.	Handheld dynamometer, maximal voluntary isometric contraction.	There was little to no difference in hip and knee strength between elite and recreational players.
50	Gissis et al	2006	Leg Press.	Uniaxial load cell, maximal voluntary isometric contraction.	The elite players outperformed the sub elite and recreational in maximal isometric strength, sprint performance, vertical jump and rate of force development.
52	Enright et al.	2015	Knee extension and flexion.	Isokinetic dynamometer, eccentric and concentric peak torque and maximal voluntary isometric contraction.	The group that performed their strength training post their endurance training showed a greater improvement in their physical testing.
53	Wollin et al	2017	Hip adduction.	Handheld dynamometer, maximal voluntary isometric contraction.	There was a strong negative correlation between force production and training load.
55	Emmonds et al	2017	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Athletes who were both chronologically and biologically older produced more force than the younger athletes.
56	O'Brien et al	2018	Hip adduction.	Sphygmomanometer, maximal voluntary isometric force.	The reliability of this measure was excellent.
62	Roth et al	2016	Trunk extension, flexion, rotation, and lateral flexion.	Four different dynamometers, maximal voluntary isometric contraction.	Muscle activation exceeding 100%MVIC during exhaustive tests to failure.
64	Mart ínez-Serrano et al	2022	Knee and hip extension.	Load cell and force plate (90:20 test), maximal voluntary isometric contraction.	There was a decrease in neuromuscular performance of the posterior chain following higher distances of high-speed running vs lower distances. There was no differences in knee extensors.

65	Soos et al	2022	Hip adduction, abduction and Nordic hamstring exercise.	Force frame, maximal voluntary isometric contraction and nordboard, peak eccentric torque.	Older players performed better than younger players in the physiological tests. Whilst goalkeeper performed best in the strength tests compared to other positions.
66	Massa et al	2022	Grip strength	Hand grip dynamometer Maximal voluntary isometric contraction.	Birth year, gonadal development and salivary testosterone were the strongest indicators of whether a player was selected for the academy.
67	Konarski et al	2020	Grip strength	Hand grip dynamometer Maximal voluntary isometric contraction.	Biological maturity was the strongest indicator of selection, whilst grip strength, vertical jump and 20m sprint were also higher in those selected.
68	Morris et al	2020	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	There was seemingly no difference in physical performance following a 6-week sled towing intervention.
71	Schoffl et al	2021	Hip adduction and abduction.	Handheld dynamometer, maximal voluntary isometric contraction.	Pre-season hip strength scores could not predict in-season injury or pain.
72	Jones et al	2021	Hip adduction, abduction and Nordic hamstring exercise.	Force frame, maximal voluntary isometric contraction and nordboard, peak eccentric torque.	Change of direction ability was related to Nordic hamstring strength.
73	Kolodziej et al	2022	Trunk flexion, extension and lateral flexion. Hip adduction and abduction. Knee extension and flexion.	Pegasus load cell, maximal voluntary isometric force. Isokinetic dynamometer, peak eccentric and concentric torque.	The model predicted with good accuracy players who did not sustain an injury, however poorly identified those who did.
77	Delang et al	2020	Hip adduction.	Force frame, maximal isometric voluntary contraction.	Player's age and previous groin pain did not affect force outputs during the squeeze test.
78	Jones et al	2020	Hip adduction, abduction and knee flexor.	Force frame, maximal isometric voluntary contraction. Nordboard, peak eccentric torque.	There was no difference in strength between injured and non-injured players.
82	Drouzas et al	2020	Knee extension and flexion.	Handheld dynamometer, maximal voluntary isometric contraction.	Unilateral plyometrics increased strength and power more than bilateral plyometrics.
83	Delang et al	2022	Hip Adduction.	Force frame, maximal isometric voluntary contraction.	Adductor squeeze test strength decreased before groin pain onset and when there were non-time loss groin pain.

84	Nielson et al	2022	Hip adduction, abduction.	Force frame, maximal voluntary isometric contraction and handheld dynamometer, 5 second squeeze test.	Tests measured by the force frame produced lower force outputs than using the 5 second squeeze test.
61	Thorlund et al.	2009	Knee extension and flexion.	Isokinetic dynamometer, maximal voluntary isometric contraction.	Following match play knee extensor and flexor peak isometric force decreased by ~10% and a decreased rate of force development up to 200ms.

Table 8. Methods to assess maturation

ID	Author	Year	Gender	Method	Assessment	Summary
6	Vandendriessche et al	2012	Male	Somatic	Mirwald (2002)	Players with a higher maturity outperformed less mature players in physical tests and possessed greater stature and weight. However, the motor co-ordination and soccer skills test did not differentiate between the two maturity groups.
7	Carling et al	2011	Male	Skeletal	Greulich-Pyle (1959)	There were significant differences between early and late maturing athletes in stature and weight. As well as speed, explosivity and strength.
15	Bidaurreazaga-Letona et al	2019	Male	Somatic	Mirwald (2002)	APHV was a better predictor of handgrip strength in younger age group, whilst body weight was a better predictor in older age group.
28	Brownlee et al	2018	Male	Somatic	Mirwald (2002)	Likely and possible moderate differences were seen between elite and non-elite youth players Pre and circa PHV.
29	Morris et al	2018	Male	Somatic	Mirwald (2002)	Biologically maturer and chronologically older athletes were stronger than their younger counter parts. However relative strength did not increase with age.
38	Grendstad et al	2019	Male	Skeletal	Greulich-Pyle (1959)	No comparison of maturation status, no biological maturation selection Bias
39	Emmonds et al	2018	Female	Somatic	Mirwald (2002)	Maturation was a higher in biologically maturer and older players.
44	Morris et al	2018	Male	Somatic	Mirwald (2002)	All three maturity groups strength improved compared to maturity matched controls.
45	Emmonds et al	2020	Female	Somatic	Mirwald (2002)	All age groups either didn't improve, or had negative changed from mid to post season.
55	Emmonds et al	2017	Female	Somatic	Mirwald (2002)	Maturation status positively impacts peak force, however relative peak force was higher in pre-PHV athletes compared to post-PHV.

66	Massa et al	2022	Male	Sexual	Tanner (1962)	Despite significant difference in gonadal development, all groups were deemed to be in the stage and there were no maturation-based differences in grip strength.
67	Konarski et al	2020	Male	Somatic	Ramis - Koche (1994)	The biologically maturer group, were significantly stronger than the less biologically mature group.
68	Morris et al	2020	Male	Somatic	Mirwald (2002)	Peak force increased in the Pre and Circa-PHV group, however seemed to decrease in the post-PHV-group.
82	Drouzas et al	2020	Male	Somatic	Mirwald (2002)	No differences in biological maturation and therefore not a factor in outcome.
86	McQuilliam et al	2023	Male	Somatic	Mirwald (2002)	No differences in biological maturation and therefore not a factor in outcome.
27	Forbes et al	2009	Male	Sexual	Peterson (1998)	Biologically maturer and chronologically older athletes were stronger than their younger counter parts.

Table 9. Methods to determine reliability

ID	Author	Sample	Assessment	Evaluation	Reported reliability	Summary
29	Morris et al	293, male, U12-U19, England, professional club academy.	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Within session: ICC = 0.98 (95% confidence intervals [CI] = 0.97-1.00 and CV = 4.91%.	IMTP was shown to have excellent reliability in this population.
44	Morris et al	112, male, 12-18 years old, England, professional soccer academy.	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Within session: ICC = 0.98 (95% confidence intervals [CI] = 0.97-1.00 and CV = 4.91%.	IMTP was shown to have excellent reliability in this population.
45	Emmonds et al	113, female, U10 - U16, England, tier 1 regional talent centre.	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Within session ICC = 0.93 and CV = 3.61%.	IMTP was shown to have excellent reliability across all age groups population.
55	Emmonds et al	157, female, U10-U16, England, Tier 1 regional talent centre.	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Within session: U10: ICC = 0.96, CV = 4.24% U12: ICC = 0.92, CV = 3.98% U14: ICC = 0.95, CV = 3.77% U16: ICC = 0.98, CV = 2.49%	IMTP was shown to have excellent reliability across all age groups population.
68	Morris et al	73, male, 12-18 years old, England, professional academy.	Mid-thigh pull.	Force platform, maximal voluntary isometric force.	Within session: ICC = 0.93 and CV = 3.61%.	IMTP was shown to have excellent reliability in this population.
5	Dos'Santos et al	13, male, 16.7±0.5, United Kingdom, professional academy.	Mid-thigh pull and power clean	Maximal voluntary isometric force, peak force at incremental time points and 1 repetition max.	IMTP: Between session: ICC = 0.96, CV = 4.61% Within session: ICC = 0.98, CV = 4.05% Power Clean 1RM Between session: ICC = 0.89	IMTP and power clean was shown to have excellent reliability in this population.
34	Markovic et al	133, male, 11-17 years old, England,	Nordic hamstring exercise.	Noardboard, Peak eccentric force.	Within session: ICC = 0.89	The Nordic hamstring exercise was shown to have high re-test reliability.

		tier 1 regional talent centre.				
42	Gerodimos et al	15, male, 15.0 ± 0.6, Greece, "elite".	Hip abduction and adduction.	Isokinetic dynamometer, eccentric and concentric peak torque.	Between session: ICC range from 0.73 (non-preferred leg concentric hip abduction 90° /s) to 0.91 (preferred leg eccentric 30° /s)	Peak torque assessment of hip adductors and abductors showed moderate to high re-test reliability, however there were higher variations at higher (90°/s vs 30°/s).
43	Wollin et al	21, male, 16.81 ± 0.54, Australia, national talent programme.	Knee flexion.	Load cell, maximal voluntary isometric contraction.	Between session: ICC = 0.87, SEM = 4.7% Within session: ICC = 0.87, SEM = 4.7%	The fixed dynamometer exercise was shown to have high inter and intra reliability when used for knee flexion assessment.
52	Enright et al.	15, male, 17.3 ± 1.6, England, premier league academy.	Knee extension and flexion. Barbell Back Squat	Isokinetic dynamometer, eccentric and concentric peak torque and maximal voluntary isometric contraction.	Within session: CV ranged from 1.6 to 12.4 % (n = 17), with the highest eccentric hamstring concentric and lowest in the barbell back squat.	The highest variability occurred in eccentric hamstring contractions (isokinetic) whilst the lowest variability was observed in the half back squat exercise.
56	O'Brien et al	58, male, 15 ± 1.9, Austria, first division club academy.	Hip adduction.	Sphygmomanometer, maximal voluntary isometric force.	Within session: Groin squeeze: ICC 0.92, SEM = 2.60	A sphygmomanometer showed excellent reliability when used for a groin squeeze assessment.
63	Siddle et al	16, male, 16.65 ± 0.61, not stated, "elite".	Knee extension	Isokinetic dynamometer, eccentric peak torque (Hamstring).	Within session: ICC = 0.84 - 0.89	The MVC of eccentric hamstring curl intra session reliability was considered high. Although there %CV was high (>10%)
64	Martínez-Serrano et al	34, male, 17.8 ± 0.8, not stated, "elite".	Knee extension and flexion.	Load cell and force plate, maximal voluntary isometric contraction.	Within session: Knee extensor MVIC: ICC = 0.98, CV = 6.2% Knee flexor MVIC: ICC = 0.98, CV = 13.35%.	Both assessments showed excellent reliability, however knee flexion showed greater variation of the mean and therefore should be interpreted with caution.

5 - DISCUSSION

5.1 Overview

The aim of this review was to determine the most common MS assessments implemented within research for male and female youth elite soccer players. To understand the limitations of the selected methods and key factors that should be considered when implementing MS assessments within this population such as chronological and biological age and the reported reliability of measures of selected assessments. Knee extension and flexion were the two mostly commonly assessed movements across all testing modalities, with isokinetic assessment being most prevalent type of evaluation. Three different methods of assessing strength were identified, MVIC, MVC and DFW; MVIC assessments were the most implemented method within the population. The IMTP was the most used MVIC assessment and was implemented with athletes aged 8-18 years of age whilst, the BS was the most prevalent DFW exercise. This exercise was used in athletes aged 10-18, with 5RM, 3RM and 1RM assessments being implemented. Despite the inclusion criteria of this review including male and female athletes, most studies focused on male athletes, highlighting a severe gender gap in current research. Within the review, papers that included maturation assessments or reliability measures were limited. These are two factors are crucial in the accurate interpretation of outcomes when assessing MS in youth athletes.

Of the 86 studies returned, a total of 84 (98%) were published within 20 years prior to the search, 69 studies (80.2%) were published in the last ten years, and 38 studies (44.2%) were published within 5 years. This prevalence evidences a recent increase in research employing MS assessments in elite youth soccer players. This increase conforms with the notion that sport science and S&C provision has grown in both senior and youth elite soccer in recent years (Asimakidis, Mukandi, et al, 2024; Paul & Nassis, 2015b; Raya-Castellano & Uriondo, 2017). The increased influence of S&C and strength assessments in elite soccer TD may be in response to

the increase in physical demands of soccer in recent years (Bush et al, 2015a). MS assessments can be utilised within the physical development pathway, to help create players that possess elite physical capabilities and, as such, can physically exploit opposition players and better tolerate the ever-increasing demands of competitive elite soccer (Bush et al, 2015b; Gualtieri et al, 2023b; Mcquilliam et al, 2023). It is therefore expected that strength assessments within youth elite soccer players is of interest to researchers due to the increased value placed on S&C provision in the TD process of youth elite soccer players (Kelly & Williams, 2020).

Sex 5.1.1

Only 8 of the 86 (9%) papers included female participants. Of the returned studies within this review, female soccer players represented just 12% of the total participants, with 88% of participants being male. This discrepancy highlights an imbalance within published literature of MS assessment in soccer, favouring male players. Women's soccer has seen exponential growth in recent years (Football Association, 2024). When comparing match attendance at the FIFA Women's World Cup, a 23% increase in match attendance was reported when comparing the 2023 and 2019 competitions (The Football Landscape – The Vision 2020-2023 | FIFA). Moreover, member association clubs reported roughly 4 million registered female soccer players in 2019, growing to 16.6 million by 2023. This growth is set to continue, as FIFA have committed to grow the number of female players to 60 million worldwide by 2026 (Football Association, 2024). This growth has been mirrored by an increase in the number of professional clubs with academy systems. In the 2020-21 season, only professional clubs in 7 leagues had female academies. By the 21-22 season this had increased to 32 leagues (FIFA, 2024). This is likely due to increased financial support highlighting clubs' intent on developing young female soccer players. Whilst this imbalance in representation is evident, this will likely improve as the female game advances and continues to grow economically (FIFA, 2024). Despite the increased growth in the woman's game, the lack of literature present within the current review makes drawing

conclusions on current MS assessments practice within youth elite female soccer players challenging. Therefore, more research in this area is paramount to support practise within the elite female game.

Providing S&C support is important for both male and female athletes (Lesinski et al, 2021; Mcquilliam et al, 2023; Sommi et al, 2018; Weakley et al, 2017). However, published reports suggest that female soccer players typically experience more severe injuries than their male counterparts during competition (Mufty et al, 2015). An important topic of concern for the young female soccer player is the complete anterior cruciate ligament (ACL) rupture. ACL injuries are reportedly 2.8 times greater in women's soccer compared to the men's game (Mancino et al, 2023). It was reported that a total of 37 players were unavailable for selection at the 2023 FIFA Women's World Cup due to an ACL injury. ACL injuries are typically non-contact and occur during a deceleration event, with a sudden change of direction with a planted foot (Koga & Muneta, 2016). Whilst there are several proposed anatomical factors as to why ACL injuries may be so prevalent in women's soccer, such as higher Q-angles, a smaller intercondylar notch, and increased medial posterior tibias slope (Ireland, 2002; Karimi et al, 2017; Mufty et al, 2015; Tillman et al, 2002), hip adductor strength and knee flexor/extensor strength ratio have been highlighted as a potential risk factor for ACL ruptures (Mancino et al, 2023). Therefore, MS assessments may be considered an important component of physical screening for female youth soccer players to attempt to reduce the ACL injury risk. The discrepancy in the volume of research that has been conducted into this topic in female athletes compared to males could be due to a lack of commercial support in the women's professional game, however, with the recent growth in the women's game, there should be more resource available for research into MS assessments on female youth elite soccer players and its influence on performance and injury mitigation.

There are sex specific differences that exist between developing male and female athletes (Malina et al, 2021; Tanner et al, 1976; Tsutsui et al, 2022). As such, normative data and reliability measures from tests performed on one sex should not be applied to the other. The difference in the volume of research published in men's and woman's football has been highlighted in previous research (McQuilliam et al, 2022b). The limited amount of research on the female soccer athlete should be addressed to ensure that information is available for practitioners to make informed decisions on implementing strength testing and training programmes within the female population.

5.1.2 Chronological age

The chronological age of participants within this review ranged from reported mean ages of 11.3 to 18.0 years, including players from as young as Under 8 to Under 21 age groups. These ages align with typical age brackets adopted within academy programmes (Bidaurrezaga-Letona et al, 2019b; Dugdale et al, 2021; McCalman et al, 2022). Based on the returns of this review, chronological age appears to be a factor that influences the method employed when assessing MS (**Figure 2**). Assessments of leg extension, leg flexion, and the Nordic hamstring exercise were conducted with players as young as 8 years old, and the IMTP, hip adduction, and hip abduction tests were conducted on players aged 9-10 years old. These assessments were performed as a MVIC, except the NHE which was performed as an eccentric muscle contraction. Selecting an MVIC strength assessment with younger cohorts is logical as MVIC's require less movement competency and more simplistic technical coaching compared to dynamic movements (Folland et al, 2005; Lum et al, 2020). Furthermore, there typically lower risk of injury performing these assessments compared with more complex weight bearing movements (Grier et al, 2022).

The youngest age a DFW strength assessment was performed was a 5RM BS with soccer players aged between 10.9 -16.0 years old (Ramirez-Campillo et al, 2018). This was the only study to implement a DFW 5RM opposed to a 3- or 1RM observed in other studies (Enright et al, 2015;

Hoppe et al, 2020). Whilst performing a 1RM could be seen as the gold standard of maximal DFW strength testing, due to the single all-out effort with the heaviest load an individual may lift, performing 5RM and 3RM protocols are both valuable assessments despite lifting lighter loads than a 1RM. Both 5RM and 3RM loads are reported to strongly correlated with 1RM loads and may also be used to predict a 1RM with accuracy (Macarilla et al, 2022a). Whilst 1RM assessments of leg extension have demonstrated adequate reliability in children aged 6-12 years old (Faigenbaum et al, 2003), performing a 1RM free-weight exercise (e.g. barbell back squat) in younger children could potentially carry larger risk of injury due to a lower technical proficiency to perform a complex movement. Furthermore, due to the nature of loading with a free weight exercise there is a larger risk if the athlete were unable to hold the weight and either drop the weight or fall vs a machine-based movement whereby the machine houses the resistance. This is why correct coaching of both the movement and how to fail a free weight repetition is paramount, as well as safety measures such as safety bars and spotting should always be administered during these types of assessments. Similarly, due to the subjective nature of exertion during dynamic exercises, the accuracy of young athletes' 'true' 1RM has been questioned (Kushner et al, 2015). Young athletes may, therefore, be better suited to achieving a representative maximum effort during exercises such as an MVIC.

The utility of upper body strength assessments was reported in studies recruiting players aged 12 years and above. Whilst there are no theoretical reasons why these assessments could not be performed at younger ages, upper body strength is typically not a developmental priority in soccer as it does not underpin key actions such as sprinting, jumping, or change of direction ability (Curovic et al, 2024; Guthrie et al, 2021). Although upper body strength is an important quality when jostling for, or shielding the ball (Curovic et al, 2025), development typically focuses on technical proficiency during younger ages (Lloyd & Oliver, 2012). It is, therefore, feasible to assume that upper body strength may not be a topic of interest until players have reached puberty and the physical demands of soccer become more influential to performance and

success. Of the upper body assessments utilised within the returned studies, grip strength was performed at the youngest age (12 years) compared RM bench press (13 years) and RM prone row (14 years). Assessing grip strength using a grip strength dynamometer requires low technical skill, is highly portable, and easy to implement, it can be used with younger athletes with little need of coaching the movement and has been shown to be highly reliable (Dugdale et al, 2019).

Chronological age seems to play a key part in the selection of strength assessments in youth elite soccer players. MVC and MVIC assessments are seemingly the preferred assessments in athletes younger than 13 years age, potentially due to the low technical proficiency required for these movements to be administered reliably (Folland et al, 2005; Horn et al, 2023; Lum et al, 2020). Out with the BS 5RM other dynamic free-weight assessments were not implemented until 13 years of age and above, which may be indicative of players maturation status and training age. It is likely at this age most players will have introduced DFW exercises into their S&C programmes therefore justifying the inclusion of these more complex movements within a testing battery.

5.1.3 Geographic location

Of the 86 articles included in this review, 55 (64%) were conducted in Europe, followed by South America where 6 (7%) studies were conducted. There are several reasons why this may be the case. A primary inclusion criterion for this review was that a study needed to be written in English, potentially reducing the number of papers included from countries without a strong link to the English language. However, of the 22 excluded papers written in languages other than English, 18 (82%) were from France, Spain, and Germany. Therefore, only 4 (5%) papers excluded from the review were from outside of Europe. Recent research has shown that 90% of scientific research in recent years has been published in English and literature published in countries where English isn't a first language outperforms research published in the country's first language (Di Bitetti & Ferreras, 2017). Therefore, the language restriction in the inclusion criteria may not have influenced this disparity substantially.

Twenty of the world's richest football clubs and eight of the top leagues in the world are situated in Europe (Deloitte, 2025). This dominance of European soccer may result in clubs within these regions having a richer culture and structure for soccer. Therefore, long-term investment into academy programmes may have contributed to greater sport science infrastructure as clubs attempt to maximise their talent development processes (Memmert & Raabe, 2018). These combined factors may have ultimately led to an increased output of scientific research within youth elite soccer players in Europe, evidenced by the disparity of geographic locations observed within studies returned within this review. Due to the dominance of European published papers within this review, conclusions of strength assessments globally should not be concluded from the findings of this review. However, despite the lack of variety in the geographic location of research, there is seemingly a variety in research design implemented within the research included in this review.

5.1.4 Study design

Observational research method was the most popular research method, utilised by 55 (64%) of the studies within this review. These studies typically assessed the physical qualities of participants in a cross-sectional approach and did not implement any intervention beyond recording participants' habitual training or testing scores. Findings from these studies, therefore, are limited to providing insight into athlete capabilities at a specific point in time and providing normative or reference data (Boyko, 2013).

Thirty-one (36%) of the 86 studies used an experimental design, these studies typically assessed the effectiveness of an intervention within a population. This study design can provide scientific evidence of (un)effective training methods that may be available for practitioners to implement to enhance the physical capabilities of youth elite soccer players (Concato, 2004; Stoner et al, 2023). Of the 31 experimental studies, only 8 studies included a control group. A control group provides a benchmark for comparison with the experimental group, allowing

researchers to isolate the effects of the intervention and establish the validity of results (Double et al, 2020). Therefore, performing experimental research without control groups reduces the validity of the experimental outcome as a practitioner cannot be confident that the intervention was the individual factor that drove the outcome (Scholtz et al, 2020). Performing experimental research elite sporting is challenging. Access to athletes is often limited leading to low sample numbers. Furthermore, establishing control groups can be difficult in applied settings as withholding potentially beneficial training from athletes can be challenging to justify to athletes and coaches (Coutts, 2017). This may explain the tendency of studies returning within this review to implement observational designs to avoid disrupting a team's training and player development. Nevertheless, experimental research with control groups provides the highest prognosis for athlete populations.

Due to a focus on long-term athletic development within football academies, longitudinal studies that assess development over a period of years are highly sought after. Only 8 of the 86 studies included longitudinal study designs and no study assessed players for longer than one season. Considering the challenges of conducting research in applied football settings, this finding is unsurprising. Longitudinal studies require the same group of players to be monitored over a period of several years/seasons which is often challenging due to high prevalence of players and staff alongside developments in technology/equipment and changes to protocols over time.

In summary, observational studies are the most common within youth elite soccer. Whilst useful, they only provide a snapshot of athletes at that singular moment in time (Boyko, 2013). Longitudinal and experimental research is limited in this area, however, potentially provide greater insights into the capabilities of youth elite soccer players and training methods. Due to the challenges of conducting experimental research within sport, limited studies included a control group within their research which may reduce the validity of the outcomes. Despite the

aims of this review being to ascertain current testing practices within elite youth soccer players, the nature of the study design is a key component of research. Understanding the type of research being performed within the field has highlighted the importance of high quality longitudinal and experimental research to add to the large body of observational studies.

5.2 Mode of Assessment

5.2.1 Maximal Voluntary Contractions assessments

Maximal voluntary contractions (MVCs) assessed via resistance machines were the most common method for evaluating MS within this review. Resistance machines are commonly used for strength assessments for several reasons. First, resistance machines demonstrate high test-retest reliability across multiple exercises (Paul & Nassis, 2015a; Wollin et al, 2016a, 2016b). Moreover, due to the fixed resistance nature of these machines, potential learning effects are minimal compared to more technically demanding protocols, such as DFW assessments (Grgic et al, 2020b). The combination of these factors make resistance machines a desirable option when assessing chronologically younger athletes with a lower training age. This is demonstrated by the predominant use of MVCs within the chronologically younger cohorts of athletes within the reviewed studies (Andrade et al, 2021; Bidaurreazaga-Letona et al, 2019a; Brownlee et al, 2018; Emmonds et al, 2017; Hoshikawa et al, 2013; Morris et al, 2018, 2021).

Of the three assessment modalities utilised to assess MVCs, isokinetic dynamometry was the most implemented, surpassing both the NHE and machine-based one-repetition maximum (1RM). Isokinetic dynamometry is widely regarded as the gold standard for strength evaluation in laboratory settings, offering the flexibility to isolate various upper and lower body movements, (Parrington & Ball, 2016). The versatility of isokinetic dynamometry allows adjustments in the range of motion, joint angle velocities, and contraction types, making it a highly adaptable tool

for measuring muscle function (Greig & Langley, 2024). Coupled with its high precision and reliability, explains its widespread use, in both clinical and applied research (Dvir & Müller, 2020). However, while isokinetic dynamometry is commonly implemented in research, its application in applied sports settings may be limited. Evidencing this, a study examining performance testing practices in elite male footballers reported that only 29% of respondents used isokinetic dynamometry for quadriceps and/or hamstring strength assessments (Asimakidis et al, 2024b). This placed it behind maximal voluntary isometric contraction (MVIC) assessments, such as the isometric mid-thigh pull (IMTP), and adductor squeeze. However, research by the same authors also conducted a systematic review of strength and power assessments in elite male football (Asimakidis, Mukandi, et al, 2024), the findings of this paper showed that isokinetic assessment of the knee extensors (58 of 115 studies, 50%) and knee flexors (55 of 115 studies, 48%) were the most common assessment in research. These findings are in agreeance with the findings of this review and highlight the difference between assessments performed within research and the applied practice. This difference between the implementation of IKD in practice and research could be due to the cost of the specialised equipment, it's lack portability, and the significant amount of time required to complete the various testing protocols. Consequently, clubs with limited resources may not have access to this equipment and due to the time demands, this method may not be practical to implement within a squad of 20+ players. Therefore, perhaps this is why other affordable and less time intensive methods such as the NHE and IMTP are implemented routinely.

In five studies, one-repetition maximum (1RM) assessments of MVC were favoured over isokinetic dynamometry. Like isokinetic devices, resistance machines can isolate specific muscle groups and range of motions. Two studies assessed leg extension strength (Hosseini Kakhak et al, 2022; Peñailillo et al, 2016), and others evaluated multi-joint exercises, such as the leg press (Grendstad et al, 2020; Lesinski et al, 2021) and lat pull-down (Ruivo et al, 2016). Perhaps simpler to administer than isokinetic dynamometry, 1RM testing provides a measure of

MS without capturing force-time characteristics or movement velocity. While resistance machines may only allow one exercise to be completed compared to the multiple exercises possible with isokinetic dynamometers, these machines are more affordable, do not require specialized training, and can be integrated into strength programs. Furthermore, bespoke facilities (such as gyms and sports centres) may be accessible by many clubs through access agreements or individual/shared facility used. These factors may make resistance machines a more economically viable option over IKD, explaining their prevalence within this review.

The third MVC method utilising within the returned studies was the assessment of peak torque of the Nordic Hamstring Exercise (NHE), which measures eccentric hamstring strength. Of the returned studies within this review, eight independently assessed eccentric hamstring strength, with six using the NHE and two using isokinetic dynamometry. Eccentric hamstring strength is of particular interest to S&C practitioners, as it has been linked to faster sprint speeds and a reduction in hamstring injuries (Oliveira et al, 2020). Given the increased sprinting and high-speed running demands in elite football over the past two decades, adequate preparation for these demands necessitates focusing on eccentric hamstring strength (Markovic et al, 2020). Due to the bodyweight nature of the exercise, it has grown in popularity since it requires minimal equipment and can be performed universally. The NHE, has been shown to be highly effective in reducing hamstring injuries among elite soccer players (Al Attar et al, 2017). A ten-week NHE program has shown to be effective at increasing peak eccentric torque and reducing hamstring injuries across a full season in competitive soccer (Krommes et al, 2017). However, uptake of this protocol in elite practice may be limited due to its high frequency and volume requirements (Van Dyk et al, 2019). Condensed protocols have since been proposed to better align with the demands of elite soccer by reducing overall training volume (Cadu et al, 2022). Whilst hamstring strains are less prevalent in youth elite soccer players (Robles-Palazón et al, 2022), ensuring players have adequate eccentric hamstring strength to cope with the demands of senior elite football is physical component of the TD process. The NHE provides a

cost-effective and accessible method for assessing eccentric hamstring strength, and its effectiveness in reducing hamstring injuries likely contributes to its prominence in research focused on eccentric hamstring strength.

A 1RM machine leg press was employed twice in the returned studies as an assessment of lower-body MS. The machine leg press was the only multi-joint resistance machine MVC used to evaluate lower-body strength, as opposed to single-muscle isolation. This type of assessment offers greater insight into performance across a movement, which may be more closely aligned with sporting actions than isolated muscle assessments (Weakley, et al, 2023). Practitioners may favour the leg press over exercises like the barbell squat due to reduced axial loading on the spine, which can cause discomfort in athletes, and the perceived enhanced safety profile of the machine (Grier et al, 2022). Leg extension and leg curl were the most frequently assessed movements using MVCs. Knee extension and flexion assess the two key muscle groups of the lower limb, the quadriceps and hamstrings. These muscle groups are critical in key football actions such as sprinting, decelerating, jumping, and ball striking (Harper et al, 2019; Markovic et al, 2020). As such, performance in these tests is often linked to improved performance in these actions (Haugen et al, 2014; Styles et al, 2016b). Additionally, hamstring and quadriceps injuries are among the most common muscle injuries in football (López-Valenciano et al, 2020). Assessing knee extensor and flexor strength may provide practitioners with valuable insight into muscle weaknesses or limb asymmetries, both of which could be risk factors for future injury (Helme et al, 2021).

The popularity of MVC's in research agrees with another review in of this topic (Asimakidis, Mukandi, et al, 2024). The popularity of MVC assessments in research is likely due to low technical proficiency required to implement the assessment effectively (Contreras-Díaz et al, 2023; Dvir & Müller, 2020) and high reliability accredited to these movements (Horn et al, 2023; Markovic et al, 2020). Despite the popularity of IKD within research, implementation of this assessment in practise has challenges, as such other methods such as the NHE may be

implemented to assess eccentric hamstring strength in a timelier manner. Practitioners may also wish to implement dynamic multi-joints strength assessments within their testing batteries.

5.2.2 Dynamic Free Weight assessments

DFW strength assessments involve athletes moving external loads, typically using barbells or dumbbells (Folland et al, 2005). These assessments commonly follow a repetition maximum (RM) protocol, where the athlete lifts the maximum resistance possible for a specified number of repetitions (Soriano et al, 2021). All returned studies employed the barbell as a loading method for external resistance. Of the 14 studies assessing DFW exercises, 10 used a 1RM test. The 1RM represents the maximum load an individual can lift for a single repetition in each exercise, making it a true indicator of MS (J. M. Reynolds et al, 2006). However, a 1RM test demands a high level of technical proficiency and as previously discussed, athletes with insufficient technical competency may be limited during 1RM assessments. Therefore, while an athlete may be capable of lifting a higher load, they might lack the technique to maintain appropriate positioning or the confidence to attempt a heavier load, resulting in an inaccurate test score. In these cases, it may be more appropriate to use repetition maximums with higher repetition targets, such as a 3RM or 5RM (Ramirez-Campillo et al, 2018). Although an increase in the number of repetitions performed shifts the focus slightly away from MS, 3RM and 5RM tests are still widely considered valid assessments of MS and are strongly correlated with 1RM performance in athletic populations (J. M. Reynolds et al, 2006). In this review, two studies reported using a 3RM (Mcquilliam et al, 2023; Sherwood et al, 2021), and one using a 5RM (Ramirez-Campillo et al, 2018). The latter was employed with the youngest participants, potentially endorsing the suggestions regarding technical competency and training age proposed above. Finally, one study utilised a linear transducer to estimate a 1RM by calculating mean concentric barbell velocity (Stern et al, 2020), based on the inverse linear relationship between %1RM and concentric barbell velocity. This method may, however, have limitations, as

individuals typically exhibit different force-velocity slopes during free weight exercises, therefore using a single equation for all athletes can result in miscalculated 1RMs (Macarilla et al, 2022b). Moreover, the accuracy of a predicted 1RM improves as the athlete nears their actual 1RM (Macarilla et al, 2022b). In the study in question, participants self-selected their loads, which could lead to discrepancies between the predicted and true 1RM depending on the chosen weight (Stern et al, 2020).

The BS was the most frequently employed DFW assessment within the returned studies. As a widely implemented exercise in soccer S&C (McQuilliam et al, 2022a), the BS provides a routine method for assessing MS in applied settings. Increases in BS strength have been correlated with improvements in sprint speed (Comfort et al, 2014; McBride et al, 2009; Styles et al, 2016b), change of direction ability (Makhlouf et al, 2018), and jump height (Chelly et al, 2009; Chrisman et al, 2012), all of which enhance athletic performance. Given its popularity in training programs, using the BS as a strength assessment may reduce the learning effects often associated with novel tests. The barbell front squat was employed in only one study returned in this review. While both the front and BS follow the same bilateral squatting pattern, the front squat requires the barbell to be held on the front of the shoulders rather than the back. Although both exercises positively impact athletic performance, the BS was favoured in the selected studies, potentially due to familiarity and utility within training practices.

The rear-elevated split squat appeared once in the returned studies. Unlike the BS, this exercise is unilateral. Some research suggests that improvements in unilateral strength transfer more effectively to locomotor performance than bilateral exercises (Liao et al, 2022). Similarly, Unilateral exercises require greater balance and stability, which some argue makes them more sport specific (Liao et al, 2022). However, due to the reduced absolute load compared to bilateral exercises, the trade-off between load and stability must be considered when selecting a free-weight exercise. Unilateral assessments also offer the advantage of detecting strength

asymmetries between limbs, which may be crucial for injury prevention or rehabilitation (Bishop et al, 2021; Fousekis et al, 2010). However, unilateral exercises can be more time-consuming to complete and require specific equipment, such as a platform to elevate the rear foot, making standardization more difficult. The Olympic power clean was included in one study. This highly technical movement demands significant coordination, making it suitable only for athletes with a high training age and proficiency (Bishop et al, 2021). Although the power clean was assessed via a 1RM, it is performed at a higher concentric velocity than squats, offering insights into an athlete's explosive and technical abilities, rather than just MS (MacKenzie et al, 2014). For this reason, single or double-leg squatting or lunging patterns may be preferred over the power clean for assessing lower-body MS. For upper-body strength assessments, the barbell bench press was the most employed test, used in six studies. Upper-body strength is important in football, where players must hold off opponents, but lower-body strength is more critical for actions like sprinting and jumping (Chelly et al, 2009). The absence of a direct correlation between upper-body strength and sprint or jump performance suggests that while it can be part of a strength testing battery, it may not replace lower-body assessments.

Maximal DFW assessments are physically demanding, both from a neuromuscular and mechanical perspective (Hooper et al, 2014). During the competitive season, athletes may struggle to perform these tests due to residual fatigue from matches which may affect the ability to obtain a true 1RM, or the resulting fatigue from these tests impacting training or match performance. Therefore, monitoring training data, such as tonnage (sets x reps x load), can provide valuable insights into strength progression without requiring frequent maximal testing (Scott et al, 2023). Technologies such as velocity transducers can estimate 1RM using submaximal loads, offering a less taxing alternative for evaluating strength. As previously discussed, dynamic free-weight assessments have high transferability to sports performance due to their full dynamic range and coordination required to maintain balance and trunk integrity. However, these exercises require technical proficiency and can be taxing on athletes, especially

younger or less experienced individuals. In such cases, 3RM or 5RM tests may be recommended. While maximal dynamic strength tests offer key insights into an athlete's strength capacity, monitoring longitudinal strength increases through regular training provides an additional, less invasive method of assessment.

DFW strength assessments are arguably the most technically complex movements to perform of the three identified assessment methods within this review. DFW movements require a certain level of movement proficiency under external load to perform an accurate test. Despite this, the BS was implemented with young athletes within this review and was shown to be a safe method within this age demographic (Ramirez-Campillo et al, 2018). Studies implemented 1RM, 3RM and 5RM methods ascertain MS, whilst each are reliable and accurate (Niewiadomski et al, 2008), a 1RM arguably provides the truest reflection of an athlete's MS capabilities, however 3RM and 5RM assessments may be more suitable to athletes with lower technical competency. Another method to assess MS which can be implemented with athletes who have minimal technical proficiency are MVIC's.

5.2.3 Maximal Voluntary Isometric Contraction assessments

Maximal voluntary isometric contractions are strength assessments whereby maximal force is exerted against an immovable object resulting in an isometric muscle contraction with no joint movement. Isometric muscle contractions occur during the amortisation phase of dynamic movements and have been linked to key sporting movements and therefore a key component of physical development. The hip was the most assessed joint in MVIC assessments. This is unsurprising, given the hip's central role in locomotion and ball striking in soccer (Contreras-Díaz et al, 2023). Additionally, due to the high volume of ball strikes in training and matches, hip overload injuries are common among adolescent soccer players (Ekstrand et al, 2011a). However, studies have shown that improving MVIC strength of the hip adductors significantly reduces the incidence of groin injuries over a full competitive season (Delang et al, 2024). Despite

the importance of hip strength, conducting comprehensive dynamic strength assessments of the hip can be challenging. While resistance machines can be used to assess MVCs, these machines often lack versatility for targeting different angles of hip movement and are often limited to a laboratory setting, as previously discussed. It is common to assess hip adduction at varying degrees to isolate different muscles within the hip complex (Contreras-Díaz et al, 2023). In contrast, MVIC assessments of the hip can be performed both in laboratory and field settings (Wollin et al, 2018). Handheld and fixed dynamometers can accurately measure hip flexion, extension, abduction, and adduction (Kolber et al, 2017). Furthermore, these devices allow for assessments at various angles, providing a more comprehensive assessment of hip musculature strength. MVIC assessments also provide valuable insights into neuromuscular fatigue following high-intensity training (Radzak & Stickley, 2020). Research suggests that both hip adduction and extension MVIC peak force decline in youth soccer athletes after exposure to high external loads, highlighting the importance of monitoring neuromuscular outputs to manage training loads and reduce injury risk (Dambroz et al, 2022). Hip adduction was the most common MVIC assessment, which is logical given the role of the adductors in ball striking and high injury rate of the groin in elite senior and youth soccer (Ekstrand et al, 2011a). Although hip abduction (7 studies) was assessed less frequently than adduction (10 studies), it was still the third most common MVIC movement. Relative strength of the hip abductors is closely linked to sprinting and change of direction performance (Królikowska et al, 2023). Therefore, its assessment provides valuable insight to the physical development of youth athletes. However, dynamic assessment of hip abduction is challenging without specialised equipment. This is due to isolation required to the hip joint and therefore the ability to fix load to the knee or ankle to provide resistance without using a fixed resistance machine which are costly. Due to the antagonistic relationship between hip adduction and abduction, it is common to assess both movements consecutively using the same equipment for time efficiency as observed in 7 studies within this review (Chrisman et al,

2012; De Ridder et al, 2017; Jones et al, 2021; Kolodziej et al, 2023; Nielsen et al, 2022; Schoffl et al, 2021; Soós et al, 2022).

The isometric mid-thigh pull (IMTP) was the second most common MVIC assessment reported within the returned studies. During the IMTP, athletes are positioned to replicate the second pull phase of a barbell clean, allowing for a comprehensive measure of lower-body force production via a series of maximal isometric contractions across multiple joints (McCormick et al, 2022). Research indicates that time to peak force of less than 250 milliseconds correlates strongly with explosive sporting actions, such as jumping and sprinting (Thomas et al, 2015). Although peak force itself may be less predictive of athletic performance, it still serves as an indicator of general lower-body strength (Wang et al, 2016). An athlete's ability to produce high amounts of force quickly is dependent on the number of motor units that can be recruited within a given time frame and the rate at which they discharge action potentials. This is a crucial underpinning for explosive actions in soccer providing insight into an athlete's lower body neuromuscular capability.

However, it is important to note that the IMTP requires less intermuscular coordination compared to dynamic free-weight exercises. Due to the need to manage the centre of mass to maintain balance throughout the exercise (Šarabon & Kozinc, 2020), co-activation of antagonistic muscles across joint to maintain joint stability (Latash, 2018) and the sequencing of muscle contractions throughout the body to generate a specific movement pattern such as the squat (Muehlbauer et al, 2007). It could be argued that high force isometric exercises/assessments do not guarantee a similar transfer to dynamic sporting actions as DFW movements.

Knee extension and knee flexion were assessed seven times, respectively, within the return studies. The limitations of isometric knee assessments are like those of the IMTP, as peak force varies dependant on the joint angle adopted (Pincivero et al, 2004). Therefore, while these assessments may be useful during congested match schedules to avoid overloading (Muehlbauer et al, 2007), dynamic strength assessments are likely more suitable for capturing

force production relevant to key sporting actions (Harper et al, 2019). It may be a viable option to assess MVIC at different fixed positions to ascertain a more complete understanding of an athlete's capabilities at different ranges (Folland et al, 2005; Nuzzo et al, 2008). However, this method may be hampered by time constraints. Grip strength could be considered a global indicator of overall strength, as it correlates with various upper and lower body strength measures. In the studies returned from this review, the handgrip MVIC was utilized five times. Handheld dynamometers (HDDs) are widely transportable, low cost, and require little familiarisation, set up, and instruction. Hence, while grip strength may not be as relevant for soccer compared to lower-body strength capabilities, its utility makes it a simplistic proxy of strength within applied settings when considering the previously discussed constraints of MS assessment in soccer.

Among the devices used, fixed load cells were the most common prevalent in 14 studies. This technology is typically attached to immovable objects, often custom-built rigs, against which athletes exert maximal force. Fixed load cells are reported to provide reliable data, provided the apparatus is secure and non-yielding (Pichardo et al, 2024). However, due to the immovable nature of the rig, load cells are less portable and may only be feasible in laboratory settings or when installed in a bespoke training facility. Furthermore, when assessing multiple athletes there may be adjustments required to ensure that the setup is suitable for each athlete's stature and limb length. This can be particularly problematic with youth athletes who are impacted by significant differences in physical growth and development. In contrast, handheld dynamometers, which were implemented 10 times within studies returned in this review, offer greater flexibility and portability. Force plates were used nine times in this review, primarily for IMTP (6 studies) and hip extension assessments (1 study). While force plates are valuable for measuring vertical force production (Meylan et al, 2011), they offer less versatility than handheld devices or load cells in assessing a wider range of movements. However, force plates can also be used for jump, rebound, and landing assessments, making them a diverse tool for assessing

multidimensional physical qualities prevalent within soccer testing batteries (Speller et al, 2024). Finally, the least common device used to assess MVICs was the sphygmomanometer, which offers an affordable and reliable alternative to load cells. In this review, sphygmomanometers were used to assess hip adduction in 1 study (O'Brien et al, 2018). While this method provides an overall assessment of hip strength, it cannot detect asymmetries, limiting its usefulness for targeted assessments.

The ease and portability of some technology available today make MVIC assessments highly popular, however the cost of this equipment may make it unattainable for some clubs. Unlike maximal dynamic strength assessments, MVIC assessments induce minimal neuromuscular fatigue, allowing them to be used throughout the competitive season without concern for overloading athletes. Some MVIC assessments such as the IMTP may even provide a post-activation potentiation effect, enhancing acute force outputs, making it a potential physical primer for training or competition (Magal et al, 2025). However, MVIC assessments may have limited transferability to angles beyond 15 degrees from the tested range of motion, emphasizing the need to assess athletes at multiple joint angles to capture a more complete picture of their force-producing capabilities. Or practitioners to be specific with the design of their tests to isolate testing to a specific sporting action, such as a supine run-specific hamstring MVIC to assess hip extensors during late swing stage of sprinting (Prince et al, 2021). One of the key benefits of MVIC is the use with biologically immature athletes, due to the low technical proficiency requirements.

5.3 Maturation

5.3.1 Maturation status

Of the 79 papers included in this review, only 16 (20.3%) reported including an estimation of maturity status within their sample. Assessing maturity status is crucial when evaluating the physical capabilities of youth athletes, as athletes who are more mature often exhibit increased

anaerobic performance when compared to their less biologically mature peers (Sinkovic et al, 2023). Consequently, interpreting physical testing results within the context of maturity status is essential to avoid bias toward early maturing players (Bolckmans et al, 2022). Among the 16 studies including an estimation of maturity status, 13 compared strength performance across defined maturation groups (pre, circa & post PHV), independent of chronological age. Each study reported a relationship between maturation status and strength, favouring more mature players. This finding reinforces this well-established bias reported in developmental literature (Ostojic et al, 2014). In the scope of the current review, it is imperative to incorporate maturity estimations alongside assessments of MS, particularly when using results to shape training focus, developmental plans, or influence (de)selection decisions. Long-term athlete development literature suggests that later-maturing players may benefit from lower-intensity strength training to improve neuromuscular coordination, while those who have experienced their growth spurt may require higher-intensity training focused on hypertrophy and MS (Lloyd & Oliver, 2012; Quatman-Yates et al, 2012; Roemmich & Rogol, 1995). Without considering maturity status, accurately assessing an athlete's capability becomes challenging. When considering the studies returned in this review, it may have been determined by researchers that older athletes (>17.0 years old) did not require a biological assessment as it was assumed they were near adulthood and were likely all post-PHV. Whilst this may be true, this may not explicitly be the case for all individuals within the cohort, as in extremely cases, players may continue to develop into their later teen years (Cumming et al, 2017; Figueiredo et al, 2009).

5.3.2 Maturation Timing

Only three of the 16 studies examined MS performance in relation to maturity timing (early, on-time or late). Understanding maturity timing is crucial when comparing players within a team (e.g, U16s) or a developmental phase (e.g, youth development). Assessment of maturity timing can provide explanation for individuals who may be perceived to be ahead or behind in their

physical development, ensuring fair comparisons within groups (Cumming et al, 2017). This concept is critical for talent identification, as early maturing players are often viewed more favourably than their later maturing peers, potentially leading to short-term misjudgements in potential (Figueiredo et al, 2009). The fact that only ~20% of studies included within this review accounted for biological maturation presents a significant concern within strength assessment literature. Whilst many studies did not directly investigate biological maturation, reporting maturation status could provide deeper insight into the physical capabilities of the group and enhance external validity (Konarski et al, 2021; Malina et al, 2015, 2021).

5.3.3 Assessment type

Three different methods were used to assess biological maturation in this review. Two studies utilised skeletal maturity assessments via the Greulich-Pyle (1959) method. This technique involves taking an X-ray of the hand and wrist, which is then compared to reference images to determine developmental status based on the ossification of growth plates. Skeletal maturation assessments are considered the gold standard due to their objective evaluation of skeletal development (Cavallo et al, 2021). However, this method requires access to X-ray equipment and skilled radiographers, making them expensive and impractical for large-scale assessments within applied environments, such as those needed in professional soccer academies. Despite its efficacy, the Greulich-Pyle (1959) method has limitations. The method was developed based on white, middle-class American children, raising concerns about its accuracy in diverse populations (Sullivan et al, 2023b). Additionally, the assessment relies on comparing the X-ray images to just five predefined images (atlas), whereas alternative methods, such as the Tanner-Whitehouse 3 (TW3), includes a more diverse referent dataset, making it applicable to a broader population. The TW3 method also evaluates individual bones within the wrist and hand for a more precise measurement and provide estimation of future adult height (Qiao et al, 2025). The second method used in this review was a sexual maturity assessment, implemented in two studies. One

study (Massa et al, 2022) followed the Tanner (1962) method, which requires a medical professional to assess an athlete's sexual maturation through comparing an individual's pubic hair and genital development. Another study (Forbes et al, 2009) used the Peterson (1998) method, which employs self-assessment of an individual's pubic hair and genital development. The Peterson (1998) method may be considered as logistically simpler as it does not require a trained professional. It may also be considered ethically preferable as young athletes are not subjected to an invasive examination. Both methods categorize individuals into the five Tanner stages based on breast/genital development and pubic hair growth (Pant, 2024).

The most common method for assessing biological maturity identified within this review was via somatic estimation equations. These methods are popular in applied settings due to their non-invasive nature, reliance on readily available anthropometric data, and cost-effectiveness (Sullivan et al, 2023b). However, there may be moderate to low concordance between somatic estimation methods and more invasive methods maturation assessments, leading to recommended caution with its interpretation and prognosis (Salter et al, 2022). The most frequently used somatic estimation methods was maturity offset, which predicts the time (in years) away from PHV. This method utilises a combination of anthropometric measurements within a predictive equation. Within this review, the Mirwald (2002) method was the primary assessment used to estimate maturity offset, used in 11 out of 12 studies that assessed somatic maturation. However, this technique may be considered to have notable limitations. Its referent population base is predominantly North American Caucasian, leading to potential over- or under-estimation in diverse populations (Salter et al, 2022). Additionally, the Mirwald (2002) method has been reported to estimate PHV accurately in younger children but overestimate PHV in older adolescents due to its assumption of standardised growth. The error margin of Mirwald's predictions has been reported to be ± 0.75 years, which may be significant in elite youth soccer contexts, particularly when relying upon these data. Similarly, maturity offset methods are considered reliable for athletes who are "on-time" maturer but may not accurately predict case

of early or late maturation (Koziet & Malina, 2018). Alternative methods, such as the Moore 2 (2015) and Fransen (2018) models, were developed to refine the Mirwald (2002) equation. However, these models still face similar age-related biases (Sullivan et al, 2023b) and neither were used within studies included in this review.

The final somatic method used in this review was predicted adult height (PAH; Khamis Roche, 1985). This estimation method incorporates athletes' current anthropometrics combined with parental height to estimate their future adult height. Typically, PHV occurs at 90-91% PAH but can range between 85-92% (Cumming et al, 2017; R. M. Malina et al, 2015). This method was used in only one of the studies returned within this review (Kornarski et al, 2021) to compare selected and non-selected Polish youth football players. In strength testing, athletes are often categorized into %PAH groups (e.g, 80-85%, 85-90%, 90-95%) to compare strength relative to biological maturity (Johnson et al, 2022). Despite its own margin of error, regular height measurements enhance PAH's reliability, making it a valuable tool for biological maturation-based strength assessments. Finally, only 3 (Emmonds et al, 2016; Emmonds, Sawczuk, et al, 2020; Emmonds, Scantlebury, et al, 2020) of the 16 studies that assessed biological maturity included female athletes. Each of these studies used the Mirwald (2002) method, which has a specific equation for females. However, research suggests that Mirwald's error rate may be higher for females than for males (R. M. Malina et al, 2015). Given the importance of strength in preventing common injuries in female soccer players, such as ACL ruptures, combined with the evident impact of growth and maturation on anaerobic performance, more research in this area is needed.

5.2.4 Implications on testing

Whilst determining maturation status when comparing MS outcomes is valuable for TI purposes, practitioners should consider their aims when performing MS assessments on prepubescent individuals. Training programmes at this age include a variety of training modalities, whilst it has

been shown that strength does improve with strength training irrespective of age (McQuilliam et al, 2020), improvements in strength are seen throughout PHV but typically the largest increase in strength occurs 6 months to a year after PHV during peak weight velocity where the rate of lean mass accrue ment is greatest due to increased circulating blood androgens such as testosterone (R. Malina, 2004). It has also been theorised that younger athletes will generally improve strength through neural pathways, although well trained individuals may also show some morphological adaptations (Behm et al, 2017). As such training programmes with prepubescent individuals should focus on developing a wide range of movement competencies, in preparation in physical capabilities post puberty (Lloyd et al, 2014). As such it is therefore unlikely that strength testing performed in prepubescent individuals will inform training practices. Whilst improvements in DFW strength assessments can highlight an improvement in technical competency and MVIC or MVC can show strength progression over time, these methods are likely not being used to guide programme design until an individual has experienced puberty (Behm et al, 2017). And therefore, practitioners should consider the rationale for performing MS assessments and if the testing will benefit the overall development of the individual. It is also paramount to ensure that strength assessments being implemented are accurate and reliable within the population being assessed.

5.4 Reliability

5.4.1 Importance of reliability

Reliability is an important concept when conducting strength assessments within youth soccer populations to ensure accurate and representative data is retrieved. Ensuring an assessment possesses adequate reliability ensures consistency across repeated trials, thereby enabling meaningful interpretation of performance outcomes (Ahmed & Ishtiaq, 2021). Conversely, if a test demonstrates poor reliability, its results may lack the ability to accurately assess strength characteristics or track physical progress (Paul & Nassis, 2015a). Reliability in strength testing is

particularly important for youth athletes, as factors such as relative training age, exercise familiarity, and motor coordination influence their ability to execute performance assessments accurately (Dugdale et al, 2019). Athletes with lower training experience and reduced coordination may struggle to produce consistent movement or force profiles, leading to greater variability in test outcomes (Quatman-Yates et al, 2012). Findings from this review revealed that only 13 studies (15%) reported internal reliability data for MS assessments. This lack of assessment of internal reliability potentially diminishes confidence in the findings and limits the ability to draw robust conclusions from these studies. While some level of assumed reliability may be inferred from established testing protocols, it appears to remain an uncommon practice within the field to report internal reliability statistics. Given the unique characteristics of each training environment and the variability inherent to youth sports, explicit reporting of internal reliability would greatly enhance the validity of strength assessments, providing a more trustworthy foundation for both research and practical application.

5.4.2 Evaluations

Within this review, the six studies that utilised the IMTP presented reliability statistics demonstrating excellent intra-day reliability ($ICC = 0.93-0.98$) across a sample of 491 male and 270 female athletes, ranging in age from 10 to 18 years. These findings align with previous research in senior male and female football players (Asimakidis, Mukandi, et al, 2024), supporting the IMTP as a reliable tool for strength assessment across a broad range of youth soccer athletes. The high reliability observed within the IMTP may be attributed to the low movement competency required for performing MVIC's. As a result, the IMTP may have minimal learning effects, is not highly fatiguing, and thus may provide a useful assessment of MS within this population (Warneke, Mizuguchi, et al, 2023a, 2023b). Other maximal voluntary isometric contraction (MVIC) assessments, such as hip adduction assessed via sphygmomanometer

(O'Brien et al, 2018) (ICC=0.92), knee flexion assessed via IKD (Wollin et al, 2016b) (ICC=0.87), and knee extension and flexion both assessed using a load cell (Martínez-Serrano et al, 2023) (ICC=0.98) , all reported good to excellent reliability within this review. These assessments also do not require a high degree of coordination to perform, owing to the single-joint nature of the exercises and the static exertion of an MVIC. All three studies were performed with male athletes aged 15 years or older. This is noteworthy, as male athletes between the ages of 12 and 15 can often experience rapid growth, which can lead to acute changes in motor competency and movement (Hill et al, 2023), thus could have potentially influenced test reliability.

The reliability of both the power clean (Dos'Santos et al, 2018) and the BS (Enright et al, 2015)(Enright et al, 2015) were included. The power clean showed good between-session reliability (ICC=0.89), whilst the specific value for the BS wasn't provided by the authors its CV value was reported as the lowest of tests, they assessed all of which were less than 13%. These evaluations were performed in individuals 17 years of age and are comparable with similar findings in senior populations (Ramirez-Campillo et al, 2018). Markovic et al. report good within-session reliability for NHE in male players aged 11-17 years old (ICC = 0.89). This high reliability of this measure across a large age range highlights means this assessment could potentially be used across a full academy confidently. The final study examined the eccentric and concentric peak torque of hip adduction and abduction, also using IKD (Gerodimos et al, 2015). These assessments demonstrated good to excellent reliability (ICC =0.73-0.91) , though slightly lower ICC values were recorded at a velocity of 90°/s compared to 30°/s, which is consistent with findings in senior populations (Goncalves et al, 2021).

Combined, these findings suggest that all the evaluation included within this review that assessed reliability showed good to excellent reliability. The IMTP (Emmonds et al, 2017; Morris et al, 2018) and NHE (Markovic et al, 2020) were the only exercises to test their reliability in athletes as young as 11 years old, the other studies participants were all older than 15 years of

age. Therefore, based on the results of this review should be only assessments implemented on younger athletes with confidence, given their minimal technical proficiency they should provide accurate and reliable measures. Whilst other methods using MVC and DFW have shown to be reliable, it is recommended that internal measure of reliability are collected as each environment is unique.

6- SUMMARY

6.1 Practical implications

This review provides a comprehensive overview of the range of strength assessments utilised within research to assess MS capabilities of elite youth soccer players. Findings from this review suggest that the selection of an appropriate assessment method is contingent upon multiple factors, including the desired physiological measure, the athlete's training age, maturation status, environment, and available resources. Given the findings from this review, it may be interpreted that maximal voluntary isometric contraction (MVIC), and maximal voluntary contraction (MVC) assessments may be a suitable option for the assessment of younger athletes who may lack the requisite technical proficiency and neuromuscular coordination for more advanced testing protocols. Furthermore, due to their suitability for a range of ages and samples, these assessments may facilitate longitudinal monitoring of strength development throughout adolescence, providing valuable insight into an athlete's physical progression over time. While DFW assessments arguably offer the highest ecological validity in relation to football-specific movements, their reliability in younger populations remains questionable. To combat this, practitioners working with younger soccer athletes should consider exposing them to dynamic free-weight exercises as part of a structured S&C training programme. Once an adequate training age has been achieved, systematic assessments may be implemented with greater confidence and accuracy.

A critical limitation identified in the existing literature is the paucity of internal reliability and sensitivity analyses within strength assessment data (Enright et al, 2018; Ward et al, 2018). It is insufficient to assume that an improved score, either at the individual or group level, is meaningful without first establishing the internal reliability of the assessment used and the smallest worthwhile change of the test to determine sensitivity (Asimakidis, Mukandi, et al, 2024). To address this gap, future research should strive to conduct internal assessments of reliability within their study design as a priority.

Finally, it is imperative to account for biological maturation differences when interpreting MS assessment outcomes among elite youth soccer players (Beunen & Malina, 1988). The process of growth and maturation is well documented to influence physical performance and judgements on ability (Cumming et al, 2017; Philippaerts et al, 2007; Rebelo et al, 2013). Failure to control for these differences can lead to erroneous conclusions regarding an athlete's true physical capabilities. The paucity of studies reporting maturity status within the current review highlights the necessity to continue to enforce these assessments alongside performance measures in youth soccer players.

6.2 Limitations of inferring findings from the senior game to the youth game.

As stated in section 2.1 one of the primary aims of TD within soccer is develop soccer players that transition to play professionally in the senior game. It is therefore important to understand the demands and trends both physically and tactically of senior competition to ensure that players are best prepared for this step (Williams et al, 2020a). However, there are key limitations of comparing trends and outcomes of research within the senior game and applying them to the context of youth football. There are vast physiological differences between senior and youth athletes. Senior athletes are faster, stronger and more powerful compared to their youth counterparts, due to the increased muscle mass and bone density due to their advanced maturation and training ages (Meylan et al 2010; Malina et al, 2015). Therefore, demands of

match play and physiological profiling between the groups should be compared to understand the rate of development required to play at the elite level, however, it should not be assumed that physical trends within the senior game apply within the youth game. Furthermore, training interventions should not be implied from one group to another. Training adaptations of a senior athlete of a senior athlete will vary greatly to that of a youth athlete, the adaptations and capacities between the two groups are different and therefore training modalities such be treated as such (Tumkur Anil Kumar et al, 2021). Senior elite soccer global focus is on performing in competition, whilst youth elite soccer, primary goal is development. Conclusions drawn from the senior game may not accurately reflect the developmental needs of youth soccer and its athletes (Mitchell et al, 2015). Furthermore, young athletes are at a different psychological and emotional stage of development to senior athletes, this effects response to coaching strategies, coping mechanisms and decision making. Inferences drawn from senior game and applied to the youth setting to influence training may be over simplified and not best suit the age-appropriate environment that considers youth athlete's developmental stage (Huijgen et al, 2015). **6.3**

Directions for future research

Despite the broad landscape of MS assessments within youth elite soccer players, the enormity of the subject matter suggests to further research questions. Firstly, as highlighted in section **5.1.1** and in concordance there is a severe difference between the volume of research conducted in female athletes versus male athletes. Whilst the reasons for this may be economic (Deloitte, 2025) given the recent increase in popularity and funding in woman's soccer there should be a push to increase the amount of high-quality research into the MS assessments in elite youth female soccer athletes and the effects of strength on performance, injury likelihood and future success.

As highlighted in section **5.3** and **5.4** the need for inclusion of maturation and reliability data to be reported within sport science practise and research is paramount. Given the ease of

implementing somatic maturation assessments and their non-invasive nature, these measures could be included to provide practitioners more context when comparing the results of studies to their own populations, furthermore, reporting reliability provides confidence that the measures reported can be trusted and are valid. Furthermore, within the population of elite youth soccer players, reliability of DFW strength assessments could be further investigated to provide greater information regarding their inclusion within testing batteries, or if methods such as measuring barbell velocity to predict 1RM could be a viable option for in season strength testing. Findings from this review suggest further research be directed towards further exploring the influence of age and maturity status on reliability of measures, specifically those demanding prerequisites motor skills and how growth rates may influence the effect on reliability.

Whilst MVIC assessments were popular within this review as highlighted in **section 4.1.3**, one omission was a common MVIC assessment utilizing force plates of ankle plantar flexion. Given the high incidence of calf and ankle injuries in soccer (Ekstrand et al, 2011b), plus the importance of ankle stiffness for sprinting (Healy et al, 2019). MVIC plantar flexion could be an important strength assessment to administer. Other research in soccer players older than 18 years of age have investigated this measure and found correlations to dynamic balance and reactive strength index (Kayhan et al, 2024). It is therefore surprising that no calf MVIC assessments were found to be included within the population of this review. Moreover, research has shown that assessing MVIC at varying hip and knee flexion angles, can correlate more closely with dynamic movements (Folland et al, 2005; Warneke, Mizuguchi, et al, 2023b) further research into this topic could provide useful testing protocols for use in-season with minimal fatigue.

Building on research conducted by (Asimakidis, Bishop, et al, 2024; Asimakidis, Mukandi, et al, 2024), research to determine common strength assessments performed within youth elite populations could highlight the difference between research and practise.

6.4 Conclusion

This review aimed to better understand the current landscape of MS assessments within youth elite soccer athletes. Three different assessment types were identified as MVC, MVIC and DFW strength assessments. The most popular assessment type was MVC due to the high popularity of IKD knee extension and flexion which were the two most common assessments. The most common MVIC evaluation was the ITMP and DFW exercise was the BS. Out with one study that assessed the BS on athletes aged 10 and above MVC and MVIC assessments were preferred by researchers on younger athletes, likely due to their lower movement competency, furthermore only the IMTP and NHE were shown to be reliable among athletes younger than 15 years old. This review highlighted several key aspects where more research is required. There is a significant lack of research performed on female athletes compared to male athletes, moreover the research published reported reliability and maturation status of the athletes tested is limited.

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