Practical Application of Resistance Training in Youth Academy Football Players

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A thesis submitted for the Degree of Doctor of Philosophy (PhD)

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October 2024

ABSTRACT

Resistance training (RT) is crucial for athletic development, especially in youth athletes, with evidence supporting its positive effects on performance. However, there is no clear consensus on the optimal RT prescription for this population. Guidelines from organisations such as the UKSCA, NSCA, ASCA, and CSEP provide recommendations, but empirical support remains limited. The varied approaches in the literature make it difficult to determine the optimal dosage for different RT variables, including training frequency, exercise selection, and intrasession sequencing.

Chapters 3 and 4 focus on training frequency, defined as the number of RT sessions per week. While guidelines recommend at least two sessions for strength gains, this may not be feasible in youth academies. Through quasi-experimental studies, we compared the effects of once- and twice-weekly sessions in youth footballers. Although no significant differences were found between groups, both improved strength and power compared to a control group. Participation issues limited full comparison, but the results suggest that training once per week is sufficient to improve strength. Chapter 5 examines exercise selection, or the types of exercises used in RT sessions. While guidelines lack specific recommendations for youth RT, we investigated whether functional RT is more effective than traditional RT. The findings showed traditional RT was better for increasing strength, while functional RT improved power and change of direction. Both methods enhanced performance, suggesting a combination may offer a balanced approach to athletic development.

Chapter 6 explores intrasession sequencing, which refers to the order of RT and sportspecific training within a session. Using a within-subjects design, we examined

whether sequencing affected performance. The results indicated no negative impact from the order of training, providing flexibility for practitioners.

Overall, the findings reassure strength and conditioning coaches that factors like training frequency, exercise selection, and sequencing do not negatively impact youth athlete performance. Even minimal RT doses can effectively improve performance.

COVID-19 IMPACT STATEMENT

The COVID-19 pandemic impacted upon the research in this thesis. In March 2020 the University of Essex suspended all face-to-face research in response to the pandemic. We had originally planned to investigate the effects of different recovery times on squat and bench press performance. Utilising measures of repetition velocity as an indicator of neuromuscular fatigue, It was theorised that less recovery time would impact the velocity of the subsequent repetitions indicating the influence of neuromuscular fatigue. Before the pandemic and lockdown rules had been applied in the UK, we had obtained permission from a League 1 English football academy to recruit their players and conduct the investigation. However, by March 2020 the academy had ceased all operations and face to face coaching. The academy did not resume normal operation until July 2021. Due to the proposed length of the data collection process this study was no longer feasible and the decision was taken to abandon it. Details of the study including the proposed methodology can be found in the appendix of this thesis.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor, Professor Gavin Sandercock. His continued guidance and unwavering support have been invaluable throughout the course of this thesis. Gavin's dedication, insight, and willingness to go above and beyond have been pivotal to my success, and for this, I will be forever grateful.

I also wish to extend my heartfelt thanks to Dr. Daniel Coughlan. As my initial supervisor, he provided immense assistance with my work, and beyond that, as close a friend, he offered emotional support and steadfast belief in my abilities throughout my academic and professional journey. His encouragement has been instrumental in helping me reach this point.

My sincere thanks also go to my family, whose constant emotional support has been a source of strength throughout this thesis and my academic career. Your encouragement has been vital, and I am deeply grateful for your presence in my life.

Finally, to my dear friends Angeline, Babz, and James: you have each been a pillar of support, always there when I needed you most. I could not have reached this milestone without your friendship, and for that, I owe you all an immense debt of gratitude.

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INTRODUCTION

1.1 INTRODUCTION

1.1.1 Resistance Training

Strength refers to the ability of a muscle or group of muscles to exert force against resistance (1). Hypertrophy, on the other hand, is the enlargement of muscle fibres resulting from resistance training, leading to increased muscle mass (2). Resistance training is any movement that involves exerting muscular force against various types of resistance, common examples are free weights (e.g., dumbbells and barbells), resistance machines, elastic resistance bands and body weight training. Understanding the key variables and terminology associated with resistance training is essential for designing effective training programmes and achieving desired outcomes. The following table (Table 1.1) outlines the primary variables and terms used in resistance training.

Table 1.1 A summary of Resistance Training nomenclature

Terminology	Definition
Repetitions (Reps)	The number of times an exercise is performed consecutively without resting.
Sets	A group of consecutive repetitions.
Intensity/Load	The amount of weight or resistance used in an exercise, often expressed as a percentage of 1RM (one-repetition maximum).
Volume (session)	The total amount of work performed, calculated as the product of sets, repetitions, and intensity.
Recovery Interval	The period of rest between sets, which can vary depending on the training goal (e.g., strength, hypertrophy, endurance).
Frequency	How often resistance training is performed, typically expressed as sessions per week.
Progressive Overload	The gradual increase of stress placed upon the body during exercise training to stimulate muscle adaptation and growth.

1.1.2 Benefits of Resistance Training

Regular engagement in resistance training leads to significant improvements in muscular strength, endurance, and hypertrophy. These physiological adaptations are essential for enhancing overall physical performance and functional abilities, particularly in sports and daily activities (3). Resistance training has been shown to offer several important health benefits. It increases bone density, which is crucial for preventing osteoporosis and reducing the risk of fractures (4). Resistance training also supports joint health by strengthening the muscles surrounding the joints, helping to prevent injuries and alleviate symptoms of arthritis (5). Moreover, resistance training positively impacts metabolic health. It helps regulate blood sugar levels, improves insulin sensitivity, and increases basal metabolic rate, contributing to weight management and reducing the risk of type 2 diabetes (6). Additionally, resistance training has been linked to improved cardiovascular health, as it lowers blood pressure and improves cholesterol profiles (7). Resistance training also enhances mental wellbeing by reducing symptoms of anxiety and depression, improving self-esteem, and promoting better sleep quality(8). The American College of Sports Medicine (ACSM) provides guidelines for resistance training to promote health, physical fitness, across all age groups. The ACSM recommends that adults perform resistance training exercises for all major muscle groups at least two days per week. Each session should consist of 2-4 sets of 8-12 repetitions for strength, 10-15 repetitions for middle-aged and older adults beginning resistance training, or 15-20 repetitions for improving muscular endurance. Rest periods between sets should be 2-3 minutes, and the intensity should be tailored to the individual's fitness level, ranging from 60-70% of one-repetition maximum (1RM) for novice lifters to 80% or higher for more advanced participants.

1.1.3 The Rise of Resistance Training as an aid to Sports Performance

Resistance training was primarily associated with bodybuilding and weightlifting. However, its adoption in professional sports began to gain momentum in the mid-20th century, as the benefits of strength and conditioning became more widely recognised. The pioneering work of strength coaches like Boyd Epley, who introduced structured strength training programmes to the University of Nebraska's football team in the 1960s, marked a significant turning point (9). This period saw the emergence of strength and conditioning as a specialised field, with professional sports teams increasingly employing dedicated coaches to develop and oversee resistance training regimens.

By the late 20th century, resistance training had become an integral component of athletic preparation across various sports. The establishment of professional organisations such as the National Strength and Conditioning Association (NSCA) in 1978 further legitimised the field and promoted evidence-based practices. Research conducted during this era provided robust evidence supporting the efficacy of resistance training in enhancing athletic performance and reducing injury risk, leading to its widespread adoption (10).

1.1.4 Benefits of Resistance Training on Athletic Performance

Force Production

The most notable benefit of resistance training is the improvement in the muscle's ability to produce force (strength), evidenced in both untrained (11) and trained individuals (12). The ability to produce high levels of force, and the rate at which this force is generated, is crucial in many sports. Resistance training, particularly when incorporating high-intensity and explosive lifts such as squats and power cleans, can significantly enhance an athlete's explosive force output (13). Increased force production translates to improved performance in activities requiring quick bursts of strength, such as jumping and sprinting. Research has shown that resistance training improves muscular power and rate of force development, enhancing neuromuscular function and resulting in faster and more powerful movements (13).

Jumping Ability

Jumping ability is a critical performance marker in sports such as basketball, volleyball, and football. Resistance training, particularly plyometrics and lower body strength exercises, has been shown to significantly enhance vertical jump height and explosive power(14). Strength training programmes that combine traditional resistance exercises with plyometric drills have been found to be especially effective in improving jump performance (15). Moreover, plyometric exercises and weight lifting significantly improve vertical jump performance by boosting muscle power and explosiveness (16).

Speed and Acceleration

Resistance training also plays a significant role in improving speed and acceleration by enhancing muscle strength and power. Plyometric exercises, which involve explosive movements like jumping, can increase muscle power and the rate of force development, leading to faster sprint times (17). Studies have demonstrated that incorporating resistance training, particularly exercises targeting the lower body, can significantly enhance sprint performance in athletes (18).

Change of Direction

Agility and the ability to change direction quickly are essential for success in many sports. Resistance training improves these abilities by strengthening the muscles involved in stabilisation and movement. Exercises such as lateral lunges and agility drills that incorporate resistance can enhance neuromuscular coordination and reactive strength, resulting in better performance in sports requiring rapid directional changes (19). Additionally, resistance training with high-velocity and high-force components significantly improves an athlete’s ability to change direction quickly (20).

Technical Skills

Technical skills such as kicking, punching, and throwing also benefit from resistance training. The force production needed for a powerful kick in football or a punch in boxing can be improved through resistance exercises that strengthen the relevant muscle groups (21). Similarly, throwing performance in sports like baseball and javelin is enhanced by exercises that increase upper body strength and power (22). Resistance training helps improve specific motor skills by enhancing muscle strength, coordination, and power output (23).

Injury Risk Reduction and Mitigation

In addition to enhancing performance, resistance training is crucial for reducing the risk of sports-related injuries. Strengthening muscles, tendons, and ligaments, as well as improving neuromuscular coordination and joint stability, contributes to injury prevention (24). For example, resistance training that targets the muscles around the knee, such as hamstring curls and squats, can significantly reduce the risk of anterior cruciate ligament (ACL) injuries (25). Similarly, shoulder injuries common in sports like swimming and baseball can be mitigated through resistance exercises that enhance shoulder stability and strength (26). Resistance training also helps correct muscle imbalances, where one group of muscles is disproportionately strong or weak compared to its opposing group. For instance, strengthening the posterior chain (hamstrings, glutes, and lower back) can prevent injuries caused by the dominance of anterior muscles (quadriceps) (27). Overall, resistance training improves the resilience of the musculoskeletal system, making athletes less susceptible to injuries by increasing bone density, enhancing joint function, and improving body mechanics (28).

1.1.5 Dose Response

Athletes with a greater rate of force production and power tend to perform better in specific capabilities like speed and change of direction, as well as in actions such as jumping, kicking, punching, and throwing (29). Moreover, increased muscular force plays a significant role in injury prevention by stabilising joints and reducing the risk of injuries, especially in high-impact sport (29). "Dose-response" refers to the relationship between the amount of a stimulus (dose) and the resulting effect (response). In exercise science, it describes how different levels of training (such as volume, intensity, or frequency) lead to varying outcomes, like strength gains or improved performance. Several meta-analyses have been conducted over the years with the aim to outline the optimal dose (sets, reps, intensity/load, frequency etc) for improving athletic performance with resistance training.

Volume

Ralston et al (30) conducted a meta-analysis that examined the impact of weekly set volume on strength gains in resistance training. Their study categorised weekly set volumes into three groups: Low Weekly Sets (LWS) with 5 or fewer sets per exercise per week, Medium Weekly Sets (MWS) with 5-9 sets, and High Weekly Sets (HWS) with 10 or more sets per exercise per week. The analysis found that performing 10 or more sets per exercise per week (HWS) resulted in significantly greater strength improvements compared to lower volumes, with a mean effect size (ES) of 1.01 for HWS, compared to 0.82 for LWS. This suggests a substantial advantage for higher volume training, particularly in well-trained individuals.

In comparison, other meta-analyses (11) have suggested that performing four sets per muscle group per workout is the most effective for maximising strength gains in both trained and untrained individuals. This demonstrated that multiple-set protocols, particularly those involving four sets, resulted in significantly greater strength improvements compared to single-set protocols. Untrained individuals were found to be particularly sensitive to increases in training volume, experiencing a larger effect size when progressing from one to four sets. However, these analyses also revealed diminishing returns when training volume exceeded four sets, especially in untrained individuals, where strength gains began to decrease. For trained individuals, while higher volumes were more tolerable, the benefits tended to plateau beyond four sets.

The systematic review by Korakakis et al (31) examines the minimum effective training volume required to increase one-repetition maximum (1RM) strength in resistancetrained men. The findings suggest sets of 6–12 repetitions per exercise, with each set taken to volitional or momentary failure is sufficient to elicit meaningful increases in 1RM strength for key lifts such as the squat and bench press.

Intensity/Load

Untrained individuals can initially achieve meaningful strength gains at training loads of 60% of 1 repetition maximum (1RM) (11), based on the standard repetition continuum model, which corresponds to loads equivalent to 12-repetition maximum (12RM). To continue to make significant gains in muscle strength, resistance trained individuals need to train at intensities of 80% of 1RM (8-repetition maximum) (11). The shows the importance of progressively increasing training intensity as individuals gain experience, highlighting that while lower intensities are effective for beginners, more advanced trainees need to lift heavier loads to sufficiently challenge their neuromuscular system.

Furthermore, Peterson et al (12) suggests that an intensity of 85% of 1RM is most effective for eliciting maximal strength gains in competitive athletes. This recommendation is higher than the intensities suggested for non-athletes, where 60% to 80% of 1RM is typically sufficient. The study found that strength gains increased as the training intensity approached 85% of 1RM, indicating that higher intensities are necessary to stimulate further neuromuscular adaptations in athletes who have already achieved a high level of conditioning.

Training Frequency

The optimal training frequency for maximising strength gains varies depending on the individual's training status. A meta-analysis conducted by Rhea et al (11) found that untrained individuals achieve maximal strength gains when each muscle group is trained three times per week. This frequency provides sufficient stimulus and recovery, enabling untrained individuals to make consistent strength gains. In contrast, for trained individuals, the optimal training frequency is slightly lower, recommending training each muscle group two times per week. The reduction in frequency for trained individuals is likely due to the higher intensity of their workouts, which necessitates more recovery time between sessions to maximize strength gains.

Grgic et al (32) examined the effect of resistance training (RT) frequency on muscular strength gains across different training volumes. Their analysis revealed that higher training frequencies generally lead to greater strength gains, with effect sizes increasing from 0.74, 0.82, 0.93, to 1.08 for training 1, 2, 3, and 4+ times per week, respectively. However, when training volume was equated across different frequencies, the study found no significant effect of frequency on strength gains. This suggests that the benefits of higher frequencies may be primarily attributed to the increased training volume rather than frequency itself.

1.2 Growth and Maturation

Growth and maturation are fundamental and interconnected processes unique to childhood and adolescence, shaping the natural development of physical fitness attributes and skill acquisition in young athletes (33-35). While growth refers to the measurable increase in size whether of the body as a whole or specific regions driven by tissue development through hyperplasia (an increase in cell number), hypertrophy (an increase in cell size), and accretion (an increase in cellular material) (36), maturation is distinct. Biological maturation specifically refers to the progression toward a fully developed, mature state, encompassing skeletal and sexual development, and is characterized by variability in timing, rate (tempo), and differences across bodily systems (35, 37).

There is considerable inter-individual variation in biological maturation, which is influenced by three key factors: the magnitude of change (level), the onset of change (timing), and the speed of change (tempo) (38). Using chronological age as a reference, individuals can be classified as biologically advanced relative to their chronological age (early maturers), aligned with their chronological age (on-time maturers), or delayed relative to their chronological age (late maturers) (35, 39).

Incorporating an athlete's maturation stage alongside their training age and technical proficiency is essential for designing effective programs and accurately interpreting performance data (40-42). Furthermore, distinguishing between improvements driven by biological maturation and those resulting from training interventions allows practitioners to better evaluate the true effectiveness of their programs (37, 43, 44). Consequently, strength and conditioning professionals working with youth athletes should be equipped to assess biological maturity and integrate this information into training practices (39, 41, 43, 45).

Measuring biological maturation

Biological maturation in youth can be assessed through skeletal, sexual, or somatic measures, each using distinct indicators and varying significantly in the way maturity status is quantified (35).

Skeletal Age

Skeletal age is assessed through radiographic evaluation of the ossification of skeletal tissue, providing insights across the entire growth period (35, 37). This involves the analysis of hand-wrist x-rays to measure bone development through key indicators such as the appearance of bone centres, changes in bone size and shape, and the fusion of epiphyses with diaphysis (35).

Several methods are commonly used to determine skeletal age. The Fels method grades hand-wrist bones by age and sex, using software to calculate skeletal age and estimate the standard error of measurement, which increases with advanced maturation (1, 46). The Greulich-Pyle (Atlas) method compares a child's left wrist xray with standardized reference plates, but its reliance on a single reference and limited applicability to diverse populations are noted limitations (1, 33). Finally, the Tanner-Whitehouse method is more ethnically diverse, validated in various global populations, and involves scoring the maturation of 13 or 20 hand-wrist bones, which is then converted into a skeletal age (47).

Each method offers unique strengths and limitations, and practitioners must carefully consider their applicability based on the population and context.

Sexual Age

Sexual age refers to the degree of maturation an individual has reached in achieving full sexual maturity and reproductive capability (33, 35). This process begins with sexual differentiation during embryonic development and progresses through puberty, the transitional phase from childhood to adulthood (35). Sexual maturity is assessed through secondary sex characteristics.

The Tanner Criteria (48) is a commonly used method for assessing sexual age, which evaluates the development of secondary sexual characteristics against five reference stages, known as Tanner stages. However, due to its invasive nature, Tanner staging is limited to qualified medical professionals and requires informed parental consent and child assent (49). Its use outside clinical settings is therefore restricted (49). Furthermore, this method has additional limitations, such as the inability to assess the tempo of maturation, the lack of differentiation between individuals within the same stage, and its inapplicability to youth who have not yet begun their pubertal growth spurt, which limits its use for long-term monitoring (33).

Self-assessment techniques for sexual maturation have been developed, but their accuracy and reliability are questionable as research has shown that males often overestimate their sexual development, whereas females tend to underestimate their maturity status (49-51).

In general, the assessment of skeletal or sexual age is limited by the requirement for trained medical professionals, the need for specialised equipment, and the invasive nature of the procedures. Consequently, for practitioners working with young athletes, somatic assessments of biological maturity are often more appropriate due to their simplicity, accessibility (in terms of cost, equipment, and expertise), and non-invasive nature.

Somatic age

Somatic maturation refers to the degree of physical growth, often measured through changes in overall stature (52, 53). This non-linear process is characterised by periods of rapid growth and plateaus. Tracking anthropometric measurements during adolescence allows practitioners to identify growth spurts, which serve as indicators of somatic maturity (53, 54). Visually, somatic growth, marked by increases in body size, is one of the most apparent expressions of biological maturity. However, accurate assessments require longitudinal data to capture growth trends effectively (35).

One common method used to estimate somatic maturity: age at peak height velocity (PHV). PHV refers to the period of the fastest growth rate in height during adolescence, governed largely by genetics but influenced by environmental factors such as nutrition (35) Regular height measurements, collected approximately every three months, can be used to plot growth velocity.

Maturity offset equations provide a practical, non-invasive approach to estimating somatic maturity, specifically focusing on predicting age at peak height velocity (PHV). The Mirwald et al. (53) maturity offset equation is one of the most widely utilised predictive methods. The method uses anthropometric variables, including height, sitting height, leg length, and body weight, as well as interactions between these variables and chronological age, to estimate maturity offset. This value represents the time (in years) before or after PHV. A negative value denotes a pre-PHV state, a value of zero indicates the individual is at PHV, and a positive value signifies a post-PHV state. The equations are sex-specific and calculate the maturity offset, which can subsequently be converted into the predicted age at PHV by subtracting the maturity offset from chronological age (53).

For boys, the equation is as follows:

$$\text{Maturity Offset (years)} = -9.326 + (0.0002708 \times (leg\ length \times sitting\ height)) + (-0.001663 \times (age \times leg\ length)) + (0.007216 \times (age \times sitting\ height)) + (0.2292 \times (mass \times height\ ratio \times 100))$$

For Girls:

Maturity Offset (years) = −9.376 + (0.0001882 × ($leg\ length$ × $sitting\ height$)) + (0.0022 × (age × $leg\ length$)) + (0.005841 × (age × $sitting\ heigh$t)) − (0.002658 × (age × $mass$)) + (0.07693 × ($mass$ × $height\ ratio$ × 100))

The standard error for this equation is approximately 7 months (0.56–0.59 years), which is considered acceptable for practical applications (53). Despite its utility, the Mirwald equation has notable limitations. It tends to overestimate the age of PHV in early maturers and underestimate it in late maturers, a systematic bias that limits its accuracy for individuals outside the average PHV range (55). Furthermore, its reliance on sitting height measurements reduces practicality in certain field settings. Additionally, as the equation was developed using data from individuals of European ancestry, its applicability to ethnically diverse populations is limited (56).

In response to these limitations, Moore et al. (57) introduced a revised version of the maturity offset equation. The updated equations simplify the calculations by removing the need for sitting height, thereby increasing their practicality for field applications.

The equation for boys is:

Maturity Offset (years)=−7.999994+(0.0036124×(age×stature)

The equation for girls is:

Maturity Offset (years) = −7.709133 + 0.0042232 × (age × $stature$)).

The revised equations retain a similar standard error to the original method, approximately 6.2–6.5 months for boys and 6.4 months for girls (57).

Both the original and revised maturity offset equations do share some common limitations. First, systematic biases remain prevalent, with predictions tending to overestimate PHV in early maturers and underestimate it in late maturers. Second, the reliance on data from European populations limits the generalisability of these equations to individuals from other ethnic groups. Third, the methods are most accurate for youth aged 12–15 years, who are close to their PHV, but they are less reliable for those at earlier or later stages of maturity (55). Despite the proposed challenges associated with maturation prediction equations in the practical setting of youth sports, they remain a fast, reliable, and non-invasive method for estimating maturation.

Effects of maturation on physical performance:

In the case of youth, maturation status can be an important factor that can influence the response to the training stimulus (58) In fact, growth and maturation play an important influence on the muscle-tendon and neuromuscular adaptations changing the responses to muscle cross-sectional area, fascicle length, pennation angle, or tendon architecture and stiffness (58).

Muscular Strength

Biological maturation plays a crucial role in the development of muscular strength and influences how young athletes respond to strength training interventions. Differences in maturation status among athletes within the same chronological age group can lead to variations in strength levels and adaptation rates, potentially creating disparities in performance outcomes (59, 60). As athletes progress through puberty, their capacity for strength development increases due to physiological changes associated with growth and hormonal fluctuations.

The mechanisms underlying strength development vary depending on an athlete's stage of maturation. In pre-pubertal athletes, strength gains are primarily driven by neuromuscular adaptations rather than muscle hypertrophy. Neural plasticity during this stage enhances intra- and intermuscular coordination, motor unit recruitment efficiency, and movement mechanics, all of which contribute to improvements in strength (61). However, post-pubertal athletes experience greater hypertrophic adaptations due to increased androgen concentrations, which facilitate muscle mass growth, improved muscle architecture, and elevated adenosine triphosphate (ATP) stores (28, 61). The transition from pre- to post-puberty is characterised by hormonal changes, particularly rising testosterone levels, which significantly influence muscle cross-sectional area, musculotendon unit architecture, and muscle-tendon stiffness. These changes contribute to an increased capacity for force production, allowing for greater strength development (56, 62, 63).

Studies have shown that muscular strength follows a characteristic growth curve, increasing steadily from childhood until puberty. In males, significant strength gains occur during and after peak height velocity (PHV), the phase marking the adolescent growth spurt (38, 62). Beunen and Thomis (64) reported that in boys, strength increases in a relatively linear manner until around 13.8 years of age, after which the effects of hormonal changes become more pronounced. Post-PHV strength gains are strongly associated with rising testosterone levels, which facilitate lean muscle mass accumulation, enhanced muscle architecture, and greater muscle-tendon stiffness (28, 35). These factors contribute to higher force production capacity and explain why strength levels among athletes of different maturation stages can vary significantly.

The extent to which an athlete responds to strength training is influenced by their stage of maturation. Research has shown that post-pubertal athletes demonstrate greater improvements in strength when exposed to resistance and plyometric training compared to pre-pubertal or early pubertal athletes (65-68). This difference is largely due to the hypertrophic adaptations experienced by post-PHV athletes, as their increased muscle mass and androgen levels allow for greater structural adaptations in response to training. This suggests that strength training programmes should be tailored to an athlete's biological maturity to optimise long-term athletic development. While post-pubertal athletes benefit from higher training intensities and volume to maximise hypertrophic and strength gains, pre-pubertal athletes should focus on movement competency, foundational strength exercises, and neuromuscular development to establish a solid base for future strength adaptations (35, 69). By aligning strength training programmes with an athlete's stage of maturation, practitioners can enhance performance development while reducing the risk of injury and promoting sustainable improvements over time.

Muscular Power

Research has shown that lower-body power development is linked to an athlete's stage of maturation, with evidence suggesting that power performance varies at different points in growth and development (61, 70-72). The timing of peak power gains and the extent of training adaptations appear to be influenced by physiological changes associated with maturation, including motor coordination, muscle fibre hypertrophy and changes in body mass (61, 70, 72). Understanding these developmental patterns is crucial for optimizing training strategies and improving athletic performance in youth populations.

Philippaerts et al. (70) and Lloyd et al. (61) identified two distinct periods of accelerated lower-body power development, separated by a phase of reduced development around PHV. Philippaerts et al. (70) found that lower-body power development peaked 18 months before PHV at a rate of 10.5 cm per year but then declined to 6.3 cm per year just before PHV. This decline was followed by a recovery phase after the growth spurt. Similarly, Lloyd et al. (61) reported a temporary decrease in power before PHV, with performance levels returning close to their previous peak afterward.

This temporary decline in power is likely due to impaired motor coordination during the growth spurt, caused by rapid growth and the uneven development of the trunk and legs (61, 73, 74). Additionally, hormonal changes during maturation lead to hypertrophy of type II muscle fibers, along with improvements in muscle coordination and motor unit activation, which significantly influence power performance (61, 68). These physiological changes may enhance an athlete's ability to generate force during jumping, resulting in greater training adaptations in vertical jump performance compared to younger, less mature athletes.

Lloyd et al (40) support this idea, reporting that post-PHV athletes show greater improvements in jumping ability following plyometric training compared to pre-PHV athletes. Similarly, research has demonstrated that plyometric training leads to significant improvements in power performance, with older youth athletes in the postPHV group showing greater adaptive responses in vertical jump performance than younger athletes in the pre-PHV group. This suggests that maturation plays a key role in determining the effectiveness of plyometric training, with older athletes experiencing greater gains in explosive power due to their advanced neuromuscular and physiological development.

Speed

Biological maturation significantly influences speed development due to its effects on neuromuscular, skeletal, and hormonal systems. Speed improvements throughout childhood do not follow a linear trajectory, with studies reporting up to a threefold increase in speed from infancy to adulthood (35, 62). A preadolescent spurt in speed has been observed between the ages of five and nine years, likely resulting from rapid central nervous system development during early childhood (75). During adolescence, earlier maturing individuals generally exhibit greater increases in muscle mass, strength, and stride length, all of which contribute to enhanced sprinting performance (76). These improvements are underpinned by several physiological and biomechanical adaptations. The rise in anabolic hormones, particularly testosterone, facilitates muscle hypertrophy and neuromuscular efficiency, thereby enhancing force production and sprint capacity (77). Improvements in motor coordination and tendon stiffness during adolescence further refine sprint mechanics, leading to superior acceleration and maximum velocity (76, 77). Sprint performance is primarily determined by stride rate and stride length, both of which are influenced by anthropometric characteristics including limb length, musculotendinous properties, and neural control. Natural improvements in sprint ability during maturation are attributed to increases in muscle size, limb length, musculotendinous stiffness, and enhanced motor coordination. Research indicates that increases in stride length, in combination with stabilised stride frequency and reduced ground contact time, contribute to faster sprinting velocity during peak height velocity (PHV) (66, 78). However, in some post PHV athletes, anthropometric changes can temporarily impair sprint efficiency as individuals adjust to new body dimensions. Studies on the relationship between maturation and sprint performance have consistently demonstrated that early maturing athletes tend to outperform later maturing peers in short distance sprints, such as 5 m and 20 m tests, particularly in sports like football and basketball during preadolescence and early adolescence (79-81). These differences tend to diminish in late adolescence, suggesting that later maturing athletes may eventually close the performance gap as they reach full physical maturity (77). Despite their advantage in linear sprinting, early maturers do not consistently outperform their peers in agility-based movements. Research suggests that while early maturing athletes demonstrate superior straight-line speed, their advantage in change of direction tasks is less pronounced, indicating that technique, neuromuscular control, and movement efficiency play substantial roles in multidirectional speed (79, 82). Maturation also affects speed trainability, with evidence showing that post PHV athletes experience greater improvements in sprint performance following plyometric training than their less mature counterparts. For example, improvements in 20 m sprint time were largest among post PHV athletes (effect size: minus 0.66), compared to smaller effects in circa PHV (minus 0.58) and pre PHV athletes (minus 0.12) (66). Older youth athletes tend to show small to moderate improvements, whereas pre PHV athletes exhibit only trivial changes. Given that both stride length and frequency contribute to sprint performance and are influenced by anthropometric development, temporary declines in sprint efficiency may occur in post PHV stages due to coordination adjustments to limb growth. Speed gains become most evident during mid and post PHV phases when stride length increases and motor control improves(78). These findings underscore the importance of tailoring speed training to an athlete's biological rather than chronological age. Early maturers may benefit from refining sprint mechanics and neuromuscular coordination, whereas later maturers may require greater emphasis on strength and power development to accelerate their physical progress (77). To optimise long term speed development in youth athletes, training programmes should be individualised based on biological age, as chronological age does not reliably reflect physical readiness (76). Supporting late maturing athletes despite temporary physical limitations is essential to promote equitable athletic development and to ensure all individuals have the opportunity to realise their full potential (77).

Injury risk

The risk of injury in youth athletes varies according to their maturation status, with overall incidence generally increasing as athletes progress through maturation (80). Specific injury types tend to cluster around particular stages of biological development. Apophyseal injuries, osteochondrosis, and avulsion fractures are most frequent at the onset and during peak height velocity (PHV), the period of fastest growth during adolescence (83-86). In contrast, the risk for muscular, cartilaginous, and ligamentous injuries increases with advancing maturity and is most prevalent in mature and post PHV athletes (80, 87). These injury types are often linked to neuromuscular control deficits, insufficient muscle capacity, imbalances in the muscle tendon unit, and greater moments of inertia in the limbs resulting from rapid growth (85). The specific timing of maturation, whether early, on time, or late, does not inherently increase injury risk; rather, an athlete's current maturation status and proximity to PHV are more significant determinants. Early maturing athletes show a higher incidence of injuries typically associated with advanced maturity, including tendinopathies, groin strains, and joint or ligament damage (87, 88). On time and late maturing athletes, by contrast, are more susceptible to injuries associated with earlier stages of growth, such as lower limb apophyseal injuries, osteochondrosis, anterior inferior iliac spine injuries, and conditions like Osgood Schlatter's and Sever's disease (88-90). Notably, late maturers often reach their growth spurt at an age when training loads are higher, potentially compounding their susceptibility to growth related and overload injuries (87-89). Several biomechanical and physiological mechanisms contribute to increased injury risk during periods of growth. Rapid gains in stature and lower limb length have been associated with an increased incidence of overuse, noncontact, and growth related injuries across various sports (87). Accelerated growth trajectories, particularly height increases exceeding 4 to 5 centimetres per year, have been linked to greater injury burden, especially during and following PHV (91). This delayed effect suggests that injuries sustained during PHV may contribute to cumulative injury risk post PHV (80, 92). Overall, injury risk in youth athletes is multifactorial, influenced by the interaction between maturation status, growth rate, and timing, with each factor shaping not only the likelihood but also the nature and timing of injuries.

1.3 RESISTANCE TRAINING IN YOUTH POPULATIONS

Resistance training has long been associated with adult populations, particularly among athletes and bodybuilders. However, one of the key factors contributing to the increased popularity of resistance training among youth is the expanding body of evidence supporting its safety. When properly supervised and appropriately structured, resistance training presents minimal risk to children and adolescents. Both the UKSCA and NSCA have endorsed youth resistance training, highlighting the importance of qualified supervision and age-appropriate programming (1, 37). Over the past few decades, there has been a significant increase in the adoption of resistance training among youth populations, driven by growing evidence of its safety, effectiveness, and numerous health benefits (1, 37, 93).

1.3.1 Health Benefits

Musculoskeletal Development

Historically, resistance training for youth was met with scepticism and concern. Early misconceptions suggested that resistance training could be harmful to the developing musculoskeletal system, potentially stunting growth or causing injury (94). There were significant concerns that resistance training could harm the developing skeleton, particularly through potential damage to the growth plates (epiphyseal plates) of young athletes, leading to stunted growth and developmental issues (95). These growth plates, composed of developing cartilage tissue near the ends of long bones, are essential for bone growth during childhood and adolescence. The fear was that heavy lifting might cause fractures or prematurely close these plates, thus impairing normal bone development (94). However, these fears and concerns were not supported by scientific evidence or clinical observations (37).

Current research has shifted the narrative, highlighting the benefits of resistance training for the developing musculoskeletal system. Childhood and adolescence are important periods for building bone mass and enhancing bone structure through weight-bearing physical activities (96-98). Resistance training positively influences bone density and muscle strength in children and adolescents. Morris et al (99) demonstrated that youth who engage in regular resistance training exhibit greater gains in bone mineral density and muscular strength compared to their non-training peers. These adaptations are particularly crucial during the growth spurts of adolescence when the musculoskeletal system is highly responsive to mechanical loading.

In addition to growth plate concerns, there were fears that resistance training could lead to other musculoskeletal injuries, such as strains and sprains, due to the lack of physical maturity and coordination in children. Injuries are an accepted risk of any physical activity or sport and any reports of injury during resistance training in youth populations has often been attribute to factors such as, improper use of equipment, unsupervised training, improper technique, excessive loading (100, 101). Research by Faigenbaum & Myer (102) highlighted that, when appropriately designed and supervised, resistance training programs could be both safe and beneficial for youth. It demonstrated that resistance training could enhance muscular strength, power, and endurance in youth without adverse effects on growth and development.

Body Composition

Obesity in youth is a growing public health concern with significant long-term implications. The prevalence of obesity among children and adolescents has been steadily increasing, leading to a rise in obesity-related comorbidities, such as type 2 diabetes and cardiovascular diseases, which were once considered adult conditions (103, 104). Resistance training can play a significant role in improving body composition in youth. Studies indicate that it helps increase lean muscle mass while reducing body fat percentage. Behringer et al (33) found that children who participated in a resistance training program experienced significant improvements in muscle mass and reductions in body fat, contributing to healthier body composition. Shaibi et al (105) demonstrated that a 16-week resistance training program significantly improved insulin sensitivity in overweight Latino adolescent males, independent of changes in body composition. It has also been shown that high-intensity progressive resistance training effectively reduced both central and whole-body fat in children and adolescents, with the most significant reductions observed in those who gained the most strength (103).

Psychological and Social Benefits

Psychological illness significantly impacts the well-being and development of youth, affecting various aspects of their lives, including their academic performance, social relationships, and overall life satisfaction. A 12-week resistance training program conducted on adolescents demonstrated significant improvements in various aspects of self-concept, including global self-worth, physical self-perception, and body adequacy (97). A study by Yu et al (106) found that the combination of diet and strength training led to significant improvements in the physical self-concept. Alongside the improvement in physical self-concept, the participants also reported better body image perceptions. The changes in body composition due to diet and strength training, such as reduced body fat and increased muscle mass, contributed to these positive psychological outcomes. Research by Lubans et al (107) also reported participation in resistance training improves body image and self-perception, which are important factors during adolescence. Resistance training has also been associated with reductions in symptoms of anxiety and depression among youth, it has been reported that regular participation in resistance training programs led to significant improvements in mental health, contributing to overall psychological wellbeing (108).

1.3.2 Resistance Training in Youth Sport

In recent years, there has been an increase in the use of resistance training in youth sports. This can be attributed to a growing body of research that highlights the numerous benefits of such training for young athletes (1, 37, 93). Initially, there were concerns about the potential risks associated with resistance training in youth, including the possibility of injury to developing bones and joints (94). However, advances in sports science and a better understanding of the physiological responses of youth to resistance training have dispelled many of these fears (109). It is now wellestablished that when resistance training programs are designed with appropriate intensity, volume, and progression, they can lead to positive adaptations in bones, muscles, and connective tissues (1, 37, 93, 95).

Position statements from leading organisations such as the National Strength and Conditioning Association (NSCA) and the United Kingdom Strength and Conditioning Association (UKSCA) strongly advocate for the inclusion of resistance training in youth fitness programs. They underline that with careful supervision and a gradual progression in training load, resistance training can be both safe and highly beneficial for young athletes (1, 37). These organisations along with the Australian strength and condition association (ASCA) and Canadian society for exercise physiology (CSEP) have also developed youth-specific training guidelines that are designed to encourage the safe and effective implementation of resistance training in youth sports (1, 37, 93, 110). These guidelines emphasise the importance of proper technique, ageappropriate program design, and the supervision of qualified professionals.

1.3.3 Effects in Youth Athletes

The benefits of resistance training in youth sports are extensive. It has been shown to improve muscular strength and motor skills such as jumping, sprinting and change of direction. It has also been shown to enhance technical skills such as kicking, throwing and punching. Additionally, resistance training can play a significant role in injury prevention by strengthening muscles and joints, thereby increasing the resilience of young athletes to the physical demands of their sports.

Muscular Strength

Muscular strength refers to the maximum amount of force a muscle or group of muscles can generate. It is the foundation upon which various motor skills and performance variables, such as speed, power, and change of direction, are built (111). These performance variables are crucial in sports, as they dictate an athlete's ability to sprint quickly, jump high, and make rapid changes in direction all of which are dependent on the ability of the muscles involved to generate and absorb force (37, 62).

It has been shown that youth athletes who participate in resistance training programs can increase strength levels to a greater extent than would be achieved through maturation alone (1, 37). Lesinski et al (112) found that resistance training programs significantly improve strength and power in youth athletes, leading to better performance in sports requiring explosive movements such as jumping, sprinting, and throwing. Studies have shown that adding resistance training to sport specific training can offer significant gains in strength. Christou et al (113) found incorporating resistance training with regular soccer training significantly enhanced maximal strength in adolescent soccer players, particularly in the lower and upper body. The strength and football training group demonstrated a 58.8% increase in leg press 1RM and a 52.3% increase in bench press 1RM over 16 weeks, outperforming the football only group. Similarly in Rugby union after a 15 week resistance training program carried out in a supervised and unsupervised group the supervised group experienced a 50.4% increase in box squat 1RM, a 16.9% increase in bench press 1RM, and a 9.1% increase in chin-ups 1RM. The unsupervised group also improved, with a 16.9% increase in box squat 1RM, a 7.0% increase in bench press 1RM, and a 3.1% increase in chin-ups 1RM (114).

Lower Limb Muscular Power

The development of lower limb muscular power is crucial not only for elite adult athletes but also for youth athletes at all stages of maturation. Enhancing muscular power early in life can help prevent neuromuscular deficiencies and promote long-term participation in physical activities. Strength training has been identified as a key method for improving lower limb muscular power, and when properly designed, it can significantly contribute to the athletic development of young athletes and reduce the risk of injuries (115). Reliable measures of lower limb muscular power, such as the countermovement jump (CMJ) and squat jump (SJ), are commonly used to assess an athlete's ability to generate explosive force, which is essential for many sports-related activities (Slimani et al 2018). A Meta analysis by Slimani et al (58) found that strength training (ST) has a positive effect on improving lower-limb muscular power in young athletes. Specifically, it showed significant but small effects on countermovement jump (CMJ) height and moderate effects on squat jump (SJ) height.

Similar to these findings, Rodriguez -Rosell et al (116) found that after 6 weeks of resistance training combined with plyometric exercises, the strength training group (STG) showed a significant improvement in jump performance. Specifically, the STG improved their countermovement jump (CMJ) height by 12.2%. In contrast, the control group (CG) experienced a decline in CMJ height by 3.5%. These findings indicate that the combined training program was effective in enhancing vertical jump performance in young soccer players, while the control group, which did not undergo the additional training, saw a decrease in their jumping ability. A study by Wong et al (117) found that after 12 weeks of on-field combined strength and power training (CSPT), the experimental group (EG) significantly improved their vertical jump height by 5.9%, increasing from 55.5 cm at the pretest to 58.8 cm at the post-test. In contrast, the control group (CG), which did not undergo the CSPT, showed no significant change in vertical jump height, remaining virtually the same from 53.4 cm to 53.5 cm.

Linear Speed

Linear sprint speed and short distance accelerations are particularly important actions during team sports including football, rugby, hockey (118) the ability to sprint or accelerate over short distances quickly is often a determinant of success in many sports (119, 120).

A meta-analysis by Behm et al (121) found that strength training was generally more effective than power training in improving sprint speed among youth. This was particularly evident in younger participants, including both children and adolescents, where strength training led to moderate improvements in sprint speed, while power training only resulted in small gains. Untrained youth benefited more from strengthbased programs, showing greater improvements in sprint speed compared to their trained counterparts.

Research by Sander et al (122) found that a two-year strength training program significantly improved sprint performance in elite youth soccer players across all age groups. The under 19 group improved sprint times by up to 3.19% over 5 m and 1.5% over 30 m. The under 17 group experienced improvements of 3.89% over 5 m and 4.69% over 30 m. The most substantial gains were seen in the under 15 group, with sprint times improving by 5.39% over 5 m and 5.89% over 30 m. In contrast, the control group showed minimal improvements or even declines in sprint performance. Studies have also reported that after 6 weeks of resistance training combined with plyometric exercises, the strength training group (STG) showed significant improvements in sprint performance (116). Specifically, the STG improved their 10 m sprint times by 2.7%, their 20 m sprint times by 2.7%, and their 10- to 20 m sprint segment by 3.5% compared to the control group (CG) who did not show any significant changes in sprint performance.

Change of Direction Speed

Change of direction speed is a crucial physical attribute in many sports, such as soccer, rugby, tennis, and combat sports, where athletes frequently need to decelerate and re-accelerate in a new direction during games and competitions (21). Resistance training is recognised as an effective method to improve key muscle qualities like strength, power, and both eccentric and concentric strength, all of which contribute to enhanced change of direction speed (21). A meta-analysis by Chaabene et al (21) demonstrated that resistance training is effective in enhancing change of direction speed in youth and young, physically active, and athletic adults. Across the studies analysed, resistance training had a significant positive impact on change of direction speed, with a substantial overall effect size. Both machine-based and free weights training resulted in large improvements in change of direction speed, with no significant differences between the two methods. Programmes that combined machine-based and free weights training also produced moderate improvements.

Although males tended to experience greater gains than females, and younger individuals (children and adolescents) showed larger improvements compared to adults, these differences were not statistically significant.

A study by Keiner et al (123) showed that a two-year strength training program led to significant improvements in change of direction and speed performance across all age groups (under 15, under 17, and under 19) of youth soccer players. The strength training group (STG) showed change of direction improvements of approximately 9% in the under 15 cohort (from 1.858 to 1.692 seconds for the 5 m left turn), 6% in the under 17 cohort (from 1.777 to 1.674 seconds), and 8% in the under 19 cohort (from 1.738 to 1.606 seconds). These gains were up to 10% better than those in the control group (CG).

Resistance training has been increasingly recognised as an important component of athletic development for youth participating in sports (124). The importance of resistance training for young athletes is well-documented, with numerous studies highlighting its role in enhancing performance, reducing the risk of injury, and supporting overall physical development by contributing to improvements in strength, speed, change of direction and motor skills, all of which are crucial for success in various sports (1, 11, 12, 37). Resistance training can improve these markers of performance beyond what is developed naturally through the process of maturation and growth (125).

However, it is not necessarily clear exactly how resistance training should be implemented in youth populations and what can be considered optimal or best practice when designing resistance training programs with the aim of improving performance in youth athletes (68). Due to the numerous variables that can be adjusted, such as sets, repetitions, load/intensity, frequency, recovery times, and training modality, it is challenging to draw definitive conclusions about the optimal dosage. Each of these variables, when altered, can significantly impact the outcomes, making it difficult to determine the most effective approach.

1.4 Optimal Exercise Prescription for Resistance Training in Youth

The effectiveness of a resistance training program is not solely dependent on the act of lifting weights; the structure of the resistance training program is equally important.

Research indicates that the specific design of a resistance training program, including factors such as exercise selection, volume, intensity, and progression, plays a pivotal role in determining the outcomes (10, 69, 93). For example, a well-structured program that appropriately balances these variables can maximise strength gains while minimising the risk of overtraining or injury (69). Additionally, the inclusion of sportspecific exercises within a resistance training regimen has been shown to enhance the transfer of strength gains to actual sports performance, further underlining the importance of a tailored approach (29). Therefore, understanding the principles of program design and tailoring resistance training to the unique needs of young athletes is crucial for optimising their performance and ensuring their long-term athletic development.

1.4.1 Youth Resistance Training Guidelines

Currently, several position statements from various national associations and governing bodies including the NSCA, UKSCA, CSEP and ASCA provide guidelines for programming resistance training for youth and adolescents (1, 37, 93, 110). A summary of these guidelines is shown in Table 1.2.

Table 1.2 A summary of Youth Resistance Training guidelines from, the NSCA, ASCA, CSEP and UKSCA

Organisation	Age/Experience Level	Load (% 1RM)	Sets	Reps	Frequency
NSCA	Novice (≤2-3 months)	50-70%	1-2	10-15	2-3 days/week
	Intermediate (3-12 months)	60-80%	2-3	8-12	2-3 days/week
	Advanced (≥12 months)	70-85%	≥3	6-10	3-4 days/week

ASCA	Level 1 (6-9 years)	Bodyweight	1	20 sec/exercise	3 days/week
	Level 2 (9-12 years)	~60%	≤ 3	10-15	3 days/week
	Level 3 (12-15 years)	~70%	2-4	8-15	3 days/week
	Level 4 (15-18 years)	~80%	3-4	6-15	3-4 days/week
CSEP	Not specified	30-60%	1-2	8-15	2-3 days/week
UKSCA	Beginner	≤60%	1-2	Not specified	2-3 days/week
	Advanced	≤80%	2-4	6-12	2-3 days/week

These guidelines are crafted by well-respected governing bodies, drawing on the expertise of professionals and coaches who possess extensive experience in strength and conditioning. The collective knowledge and evidence-based practices compiled in these documents reflect the highest standards in the industry, making them essential resources for anyone involved in training young athletes.

The target audience for these position papers is primarily strength and conditioning practitioners who are responsible for the development and safety of youth athletes. These professionals rely on such guidelines to shape their training programs, ensuring that they are both effective and appropriate for the developmental stages of their athletes. By adhering to the recommendations provided by these governing bodies, practitioners should be able to confidently implement training that promote the physical and psychological well-being of young athletes, while also fostering long-term athletic development. All four position papers agree on the importance of tailoring youth resistance training programs to the individual's developmental stage, training age, and current physical condition. They collectively emphasise the need for a gradual, wellsupervised progression that focuses on building technical skills and foundational strength before advancing to more complex and intense training.

Both NSCA and the ASCA go into more detail on how best to ascertain physical state or readiness to train. The ASCA's model offers a clear framework for coaches to follow, ensuring that training programs are developmentally appropriate and aligned with the athlete's experience level. This structured approach helps in safely advancing youth athletes through different stages of their training.

Volume and Load

The position papers provide progressive guidelines on training volume and load tailored to an athlete's training age and competency. For beginners, all papers recommend starting with 1–2 sets of 8–15 repetitions per exercise using light to moderate loads (30–60% of 1RM), with a focus on developing proper technique, motor skills, and foundational strength (1, 33, 34, 52). As athletes reach the intermediate stage, recommendations diverge slightly. The UKSCA advises 2–4 sets of 6–12 repetitions at 60–80% of 1RM to increase both volume and intensity in line with technical improvement (33). The NSCA suggests 2–3 sets of 6–12 repetitions at 50–70% of 1RM to maintain progressive overload while preserving form (1). The ASCA provides age-specific guidance: Level 2 athletes (9–12 years) should perform 1–3 sets of 6–12 repetitions at 50–70% of 1RM, while Level 3 athletes (12–15 years) can increase to 2–4 sets at 70–85% of 1RM (52). The CSEP offers no specific intermediate prescription, instead recommending individual adjustments based on progression (34). For advanced athletes, all guidelines shift toward higher intensity and lower repetition ranges. The UKSCA recommends 3–5 sets of 1–6 repetitions at 80–90% or more of 1RM to target strength and power development (33). The NSCA aligns closely, advising 3–6 sets of 1–6 repetitions at 75–90% of 1RM (1). The ASCA suggests that Level 4 athletes (15–18 years) perform 2–5 sets of 3–6 repetitions at 85–95% of 1RM, with emphasis on individualised programming based on goals and competency (52). The CSEP recommends 3 sets of 6–12 repetitions using a 6–12RM load to continue strength and power development as technical skills improve (34). In summary, the papers agree on starting with low volumes and light loads for beginners, then progressively increasing volume and intensity through the intermediate stage, with advanced programs focusing on high-intensity, lower-repetition training aligned with individual capacity and performance goals.

Training Frequency

The guidelines consistently recommend that youth resistance training be conducted 2-3 times per week. This frequency is supported by evidence indicating that it allows for sufficient recovery between sessions while providing an adequate training stimulus to promote strength and conditioning gains. Research cited in these papers indicates that training 2-3 times per week is effective for enhancing muscular strength, power, and overall physical development in youth without leading to overtraining or injury (1, 37, 93, 110).

The papers generally discourage less than two sessions per week for optimal performance gains. For instance, the NSCA notes that limited evidence suggests that a frequency of just one session per week is suboptimal for enhancing muscular strength in youth, although it may be effective for maintaining strength gains after a more intensive period of training (1). Similarly, the CSEP highlights that a training frequency of at least two non-consecutive days per week is recommended, as training once per week may result in suboptimal adaptations (34). The UKSCA also suggest that training frequency can be increased (>3 sessions per week) as children progress through adolescence and approach adulthood, particularly for those involved in competitive sports. It acknowledges that while increasing frequency may be necessary for further development, it must be balanced with adequate rest and recovery to prevent overtraining. The paper emphasises that higher training frequencies should be monitored closely, especially in youth, to avoid the risks associated with excessive exercise volumes, such as non-functional overreaching or overtraining (33).

Recovery Times

The UKSCA, NSCA, CSEP, and ASCA position papers all provide similar recommendations regarding intra-set recovery times for youth resistance training, generally suggesting rest periods of 1-3 minutes between sets. This range allows for flexibility depending on the exercise intensity and training goals. For less intense exercises or those aimed at developing muscular endurance, shorter rest periods of 12 minutes are typically sufficient. In contrast, for more demanding exercises focused on building strength and power, longer rest periods of 2-3 minutes are recommended to ensure adequate recovery and optimal performance in subsequent sets.

Training Sequence

Despite no specific recommendations being made, all four position papers agree on the importance of careful training sequencing in youth resistance training programs. They suggest scheduling resistance training sessions on non-consecutive days, ensuring adequate recovery time between sessions. Additionally, resistance training should be strategically placed within the weekly schedule, often before or separate from other high-intensity activities, to optimise performance and prevent fatigue from compromising technique and effort.

Exercise Selection

Each organisation emphasises the developing fundamental movement and lifting skills before progressing onto advanced exercises. They recommend starting with basic exercises such as bodyweight squats, lunges, presses, and pulls, where possible the inclusion of child sized resistance equipment is also suggested to progress load. As athletes develop technical competency, they recommend the gradual introduction of free weights and multi-joint, compound exercises. such as squats, deadlifts, and overhead presses, using free weights. They also caveat these recommendations by suggesting that the selection of exercises should always be tailored to the athlete's age, technical proficiency, training experience, and specific sport requirements. The NSCA, UKSCA and ASCA also advocate for the inclusion Olympic lifts (e.g., clean and jerk, snatch) as athletes progress, given their effectiveness in developing power and dynamic strength.

The position paper guidelines provide a valuable foundation for coaches and practitioners implementing resistance training with youth athletes, covering key aspects like training volume, load, exercise selection, and frequency. These guidelines offer clear and practical advice for developing training programs.

However, it is important to recognise that these guidelines are not exhaustive. Programming resistance training is highly nuanced, with many variables to consider. The process of designing and adjusting training programs is complex, and while the guidelines offer a strong basis, they are not intended to be a gold standard.

1.4.2 Evidence for Resistance Training Prescription and Dose in youth

The guidelines have faced critique, particularly concerning the strength of the evidence supporting them (126). The existing guidelines for resistance training prescription are founded on expert opinions and often apply results from investigations in general population and transfer them to youth athletes. This is significant because the optimal training dose required to achieve a desired outcome is likely to differ between trained and untrained youth (112).

The findings from the meta-analyses by Rhea et al (11) and Peterson et al (12) align closely with the recommendations provided by In the guidelines summarised Both meta-analyses suggest the use multiple sets for achieving maximal strength gains. Specifically, Rhea et al. (11) found that four sets per muscle group elicited the greatest gains in strength for both trained and untrained individuals, which is comparable to the recommendations of 3-4 sets for more experienced athletes in the NSCA, UKSCA and ASCA guidelines. In terms of load/intensity, Rhea et al. (11) reported that a training intensity of 60% of one repetition maximum (1RM) is most effective for untrained individuals, while 80% of 1RM is optimal for trained individuals. These findings align

with the NSCA, UKSCA and ASCAs recommendations of 60-80% of 1RM for intermediate and >80% of 1RM for advanced. Peterson et al. (12) further support this by suggesting that training at 85% of 1RM yields the best strength gains in competitive athletes. The studies also highlight the importance of training frequency, which is consistent with the guidelines. Rhea et al. (11) found that untrained individuals benefit most from training each muscle group three days per week, whereas trained individuals achieve optimal results with two days per week. This finding is in line with the recommendations of 2-3 days per week depending on the athlete's experience level. Additionally, Peterson et al. (12) noted that there was no significant benefit to training muscle groups more than two times per week for competitive athletes.

To the best of the authors knowledge there is one meta-analysis which has sought to corroborate the literature and extract a dose relationship for youth athletes (55). The analysis acknowledges the effectiveness of both single-set and multiple-set resistance training programs, with similar effect sizes for muscle strength gains. However, it notes that 5 sets generally produce larger strength gains compared to single sets. It goes on to suggests that while single-set programs might be time-efficient and suitable during the initial phases of resistance training, multiple sets are likely necessary for long-term strength development in youth athletes. It also suggests that using a rep range of 6-8 reps is optimal. The analysis suggests that using average training intensities of 8089% of 1RM are most effective for improving muscle strength in youth athletes. This aligns with the different guidelines positions that that trained individuals should work at intensities of around 80-85% of 1RM. It doesn’t comment on how load may affect untrained individuals. The analysis suggests that a training frequency of 2-3 times per week most effective which aligns well with the guideline’s recommendations for most age and experience levels. It also mentions that while one session per week can maintain gains, two sessions per week are preferred for further strength development in youth athletes.

Summary

While the guidelines provide a valuable starting platform for coaches, there remains a significant question as to whether these recommendations are truly practicable within youth sports. The realities of scheduling, individual variability, and the multifaceted demands of an athletic training program often make it challenging to apply these guidelines as they are presented.

Given these challenges, it would be highly beneficial to conduct further investigation into what has already been studied and in what specific scenarios. Additionally, research focused on testing the practicality and effectiveness of these guidelines in real-world settings would also be beneficial. This would allow for a better understanding of what works in practice and where the guidelines may need to be adjusted to meet the needs of youth athletes more effectively. It is worth recognising that much of the research and recommendations in youth resistance training often reflect optimal training doses observed in controlled, artificial environments, captured in specific snapshots of time. These conditions are very different from the complex, dynamic scenarios that strength and conditioning coaches encounter daily when working with youth athletes in real-world settings, it would be advantageous for the recommendations to be applied in real world settings to see if they can be effectively executed.

1.5 Barriers to strength training in youth sports

To accurately convey the overarching purpose of the thesis, it is important to first outline the personal and professional experiences of the author in youth sports. The following section provides a detailed examination of common challenges encountered, which, while personal to the authors experience, are also reflective of the experiences of many practitioners working in youth and academy team sports (127).

Lack of Time Available to Athletes

One of the primary challenges faced was the limited time available to the athletes.

Youth athletes had a multitude of commitments that extended beyond their training. They had school obligations, social engagements, and family responsibilities, unlike professional athletes, their training was an addition to their already busy lives, and not their primary focus. This often resulted in limited windows for strength and conditioning sessions, making it difficult to establish a consistent training regimen. The academy training schedule had athletes attend training 3 times per week, this was a combination of after school hours or during the day (weekends). Training sessions themselves lasted approximately 2 hours, and most of that time (≈ 90minutes) was spent with technical coaches in skill-based training sessions. When factoring in other obstacles such as, late arrival, time to get changed, skills-based session overrunning, this would leave a very small window in which to prescribe a quality strength and conditioning session. Although this is a personal experience, it would not be unreasonable to suggest this was a common occurrence in other academies and in other sports

Competing Demands

The time constraints were further exacerbated by the competing demands within the academy training structure. Technical coaches, who were integral to the development of the athletes' skills, often vied for their time and commitment. It was not uncommon for technical coaches to overrun, or to keep the players training for the entire 2-hour session. Although training sessions might have been scheduled on the same days and times each week, the specific training activities could vary greatly.

For example, inter-academy fixtures were often added to the schedule with little notice, disrupting the planned training sessions. Consequently, strength and conditioning support was frequently overlooked or compressed into the final minutes of the training evening.

This competition for time created a challenging environment where strength and conditioning training was frequently deprioritised. There was also the added concern about whether the players would be able to perform at their full capacity in the gym after completing over 90 minutes of intense physical training. Balancing these competing interests required careful scheduling and negotiation to ensure that athletes received a well-balanced training session.

Strength Training with Teams

Squads can consist of 11 or more players, which makes it incredibly challenging to deliver the level of care and personal attention that the guidelines recommend. Given the size of these groups, the practicality of implementing individualised training programs with tailored loading, sets, reps, and alternative exercises becomes very difficult. The limited coach-to-player ratio further complicates the focus on specific techniques, especially for more complex exercises. Also ensuring that players accurately record session information and perform what was prescribed is not achievable. Intensity is prescribed as suggested loads or RPE (Rate of Perceived Exertion), leaving the players to determine their own intensity. Ideally, coaches would be able to ensure that each player is working with adequate effort and intensity, but the inability to closely monitor every individual makes this difficult to achieve.

Given the challenges discussed above, the author frequently questioned whether the training stimulus prescribed to players was sufficient to support meaningful progress. The time constraints and the lack of structure imposed by the demands of the academy raised concerns about the feasibility of adhering to optimal training guidelines. Additionally, the difficulty of working with larger groups further complicated efforts to provide a training stimulus that aligned with best practices. Despite the desire to offer players a program that matched these guidelines, the real-world experiences of academy training made this goal impractical.

1.6 The Evolution and Structure of Academy Football: Implications for Strength and Conditioning.

The historical development of academy football has played a crucial role in shaping the modern framework for player development, particularly in relation to strength and conditioning provision. Academy football serves as a structured pathway that nurtures young talent and facilitates their progression into professional football. Over the years, the academy system has evolved significantly, integrating a multidisciplinary approach that encompasses technical, tactical, psychological and physical training. The introduction of the Elite Player Performance Plan (128) marked a turning point in the modernisation of academy football in England. Designed by the Premier League, in collaboration with the Football Association and the Football League, the EPPP established a systematic structure aimed at improving coaching standards, increasing player contact time, and embedding sports science and strength and conditioning practices into youth development programmes (128). This initiative has had a profound impact on the way football clubs approach physical preparation, ensuring that players are developed using a scientifically informed, long-term approach that prioritises performance enhancement and injury prevention (128).

The evolution of academy football can be traced through several key stages, each representing a shift towards a more structured and systematic approach to player development. In the early years, particularly before the 1990s, youth football in England was largely informal, with players progressing to professional teams through local scouting networks and school football. There was little emphasis on structured coaching methodologies, and strength and conditioning played a minimal role in player development. Physical fitness was primarily developed through natural play and match experience rather than through targeted training programmes. As a result, there was considerable variance in the physical preparedness of young players making the transition to the professional level.

The FA Charter for Quality, introduced in 1998, marked the first major effort to formalise youth development in English football. This initiative established a two-tier system that distinguished between academies and centres of excellence. The key objectives of the FA Charter for Quality were to enhance coaching standards, increase contact time with players, and introduce structured training curricula. Although this represented a significant improvement in the youth development model, the focus remained largely on technical and tactical aspects of the game, with strength and conditioning still playing a secondary role. While academies began to incorporate some aspects of fitness training, the integration of sports science and evidence-based conditioning methodologies was still in its infancy.

The introduction of the EPPP in 2011 marked a watershed moment in the development of academy football, as it established a highly structured and tiered system aimed at producing elite-level footballers (128). The EPPP was implemented to modernise the academy system, improve efficiency in player development, and create a pathway for young players to transition seamlessly into senior football. A fundamental component of the EPPP was the categorisation of academies into four tiers, with each category dictating the level of investment, facilities and access to coaching resources (128). Category 1 academies, positioned at the highest level, were required to meet the most stringent criteria in terms of infrastructure, coaching quality and player contact time.

These academies were granted the ability to recruit players nationally and were expected to produce individuals capable of competing in the Premier League. Category 2 academies, while still maintaining a high standard of coaching and player development, operated with slightly fewer resources and primarily recruited regionally. Category 3 academies focused on the development of players for lower-league professional football and operated on a more restricted budget. Category 4 academies, introduced as part of the EPPP, focused on late-developing players, with training programmes beginning at the under-17 age level (128).

The organisational structure of academies under the EPPP reflects a multidisciplinary approach, integrating various departments that collectively contribute to the holistic development of young players (128). The technical and coaching department is responsible for implementing the club’s football philosophy, overseeing training methodologies and ensuring that the academy's playing style is aligned with that of the senior team. The medical and sports science team plays a crucial role in monitoring players’ physical development, injury prevention and rehabilitation, working closely with strength and conditioning coaches to optimise performance. The education and welfare department ensures that players receive academic and personal development support, recognising that a well-rounded education is essential for their long-term success. The strength and conditioning department, now a fundamental component of modern academies, designs and implements age-specific physical development programmes, focusing on enhancing athletic attributes such as speed, strength, agility and endurance. Additionally, recruitment and scouting teams identify and sign young players with the potential to develop into professionals, while the games programme administration ensures that competitive fixtures, tournaments and international matches provide players with valuable experience (128).

One of the most significant impacts of the EPPP on academy football has been the increased emphasis on strength and conditioning provision. Prior to the implementation of this framework, physical development was often secondary to technical and tactical training, and strength and conditioning methodologies varied widely across different clubs. The structured approach introduced by the EPPP has ensured that strength and conditioning is now an integral part of the academy system, with tailored training programmes designed to align with each stage of a player's development (128). Strength and conditioning coaches in academies now employ a long-term athlete development model that ensures players progress through structured training phases (128).

The EPPP (2011) outlines specific strength and conditioning (S&C) provisions for each academy category, reflecting the differences in resources, coaching contact time and sports science support available at each level. Strength and conditioning in academies is integrated into a wider sports science and medicine framework, ensuring that players receive age-appropriate physical development tailored to their competitive and physiological needs. Each academy category (Categories 1–4) has distinct S&C requirements and recommendations, reflecting their differing levels of investment, facilities and player development priorities (128).

Category 1 academies represent the highest level of youth development within the EPPP framework. These academies have the most extensive sports science and S&C provisions, with dedicated full-time strength and conditioning specialists, advanced biomechanical testing and sports science research integration. The strength and conditioning framework for Category 1 academies is highly structured and progressive, covering all age groups from under-5 to under-21 (128). In the Foundation Phase (under-5 to under-11), the emphasis is on physical literacy and multi-sport experience, ensuring that young players develop basic movement skills such as agility, balance, coordination and flexibility. Strength and conditioning at this stage is integrated into coaching sessions, with an emphasis on fundamental movement rather than formal resistance training. Players are introduced to bio-banding, a method used to categorise players based on biological maturation rather than chronological age, allowing for tailored strength and conditioning interventions based on growth and development rates (128).

In the Youth Development Phase (under-12 to under-16), structured strength and conditioning begins, with players introduced to basic S&C techniques between under12 and under-14. From under-14 to under-16, preliminary strength training programmes are implemented, focusing on speed, strength, power and core stability. Individual physiological and biomechanical assessments are conducted for under-15 players, ensuring that strength training aligns with individual maturation rates. National benchmark testing is carried out three times per season to monitor physical development. During the Professional Development Phase (under-17 to under-21), players follow individualised strength and conditioning programmes, including lifting techniques, speed and power training, core flexibility work, plyometric exercises and aerobic and anaerobic conditioning. At this stage, training becomes highly specific to playing position and performance demands, incorporating GPS tracking, hormonal response analysis and stress management techniques. Strength and conditioning programmes are periodised across the season to optimise peak performance and recovery (128).

Category 2 academies follow a structured approach to strength and conditioning, although they operate with slightly fewer resources than Category 1 academies. Strength and conditioning is still an integral part of the academy programme, with dedicated S&C coaches and sports science staff, but the scope of individualised assessments and testing may be more limited (128). In the Foundation Phase (under5 to under-11), the focus remains on physical literacy and multi-sport participation, mirroring Category 1 academies. Players do not engage in structured resistance training but develop general movement skills that prepare them for later athletic development. Strength and conditioning delivery is integrated into the coaching programme rather than being a standalone element.

During the Youth Development Phase (under-12 to under-16), strength and conditioning progresses from basic movement patterns to structured S&C work. Players are introduced to basic techniques between under-12 and under-14, and by under-14 to under-16, preliminary strength training programmes are introduced. Strength training is applied at a squad level, with some individualisation based on maturation measurements. National benchmark testing is conducted three times per season, but the extent of individualised biomechanical assessments is more limited compared to Category 1 academies. In the Professional Development Phase (under17 to under-21), strength and conditioning focuses on position-specific training, incorporating lifting techniques, plyometric exercises and aerobic and anaerobic conditioning. Players are monitored through periodic physical testing, but access to advanced technologies, such as GPS tracking and hormonal response analysis, is more restricted than in Category 1 academies. Testing and re-evaluation occur every six weeks, ensuring that physical development is systematically tracked (128). Category 3 academies operate on a part-time training model, meaning that strength and conditioning provision is more limited compared to Category 1 and Category 2 academies. The focus in these academies is on developing fundamental physical attributes, but resources and access to specialist support staff are reduced (128). In the Foundation Phase (under-5 to under-11), strength and conditioning is integrated into general football training, with an emphasis on physical literacy and multi-sport participation. Players have less contact time with S&C coaches, and formalised strength training is not introduced at this stage.

During the Youth Development Phase (under-12 to under-16), players are introduced to basic S&C techniques between under-12 and under-14, with preliminary strength training beginning from under-14 to under-16. Unlike in higher-category academies, S&C sessions are primarily squad-based rather than individualised, and access to physiological and biomechanical testing is limited. Physical development is monitored at a club level, and national benchmark testing is conducted three times per season.

In the Professional Development Phase (under-17 to under-21), strength and conditioning becomes more structured, incorporating lifting techniques, core flexibility, plyometric training and aerobic and anaerobic conditioning. However, players do not have access to the same level of individualised programming and data tracking as in Category 1 and 2 academies. Instead, general fitness assessments and periodic testing are conducted at a club level rather than through centralised benchmarking (128).

Category 4 academies differ from the other categories as they focus solely on latedeveloping players from under-17 onwards. As such, strength and conditioning provision in these academies is less structured across multiple age groups but becomes a major focus in the Professional Development Phase (128). Since Category 4 academies do not have Foundation or Youth Development phases, strength and conditioning is not a part of the programme until players enter the Professional Development Phase. At this stage, players follow individualised strength training programmes, including lifting techniques, speed, power, core flexibility, plyometrics and endurance training.

Given that many Category 4 players have not undergone structured academy training earlier in their careers, injury prevention and fundamental movement training are prioritised. Testing and re-evaluation are determined locally by the club, and there is no national benchmark testing beyond under-18. Strength and conditioning in Category 4 academies is geared towards rapidly developing physical attributes that may have been underdeveloped due to a lack of earlier exposure to structured S&C training (128)

1.7 Physical and Physiological Demands of Football

Football is a team-based sport characterised by its intermittent nature, involving frequent transitions between different locomotor patterns (such as walking, running, and sprinting), directional shifts (including cutting and pivoting), and sport-specific actions (like tackles, headers, and dribbles) (129, 130). Physiological attributes such as aerobic endurance (131-134), speed (130, 135, 136), change of direction (29, 137) strength (138-140) and power (141-143) have been identified as key factors influencing successful football performance.

There is a limited amount of research available on match-play demands in youth football. However, recent studies on elite youth players indicate that total match distance may range from approximately 6 km in younger age groups (under 12s), increasing up to 10 km in players around 18 years of age (144-146). Anywhere from 3% to 30% is performed at high-speed running intensities (4.2–5.0 $m \cdot s^{-1}$), reflecting the intermittent and increasingly anaerobic nature of the game (147-150). It has also been reported that on average, youth players also complete around 750 metres of high-speed running, 250 metres of sprinting, and perform between 80 to 155 accelerations during a match (144). These evolving physical and physiological demands not only shape match performance but also significantly influence the developmental trajectory of youth players. The transition from academy to senior football requires athletes to possess the physical capacity to tolerate elevated training loads and the intensified demands of professional competition (151). Furthermore, longitudinal data highlight a continuous rise in fitness standards over the past decade, suggesting the need for structured athletic development to meet the increasing demands of the modern game (152).

Within this context, the primary role of strength and conditioning coach in youth sport is to promote long-term athletic development and to lay the foundation for sustained progression and injury resilience throughout the athlete's development pathway (69, 153-155).

Muscular Strength

Muscular strength, particularly maximal strength, is a key determinant of performance in football, influencing various physical attributes such as sprinting ability, acceleration, jumping, change of direction, and injury prevention (156, 157). Strength enables players to generate greater force against the ground, which translates into improved movement efficiency, power production, and resilience in physical duels (138, 140).

Research into youth footballers has shown that maximal strength is linked to key aspects of football performance. Comfort et al. (158) reported that relative strength showed a slightly stronger correlation with 20-m sprint performance ($r = -0.672$, $p <$

0.001) than absolute strength ($r = -0.645$, $p < 0.001$), However, absolute strength demonstrated the strongest associations with 5-m sprint times, squat jumps, and countermovement jumps ($r = -0.596$, 0.762, and 0.760, respectively; $p < 0.001$). Similarly, Peñailillo et al. (159) found significant correlations between leg extension strength and sprint times in youth elite footballers, with moderate to very high associations for 5 m ($r = -0.39$), 20 m ($r = -0.67$), and flying 15 m sprints ($r = -0.72$), particularly during max velocity phases.

To the best of the author's knowledge, no comprehensive normative reference values currently exist to define a standardised strength profile for youth footballers across age and maturation stages. However, studies have reported valuable data on strength characteristics in youth footballers by comparing age groups (160-162) and competition levels (163, 164).

Studies have reported that strength increases progressively during adolescence in youth footballers. Morris et al. (160) reported a steady rise in isometric mid-thigh pull (IMTP) peak force from 1,130.7 N at U12 to 1,320.5 N (U13), 1,491.9 N (U14), 1,806.2 N (U15), 2,039.3 N (U16), and 2,267.0 N at U18. Dickinson et al. (161) similarly observed an increase in IMTP peak force from 2,206 ± 274 N at U15 to 2,743 ± 319 N at U18, while relative strength (~38–39 $N \cdot kg^{-1}$) remained consistent, indicating that gains were largely mass-related. Sherwood et al. (162) found that estimated 1RM back squat strength rose from 86.1 ± 11.0 kg at U16 to 131.2 ± 11.1 kg at U18, with relative strength increasing from 1.42 to 1.81 $kg \cdot BW^{-1}$, suggesting improvements in force production beyond growth alone

Studies by Gissis et al. (163, 164) have shown that elite youth footballers produce significantly greater maximal isometric force than their sub elite and recreational counterparts, despite being of similar age. Int the study by Gissis et al (164) elite players (~16 years) recorded higher absolute (1,282.4 N) and relative (2.21 $N \cdot kg^{-1}$) force than sub elite (1,065.4 N; 1.91 $N \cdot kg^{-1}$) and recreational players (954.6 N; 1.81 $N \cdot kg^{-1}$), with no significant difference between the latter two groups. Similar findings were reported in a younger cohort (~14), where elite players again showed higher absolute (1,275.1 N) and relative (2.21 $N \cdot kg^{-1}$) force than middle-tier and lower-tier players (163). These results indicate that strength performance differs according to competition level, with higher-level players consistently demonstrating superior force capabilities. This suggests that strength may play a more critical role in performance and selection at higher levels of youth football

Taken together, the data from these studies may be considered indicative of the strength levels typically observed at different ages and competitive standards. While individual variation must be acknowledged, these values offer a practical reference from which practitioners can benchmark the strength development of youth players

Muscular Power

Muscular power is a crucial component of football performance, underpinning speed, acceleration, and explosive movements such as sprinting, jumping, and rapid directional changes (137, 140, 143, 165-167). Football is characterised by frequent short sprints < 30 metres (96%) and <10 metres (50%) highlighting the importance of acceleration (130, 135, 168). Given the game’s intermittent nature, players seldom reach maximal velocity, making acceleration more decisive for both offensive and defensive performance (136, 137, 156, 169). On average, players sprint every 90 seconds, typically during pivotal phases of play (168).

Acceleration ability is largely dependent on lower-body muscular power, particularly the capacity to produce force rapidly (29). Both peak power output and rate of force development are strongly linked to sprint performance, especially during the initial acceleration phase (138, 140). This explosive strength also assists key match actions such as jumping, tackling, and aerial contests. Notably, Wing et al. (167) investigated youth footballers and found significant correlations between jumping performance and heading success. Reporting that countermovement jump (CMJ) and squat jump (SJ) scores were highly predictive of aerial performance, with correlation coefficients of r = .80 and r = .79, respectively. These findings show the role of muscular power not only in ground-based acceleration but also in vertical force production relevant to aerial duels.

To the best of the author's knowledge, no universally accepted normative values currently exist for key neuromuscular performance measures such as sprint speed or countermovement jump (CMJ) height in youth football populations. Nonetheless, several studies (161, 170-172) have explored these variables and made comparison between ages (table 1.3). Research has also examined how sprint and jump performance differ by playing competitive level (173-175) data for these studies can be found in Table 1.4 . Although the data does not constitute an official normative dataset, it offers valuable insight into expected performance trends across different age groups and highlights meaningful distinctions between players competing at elite and sub-elite levels. This data, while not definitive, can serve as a practical reference for identifying typical performance benchmarks within age categories and for understanding the physical and technical standards associated with higher levels of youth football.

Table 1.3. Sprint and Jump Performance Characteristics (10 m, 20 m, 30 m, CMJ) in Youth Athletes by Age Group from Previous Studies

Reference	Age	10m (m/s)	20m (m/s)	30m (m/s)	CMJ (cm)
Emmonds et al (2016)	11.95 ± 0.35 (n= 149)	5.0 ± 0.27	5.69 ± 0.21		
	12.95 ± 0.30 (n= 170)	5.02 ± 0.25	5.83 ± 0.3		
	13.84 ± 0.32 (n= 144)	5.26 ± 0.27	6.09 ± 0.16		
	14.84 ± 0.30 (n= 151)	5.43 ± 0.08	6.34 ± 0.34		
	15.73 ± 0.33 (n= 123)	5.49 ± 0.21	6.47 ± 0.16		
	17.61 ± 0.45 (n= 269)	5.58 ± 0.15	6.60 ± 0.26		
Dickinson et al (2025)	14.65 ±0.25 (n= 15)		6.60 ± 0.26		33 ± 1.82
	15.46 ± 0.36 (n= 15)		6.77 ± 0.32		35 ± 2.4
	17.02 ± 1.0 (n= 15)		6.66 ± 0.2		36 ± 3.29
Williams et al (2011)	Under 12 (n= 40)	5.05 ± 0.23		5.95 ± 0.24	44.9 ± 3.2
	Under 13 (n= 47)	5.08 ± 0.36		6.04 ± 0.4	47.9 ± 5.7
	Under 14 (n= 40)	5.29 ± 0.22		6.37 ± 0.34	50.5 ± 4.8

	Under 15 (n= 41)	5.59 ± 0.28		6.73 ± 0.35	53.1 ± 4.5
	Under 16 (n= 32)	5.65 ± 0.19		6.99 ± 0.24	57.3 ± 5.3
Lovell et al (2019)	13.8 ± 0.2 (n= 30)	5.13 + 0.13	5.99 ± 0.16		34.1 ± 3.2
	14.9 ± 0.2 (n= 31)	5.26 ± 0.17	6.17 ± 0.15		35.2 ± 3.4
	15.9 ± 0.3 (n= 31)	5.35 ± 0.14	6.29 ± 0.14		36.4 ± 3.6
	16.9 ± 0.3 (n= 31)	5.41 ± 0.15	6.37 ± 0.14		37.5 ± 3.5

Table 1.4 Sprint and Jump Performance Characteristics (10 m, 20 m, 30 m, CMJ) in Youth Athletes by performance level from Previous Studies

Reference	Level	10m (m/s)	20m (m/s)	30m (m/s)	CMJ
Waldron & Murphy (2013)	Elite (n= 15)	5.26 ± 0.27		6.97 ± 0.16	41.1 ± 4.4
	Sub-elite (n= 16)	4.34 ± 0.37		5.88 ± 0.23	40.7 ± 4.3
Murtagh et al (2018)	Elite (n= 213)	5.31 ± 0.46	6.02 = 0.62		30 ± 9.0
	Amateur (n= 113)	5.20 ± 0.48	5.86 ± 0.62		28 ± 7.1
Koudelis et al (2019)	Elite (n= 64)	5.68 ± 0.06			40.6 ± 0.8
	Sub-elite (n= 82)	5.37 ± 0.05			35.2 ± 0.7
	Non-elite (n= 97)	4.90 ± 0.02			31.5 ± 0.4

Maximal aerobic capacity

Maximal aerobic capacity is a key physiological determinant of success in football, influencing a player's ability to sustain high-intensity efforts, recover quickly, and maintain overall match performance (156). Football is characterised by intermittent bursts of high-intensity actions interspersed with periods of lower-intensity activity, requiring a well-developed aerobic system to sustain repeated exertions throughout a match (133, 134, 176, 177).

Players with higher aerobic capacity tend to cover greater distances during matches, execute more sprints, and engage more frequently in ball-related actions (131, 132, 150). Helgerud et al. (176) found that in elite youth footballers (18.1 ± 0.8 yrs) improvements in $\dot{V}$ O2max led to a 20% increase in total distance covered, a 100% increase in the number of sprints, and a 24% increase in ball involvement, reinforcing the importance of aerobic conditioning in football.

Additionally, superior $\dot{V}$ O2max allows players to sustain higher work intensities throughout a match, delaying fatigue and maintaining tactical and technical effectiveness during critical phases of play (176).

Ghouili et al. (178) conducted a study to establish normative reference values for aerobic capacity, specifically maximal oxygen uptake (VO_2max) and maximal aerobic speed (MAS), in elite male Tunisian soccer players aged 11 to 18 years. A total of 742 players were assessed using the 20 m shuttle run test. VO_2max was estimated using standard regression equations based on MAS and age (table 1.5).

The study used statistical modelling to create age-based reference curves for MAS and VO_2max. Both measures showed a steady improvement with age, with VO_2max increasing from 46.6 to 51.0 ml per kg per min and MAS rising from 10.4 to 13.0 kilometres per hour between ages 11 and 18.

Significant positive correlations were found between VO_2max and several variables: age (r = 0.333), height (r = 0.279), weight (r = 0.266), body mass index (r = 0.10), and training experience (r = 0.324), all with p-values less than 0.05.

This study provides age-specific normative data for aerobic fitness in youth football and offers a valuable reference for coaches and practitioners. By identifying expected performance benchmarks across age groups.

Table 1.5 Reference Values for MAS and VO_2max Across Youth Age Groups from Existing Literature

Age Group	Sample Size (n)	MAS (km/h)	VO2max (ml/kg/min)
11–11.99	88	11.64	52.03
12–12.99	74	12.8	54.97
13–13.99	92	13.13	55.82
14–14.99	92	13.18	55.56
15–15.99	100	13.63	56.64
16–16.99	98	13.97	58.28
17–17.99	93	13.74	57.91
18–18.99	105	14.19	59.55

1.8 Purpose of the thesis

The purpose of this thesis is to explore and identify practical solutions to address the challenges and constraints faced in youth team sports. Specifically, this research aims to investigate how these concerns such as time constraints, competing demands, and the difficulties of working with large groups, can be mitigated to ensure that they do not significantly hinder the effectiveness of the training stimulus provided. By examining whether the current training practices deliver sufficient stimulus for athletic development, this thesis seeks to determine if the perceived limitations are truly detrimental or if they can be managed effectively. Furthermore, the thesis will explore modifications to existing training practices and guidelines to minimise the impact of these unavoidable challenges, ensuring that despite the constraints, the prescribed training remains effective and conducive to the athletes' progress. Ultimately, this thesis seeks to offer actionable insights that can help practitioners optimise youth training programs within the realistic constraints of youth team sport environments.

Throughout the thesis, the approach to research design, evaluation and interpretation will take into consideration the following overarching position statements from the NSCA.

1. Children and adolescents must not be treated as miniature adults, nor should adult exercise guidelines and training philosophies be imposed on youth.

This will be addressed by focusing on existing evidence specific to youth, particularly regarding the timing and implementation of interventions suited for young athletes

2. It is the systematic structuring of program variables along with individual effort and qualified instruction that will determine the outcomes associated with resistance training

This is addressed by evaluating interventions designed by and supervised by strength and conditioning specialists

3. **The act of resistance training itself does not ensure that optimal gains in strength and power will be realised, the ideal approach is to incorporate resistance training into a progressive conditioning program in which the volume and intensity of training change throughout the year**.

This is addressed by undertaking all empirical research and running all interventions in a real-world environment of a youth sports academy.
The constraints this environment places on research design and evaluation strategies adds to the ecological validity of findings.

CHAPTER 2 Establishing the reliability of performance test on youth footballers

2.1 Introduction

Ensuring that the methods used to assess physical performance are both reliable and valid is essential for the integrity of any empirical research. In the context of this thesis, which investigates physical performance outcomes in youth football players, it is critical that any changes observed across testing periods can be confidently attributed to real improvements in ability rather than inconsistencies or errors in measurement. Therefore, this chapter outlines the process undertaken to establish the measurement reliability of the performance tests used throughout the study.

In applied sports science, test reliability is widely recognised as a key consideration when assessing physical performance (179). It enables practitioners and researchers to determine whether changes in test scores are likely to reflect genuine physiological adaptations or are simply due to random variation or procedural inconsistency (180). Although often discussed as a straightforward concept, the assessment and interpretation of reliability is nuanced and highly context-dependent.

Reliability refers to the consistency of a measure across repeated applications (179, 180). In performance testing, this may involve assessments conducted over time (test–retest reliability), by different raters (inter-rater reliability), or repeatedly by the same rater (intra-rater reliability). Reliability is commonly divided into relative reliability, which reflects the consistency of individuals' rank ordering across trials, and absolute reliability, which concerns the precision of individual scores (180). Reliability is particularly important in youth populations, where biological maturation, growth rates, and neuromuscular development can significantly influence test outcomes (37). In such cohorts, even small physiological changes may be difficult to detect without precise and consistent measurement tools.

Reliability data for performance tests including the countermovement jump (CMJ), 10 m sprint, 20 m sprint, and 505 change of direction test exist in youth football populations with comparable age and characteristics (181). However, it remains important to establish test reliability within the specific context of this thesis. Variations in testing equipment, environmental conditions, procedural standardisation, and participant familiarity can all influence measurement consistency (179, 180). Moreover, to the best of the author's knowledge, no studies have specifically examined the test–retest reliability of the isometric mid-thigh pull (IMTP) in male under-14 footballers. Therefore, conducting an independent reliability assessment using the same methodology, sample, and equipment as the main body of this research ensures methodological alignment and enhances the internal validity of subsequent performance evaluations.

This chapter aims to establish a methodological basis for interpreting performance data by evaluating the relative and absolute reliability of the testing battery. Using standard statistical measures, intraclass correlation coefficient (ICC), standard error of measurement (SEM), and minimal detectable change (MDC), to ensure that the tests are both consistent and sensitive enough to detect meaningful changes, thereby supporting the validity of longitudinal findings.

These approaches are considered best practice in clinical and sports performance research and are widely cited in the literature (182-185). However, while the MDC provides a useful threshold for identifying real changes beyond measurement error, it can be relatively large compared to expected improvements observed in some contexts, thereby reducing its sensitivity to detecting small but practically meaningful changes (186, 187). The values calculated in this study will serve as thresholds for interpreting meaningful change and will be used to contextualise and evaluate the performance outcomes observed across testing sessions.

2.2 Method

Participants

Sixteen male youth football players participated in this study. Participants had a mean age of 13.54 (±0.36) years, with an average height of 161.38 cm (± 9.19) and body mass of 49.60 kg (± 8.48). The mean maturity offset was –0.10 (±0.54) years, indicating that, on average, participants were slightly pre–peak height velocity (Moore et al 2015). All participants were recruited from an amateur football club competing at the under-14 (U14) level. Inclusion criteria required players to be free from injury, actively participating in training and matches, and cleared for full physical activity by their club. Parental consent and player assent were obtained prior to testing. The study received ethical approval from the University of Essex Ethics Committee.

Design

A repeated-measures design was used to evaluate test-retest reliability across a battery of performance assessments. Each participant completed the same physical performance tests on two separate occasions spaced two days apart. This interval was chosen to minimise both learning effects and physiological adaptations, aligning with best practices for MDC evaluation.

Procedures

Participants attended a familiarisation session one week prior to formal data collection, during which all testing procedures were demonstrated and practised. Formal testing took place on two non-consecutive evenings with a two-day interval between sessions to minimise the effects of fatigue and physiological adaptation. Both sessions were conducted at the same time of day to control for diurnal variation and were held on an outdoor artificial surface under consistent environmental conditions.

Each testing session began with a standardised dynamic warm-up was completed prior to testing on both occasions under the supervision of the research team. Following the warm-up, the tests were performed in a fixed sequence designed to minimise cumulative fatigue. The order of testing was as follows: Countermovement Jump (CMJ), Isometric Mid-Thigh Pull (IMTP), 10 m and 20 m linear sprints, and 505 change of direction tests (left and right). A minimum of three minutes of rest was provided between test components to allow for recovery (171). This sequence was identical across both sessions to ensure methodological consistency.

Countermovement Jump

The countermovement vertical jump has been reported as a valid and reliable measure of lower-limb explosive power (181). A member of the research team provided a verbal explanation and physical demonstration of the correct jump technique prior to testing. Participants performed three maximal effort jumps and had approximately a 2 min recovery between trials (171). Jump testing was conducted using a portable force platform (model PS-2141, Pasco, California, USA), which recorded ground reaction force data at a sampling frequency of 1000 Hz. Jump height was calculated, recorded and analysed via SPARKvue software (PS-2400, version 3.1.3; Pasco, California, USA). The highest jump height recorded across the three trials was used for further analysis.

Each jump was performed with a two-footed take-off and landing, incorporating a selfselected depth of countermovement to maximise jump height. Participants were instructed to bend at the knees during the downward phase and to extend their legs fully during take-off to produce a vertical trajectory (171). Participants were instructed to keep hands on hips to eliminate arm swing. Participants were also instructed to aim to take off from and land on the same point on the platform.

Isometric mid-thigh pull

The isometric mid-thigh pull (IMTP) has been reported as a valid and reliable measure of maximal force production in both adult and youth athletic populations (188-191). IMTP testing in the present study was performed using a portable force platform (Model PS-2141; Pasco, California, USA) sampling at 1,000 Hz. Ground reaction force data were recorded using SPARKvue software (PS-2400, version 3.1.3; Pasco, California, USA). Sampling at this frequency has been shown to provide high reliability for isometric force-time variables (189).

All IMTP trials were performed to reflect the position of the second pull of the clean, the bar was positioned just below the hip crease with feet shoulder-width apart, knees aligned over the toes, shoulders slightly behind the bar, and an upright torso (189, 192).

Participants exerted maximal effort for five seconds while ground reaction force was collected continuously over an eight-second window (189, 192).

Verbal encouragement was provided throughout all trials. Any trial that exhibited visible countermovement or an unstable force baseline was excluded and repeated. Each participant completed three maximal-effort trials, separated by two-minute rest intervals, the highest value of peak force was used for analysis.

10 m and 20 m sprints

All 10 m and 20 m sprint tests were conducted on an indoor synthetic sports surface to ensure consistency across trials. Sprint times were measured using infrared timing gates (Brower Timing Systems: Utah, USA), which were positioned at 0 m, 10 m, and 20 m. This configuration allowed for the collection of times for both 10 m and 20 m, providing insight into initial acceleration and total sprint performance.

Previous research has shown reliability and validity for similar sprint distances in youth team sport athletes under comparable surface and environmental conditions (193). Each sprint commenced from a stationary standing start, with participants positioned 1 metre behind the first timing gate. A three-second verbal countdown was provided before each sprint, and participants were instructed to accelerate maximally through the entire 20 m distance. Verbal encouragement was provided throughout each sprint by members of the research team located at the start and finish lines. Following the completion of each sprint, participants were instructed to walk slowly back to the start line to ensure active recovery. Each participant performed three trials, with approximately five minutes of rest between efforts to minimise the effects of fatigue (171). The fastest recorded time from the three trials for each distance was retained for further analysis.

505 change of direction test

The 505 change of direction test was administered as a valid and reliable measure of multidirectional speed and change of direction (194-196) . The test was conducted in accordance with established guidelines in the literature (194, 195, 197).

A photocell timing system (Brower Timing Systems, Utah, USA) was used to capture sprint times, with timing gates positioned 10 metres from the start line to ensure precise measurement of the final 5 m of the 15 m sprint segment following the change of direction. Each participant performed four total trials, 2 using the right foot as the plant foot, and 2 using the left, participants were given 2 minutes recovery between each attempt to help mitigate fatigue (198). The direction of the initial turn (left or right) was randomised between participants to mitigate any order effects. The testing procedure and instructions were consistent with those described in previous research (195).

To ensure validity and compliance with the protocol, a member of the research team was positioned at the turning line to observe whether the participant's foot fully crossed the designated line and that the correct foot was used to initiate the turn. If either of these requirements was not met, the attempt was deemed invalid, and the participant was asked to repeat the trial. For analysis, the fastest time from each turning direction (left and right) was retained. These two values were then averaged to produce a combined score, reflecting the participant’s overall change of direction speed across both limbs.

2.3 Data Analysis

To ensure the robustness of the performance assessments used throughout this thesis, test–retest reliability was evaluated using a combination of relative and absolute reliability metrics. This section outlines the statistical framework used to quantify the consistency and precision of the tests across repeated measurements

Intraclass correlation coefficient (ICC)

The intraclass correlation coefficient (ICC) is a widely accepted measure of relative reliability, estimating the proportion of total variance in observed scores that can be attributed to true differences between individuals rather than random error (199, 200). ICC values range from 0 to 1, with higher values indicating greater reliability. According to the classification proposed by Koo and Li (199), ICCs below 0.50 are considered poor, between 0.50 and 0.75 moderate, between 0.75 and 0.90 good, and above 0.90 excellent.

Different ICC models exist depending on study design and the treatment of raters or trials as fixed or random effects. In this study, a two-way random effects model with absolute agreement was used to calculate single measures ICCs (ICC[2,1]), accounting for both systematic and random error. This model is particularly suitable for evaluating consistency in performance testing where the same participants are assessed across multiple trials under identical conditions (201, 202).

It is important to note that ICC values can be influenced by the degree of betweensubject variability. In homogeneous samples, such as youth athletes of similar age and training level, lower ICC values may occur despite high within-subject consistency (199, 202). Therefore, ICCs should be interpreted alongside absolute reliability indices.

Standard error of measurement (SEM)

The standard error of measurement (SEM) is used to quantify the amount of measurement error inherent in an individual's score due to random variability (179, 203). Unlike ICC, which reflects relative consistency, SEM provides an absolute index of reliability and is expressed in the same units as the measured variable (204). SEM was calculated using the standard deviation of the difference scores between test and retest (SD_diff), based on the following formula:

$$SEM = SD\_diff / \sqrt{2}$$

This method assumes no systematic bias and homogeneity of variance between trials, which are reasonable assumptions in test–retest designs when familiarisation and procedural control are present.

Minimal detectable change (MDC)

The minimal detectable change (MDC) represents the smallest change in a test score that can be interpreted as a real difference rather than random measurement error(182, 183). It is derived from the SEM and incorporates the 95% confidence interval for change detection:

$$MDC_{95} = 1.96 \times SEM \times \sqrt{2}$$

This calculation accounts for error in both the initial and follow-up measurements and is particularly useful in applied sports contexts, where it is important to determine whether performance improvements are meaningful (184, 185). All statistical analyses were performed using SPSS Statistics (version 27.0; IBM Corp., Armonk, NY, USA).

2.4 Results

Table 2.1 Test–Retest Reliability of Physical Performance Measures: ICC Values, 95% Confidence Intervals, and Interpretation

	ICC (95% CI)	p-value	Interpretation
IMTP	.956 [.878, .984]	< .001	Excellent
CMJ	.839 [.598, .941]	< .001	Good
10m Sprint	.879 [.693, .956]	< .001	Good–Excellent
20m Sprint	.843 [.604, .942]	< .001	Good
505 CoD	.671 [–.026, .924]	< .001	Moderate

Table 2.2 Standard Error of Measurement (SEM) and Minimal Detectable Change (MDC_{95}) for Physical Performance Tests

	SEM	MDC_{95}
IMTP	51.88 N	143.81 N
CMJ	0.81 cm	2.25 cm
Estimated Peak Power	43.95 W	121.82 W
10m Sprint	0.05 s	0.13 s
20m Sprint	0.14 s	0.38 s
505 CoD	0.02 s	0.07 s

Test–retest reliability was evaluated for five performance tests: Isometric Mid-Thigh Pull (IMTP), Countermovement Jump (CMJ), 10-meter sprint, 20-meter sprint, and the combined 505 change-of-direction (CoD) test. Single measures intraclass correlation coefficients (ICC[2,1]) were calculated using a two-way random effects model with absolute agreement, including 95% confidence intervals (CIs) and significance levels. The IMTP demonstrated excellent reliability (ICC = .956, 95% CI [.878, .984], $p < .001$), while the CMJ, 10-meter, and 20-meter sprints showed good to excellent reliability

(ICC range = .839–.879, all $p < .001$). The 505 CoD test exhibited moderate reliability (ICC = .671, 95% CI [–.026, .924], $p < .001$), indicating greater variability.

Absolute reliability was assessed via the standard error of measurement (SEM) and minimal detectable change at 95% confidence (MDC_{95}), calculated using: $SEM = SDdiff / \sqrt{2}$ and $MDC_{95} = 1.96 \times SEM \times \sqrt{2}$. The IMTP showed the greatest measurement error (SEM = 51.88 N; MDC_{95} = 143.81 N), followed by estimated peak power (SEM = 43.95 W; MDC_{95} = 121.82 W). CMJ demonstrated lower error (SEM = 0.81 cm; MDC_{95} = 2.25 cm), while 10 m and 20 m sprints showed SEMs of 0.05 and 0.14 seconds, respectively. The 505 CoD test showed the lowest absolute SEM (0.02 s) among the timed tests, suggesting acceptable measurement precision relative to the test demands.

2.5 Discussion

The results from the current study suggest that the countermovement jump (CMJ), 10 m sprint, and 20 m sprint tests demonstrate good to excellent test–retest reliability in under-14 male footballers. Intraclass correlation coefficient (ICC) values ranged from .839 to .879 across these three assessments, indicating strong relative reliability within this age group.

These findings are broadly consistent with those reported by Dugdale et al. (181), who observed ICCs of 0.87 for the CMJ, 0.89 for the 10 m sprint, and 0.94 for the 20 m sprint in a sample of under-13 and under-14 football players. While the ICC values in the present study are slightly lower, they remain within the acceptable thresholds for good to excellent reliability (199), suggesting comparability between studies and reaffirming the suitability of these tests for use in youth football populations.

In terms of absolute reliability, the standard error of measurement (SEM) values observed in the current study were 0.81 cm for the CMJ, 0.05 s for the 10 m sprint, and 0.14 s for the 20 m sprint. These are closely aligned with the SEMs reported by Dugdale et al. (181), who found values of 1.62 cm, 0.06 s, and 0.12 s for the same respective tests. The similarities in SEM between the two studies reinforce the consistency and precision of these measures and support their continued application in longitudinal monitoring of youth athletes.

In contrast, the 505 change-of-direction (CoD) test demonstrated only moderate relative reliability in the present study, with an ICC of .671. This is lower than the ICC of 0.89 reported by Dugdale et al. (181) for the same test. The difference may be attributed to variations in technical execution, familiarity with the movement pattern, or differences in biological maturation. However, the 505 CoD test still showed strong absolute reliability, with a low SEM of 0.02 s. This suggests that, despite the moderate ICC, the test remains capable of detecting small, meaningful changes in individual performance and can therefore be considered a valid and appropriate measure for use within this thesis.

Dugdale et al. (181) reported a larger MDC_{95} for the CMJ (4.48 cm) compared to the 2.25 cm observed here, suggesting greater measurement precision in the current study. For the 10 m sprint, the MDC_{95} was almost identical (0.12 s vs. 0.13 s), and for the 20 m sprint, Dugdale et al. reported a slightly lower value (0.22 s vs. 0.38 s), indicating marginally greater variability in the present sample. Conversely, the MDC_{95} for the 505 CoD was higher in Dugdale et al. (0.11 s) compared to 0.07 s observed here, possibly reflecting greater technical consistency or procedural differences.

Despite these small variations, the SEM and MDC_{95} values reported in this study remain broadly consistent with previous research and support the use of these tests for monitoring meaningful changes in youth football players.

To the best of the author's knowledge, no prior research has specifically examined the test–retest reliability of the isometric mid-thigh pull (IMTP) in male under-14 footballers. However, several studies have evaluated IMTP reliability across other youth athletic populations. Dos'Santos et al. (190) assessed 16.7-year-old male soccer players and reported excellent reliability for peak force (ICC = 0.96, CV = 4.61%), Kolokythas et al. (205) found similarly high reliability in a mixed-sex cohort of adolescent dancers (ICC = 0.98, CV = 3%), and Till et al. (71) reported excellent withinsession reliability (ICC = 0.94, CV = 4.3%) for 15.3-year-old male rugby league players. Comparatively, the present study demonstrated an ICC of 0.956 for IMTP peak force, indicating excellent relative reliability consistent with values previously reported across slightly older or mixed athletic populations.

Further comparison of absolute reliability metrics shows that the SEM observed in this study (51.88 N) is closely aligned with that reported by Kolokythas et al (205) (48 N) and somewhat lower than that reported by Dos'Santos et al. (190) (68.52 N), suggesting consistent measurement precision across studies. The MDC_{95} reported here (143.81 N) is also comparable to that of Kolokythas et al. (205) (134 N), further supporting the repeatability of peak force assessment in youth athletes.

Although differences in participant characteristics such as age, sex, training background, and maturity status must be considered when interpreting these comparisons, the findings broadly support the applicability of the MDC thresholds for monitoring meaningful changes in strength among early adolescent athletic populations

2.6 Implications for this thesis

The MDC_{95} values established for each test will be used to determine whether observed performance changes exceed measurement error thresholds. Specifically, changes greater than the MDC_{95} will be interpreted as likely representing true improvements rather than random variation, providing a robust basis for evaluating training intervention effects. It is important to acknowledge that while changes exceeding the MDC_{95} threshold are statistically meaningful, further interpretation is required to assess their practical relevance within the context of athletic development (206, 207).

In summary, the performance tests used in this thesis demonstrated acceptable levels of test–retest reliability for youth football players. These findings provide confidence in the use of this testing battery for monitoring meaningful performance changes in subsequent intervention phases. The established MDC thresholds will inform future analyses and interpretation of training effects.

CHAPTER 3

Resistance training in youth team sports: a scoping review of the literature

3.7 INTRODUCTION

Properly structured resistance training programmes can enhance physical and sporting performance by improving key athletic attributes such as speed, strength, and power (69, 208). The programming of training variables such as sets, repetitions, load, frequency and recovery periods determines the adaptations that can be achieved. Manipulating these variables allows strength and conditioning practitioners to utilise the FITT principles (frequency, intensity time and type) to optimise both short- and long-term outcomes for athletes (10, 209).

There is much research already which advises the optimal dose for sets (11, 30) repetitions (31) load/intensity (11, 12) and Frequency (32) in adult populations. In youth athletes, however, the effective implementation of resistance training is particularly challenging. Youth athletes often engage in multiple training sessions per week, but these sessions are typically limited in duration and must accommodate various other training and educational commitments (33, 71). Consequently, strength and conditioning coaches must balance the inclusion of sufficient stimulus to promote adaptation while avoiding overtraining and potential injuries. Understanding the minimal effective dose of resistance training stimulus is crucial for developing efficient training programmes that foster essential physiological adaptations without overloading the athlete (112, 121).

Training session variables, including the number of sets and repetitions, recovery intervals, exercise selection, and exercise order, significantly influence the adaptations and well-being of the participants (210). Additionally, design factors such as session frequency and duration, meso/microcycle length, and the periodisation model (e.g., linear, undulating, or mixed) can contribute to the potential effects of a training programme (11).

Despite the recognised benefits of resistance training, most research on optimal resistance training programming has been conducted on adult populations (11, 12, 30-32). Studies on adults, both trained and untrained, provide valuable insights but may not be directly applicable to youth athletes due to differences in age, maturation status, and developmental stages (65). The distinct physiological characteristics of youth necessitate tailored resistance training programmes that accommodate their unique needs and capacities (33). National governing bodies such as the United Kingdom Strength and Conditioning Association (UKSCA), the National Strength and Conditioning Association (NSCA), the Australian Strength and Conditioning Association (ASCA), and the Canadian Society for Exercise Physiology (CSEP) provide guidelines for resistance training in youth populations. However, the lack of research directly involving youth makes it difficult for these organisations to substantiate these guidelines and to speak definitively on their efficacy. As a practitioner working in youth football, the challenges surrounding resistance training with academy athletes, as outlined earlier in this thesis, highlight the importance of determining the effectiveness of these guidelines.

3.7.1 Need for a Review of Literature

There is a need to identify what is currently available in the literature, particularly regarding resistance training in youth sports. Specifically, it is important to determine whether the training variable parameters recommended by guidelines have been investigated. Additionally, there is a need to evaluate whether the recommended guidelines for training variables such as sets, repetitions, and frequency are effective.

If these guidelines do not prove effective, it is crucial to identify what is and what aspects need further investigation. This thesis will be conducted within the context of youth academy football, therefore, focusing on the literature available for team sports is particularly pertinent.

3.7.2 Rationale for study selection

Sports such as Football (211), Rugby (212), Basketball (213) and field hockey (214, 215) share a range of physiological and physical characteristics. These sports demand a combination of aerobic endurance and anaerobic power due to frequent highintensity sprints interspersed with periods of moderate activity or rest, requiring both stamina and explosive strength. They involve similar volumes of movements such as sprinting, jumping, cutting, and changing direction, necessitating agility, balance, coordination, and rapid force exertion. Players often perform repeated high-intensity efforts throughout a game, highlighting the importance of muscular endurance and recovery, effectively targeted by specific strength and conditioning programmes. These commonalities provide a solid foundation for applying and generalising strength training research across these sports (216).

Given these similarities, focusing on team sports as a cohesive group for this research is logical. The shared requirements of these sports mean that findings from strength training studies can be more readily generalised and applied across different sports within this category. Furthermore, focusing on this group allows for a more streamlined and targeted analysis of existing literature, ensuring that the selected studies are directly applicable to the populations and settings of interest.

3.7.3 Purpose of the Review

The purpose of this review is to address the following points:

1. Describe the existing research on resistance training in youth athletes competing in team sports.
2. Identify the most frequently investigated elements of resistance training in these studies.
3. Assess whether the findings support the existing guidelines provided by major strength and conditioning organisations.
4. Identify what aspects of resistance training need further investigation.

By adopting this broader strategy and narrowing the focus to resistance training in youth athlete populations competing in field-based team sports, this review aims to offer valuable insights that can inform the development of more effective resistance training programmes, promoting the physical development and overall well-being of these athletes.

3.8 METHODS

A search of the literature was conducted on 09/04/2020 in the databases CINAHL, Medline, and SPORTDiscus, using the following Boolean search syntax: (Youth OR Adolescent OR Young people OR Teenager OR Teen OR Children OR Child OR PrePubescent) AND (Resistance training OR Strength training OR Weight training OR Resistance exercise OR Weightlifting). The search was limited to abstracts, and results were filtered to include only English language papers from academic journals. No date filter was applied.

The initial search strategy yielded a total of 2715 results, which was reduced to 1757 after duplicates were removed, a diagram of the search process can be seen in Figure

1 Titles and abstracts were reviewed for relevance by the author during the first stage of screening, and papers were excluded based on the following criteria:

3.8.4 Exclusion Criteria

- Populations with any medical contraindications (e.g., obesity, cerebral palsy, asthma, diabetes, musculoskeletal injury)
- Participants older than 17 years of age
- Any position statements, including from recognised strength and conditioning governing bodies such as UKSCA, NSCA, CSCA, ASCA
- Opinion pieces, roundtable discussions, letters to the editor, conference abstracts/contributions, author communications
- Papers that did not conduct original research
- Studies focused on rehabilitation or specific injury risk reduction

A total of 1397 papers were excluded based on these criteria, leaving 360 papers for full-text review. Papers that matched the following inclusion criteria were selected for this review:

3.8.5 Inclusion Criteria

- Participants ≤17 years of age
- Studies with multiple age groups where at least two groups had an average age of ≤17

- Studies that made a comparison or measured effects of at least one experimental group performing resistance training
- Studies that measured at least one form of physical performance outcome (e.g., speed, strength, power, muscular or aerobic endurance)
- Full text available

A further 260 papers were excluded for failing to meet the inclusion criteria, resulting in 100 papers being included in this review. Although meta-analyses and systematic reviews were excluded from analysis, they were all subjected to full-text review. Any papers meeting the inclusion criteria that were missed or not included in the initial search phase were added to the review. To facilitate a more concise and convenient analysis of the research, the full texts were reviewed again and categorised based on the characteristics and purpose of the research.

To refine the focus of the review, additional exclusion criteria were applied to concentrate specifically on studies investigating team field-based sports. This step was necessary to ensure the relevance and applicability of the findings to the specific research focus.

3.8.6 Further Exclusion Criteria

- Studies that did not focus on youth populations participating in team sports

By applying these criteria, the initial pool of 100 papers were reviewed, resulting in the exclusion of 71 studies that did not meet the specified criteria. Consequently, a refined selection of 29 papers remained, each directly addressing the research focus on youth populations in field-based team sports.

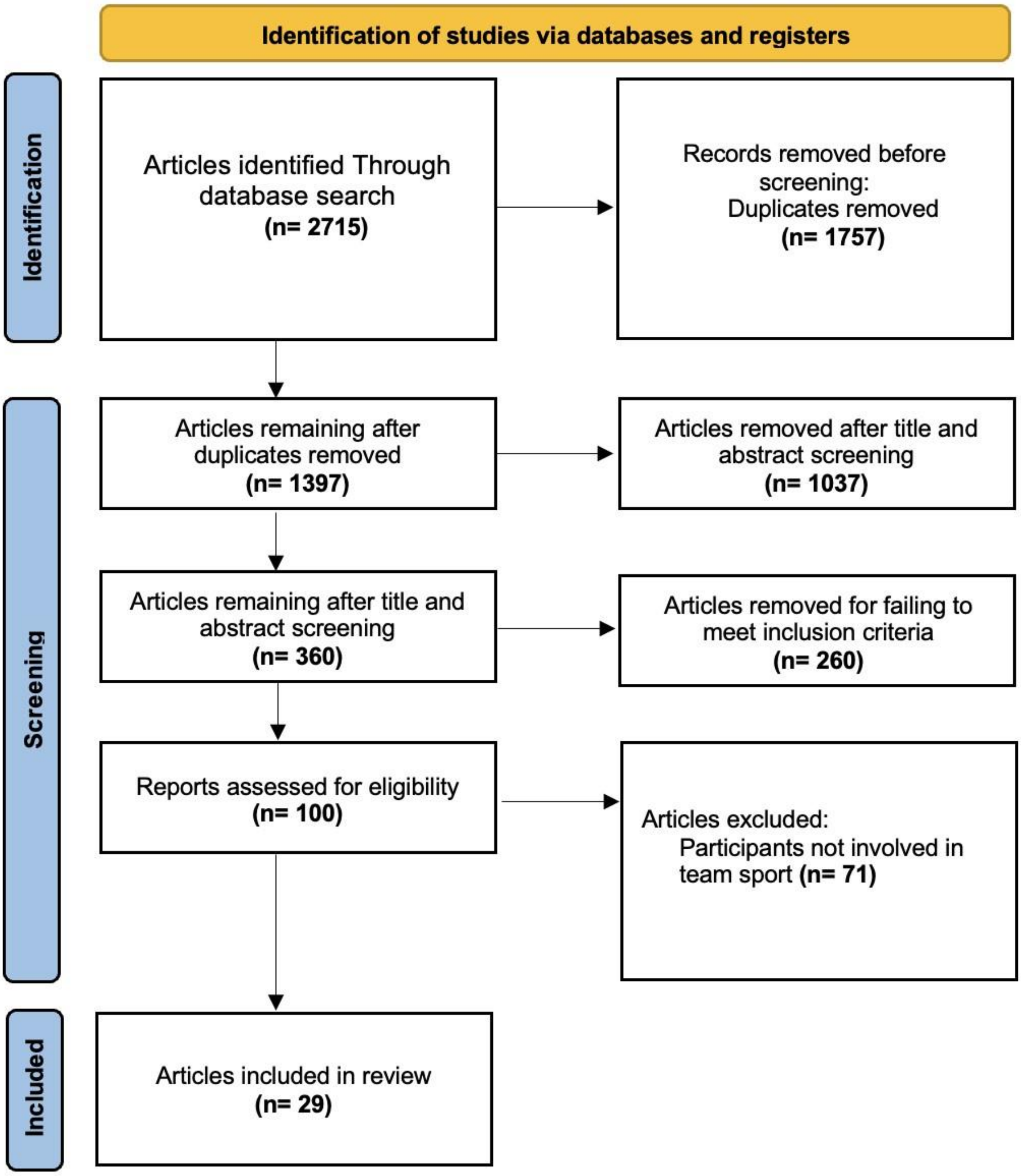

Figure 1. A flow diagram of the study selection process

3.9 RESULTS

There were 29 studies included in the review. A total of 1053 participants ranged from 9 to 17 years, with a mean age of 14.97 years (SD = 2.08). The studies primarily focused on Football/Soccer (19 studies), followed by Handball (three studies), Rugby union (three studies), Basketball (two studies), American football (one study), and Field hockey (one study). A total of 17 studies included only male participants (*n*= 489), four studies included only female participants (*n*=83), one study investigated a mix of male and female (M *n*= 24, F *n*= 22), and 7 studies did not fully report the sex of participants (*n*=435).

Details of the resistance training variables used by the studies in this review are shown in Table 3.1. The repetitions varied from 3 to 25 reps, with the most common prescription centring around 10 reps. The load ranged from body weight or percentages of 1RM (repetition maximum), specifically from 30% 1RM to 90% 1RM, including specific RM loads like 4-6RM, 6-8RM, etc. The most frequently used loading prescription was 60-70% 1RM.

Recovery times between sets varied significantly, ranging from 10 seconds to 300 seconds. The mode for recovery time was 120 seconds. The duration of the training programs also showed considerable variability, ranging from 4 weeks to 104 weeks. The most common duration for the training programs was 12 weeks

Comparison with current guidelines

The NSCA and UKSCA recommend training 2-3 time per week (1, 33). Sixteen studies align with the recommended training frequency of 2-3 times per week. Four studies deviated from the frequency recommendations; three utilised a lower frequency of once per week (217-219) and only one employed a higher frequency of four times per week (220).

The NSCA and UKSCA recommend using a training load/intensity of 30-90% 1RM (1, 33) Eighteen studies prescribed loads within the guideline range (30-90% 1RM), five studies employed a higher than recommend loads of 85-90% 1RM, matching the guidelines recommendations for advanced youth athletes.

The NSCA and UKSCA recommend using a rep range of 2-4 sets per exercise (1, 33) Twenty studies also utilised 2-4 sets per exercise, which matches the guidelines. Rep ranges vary from 4 to 25, fitting within the suggested guidelines, studies like Ramalingham (221), which employ very high repetitions, align more with endurance training principles rather than standard strength training guidelines.

The NSCA and UKSCA recommend using recovery times of between 60-180 seconds (1, 33).

Fifteen studies employed recovery times between 60-180 seconds, aligning with guidelines. However, two studies (222, 223) utilised much lower recovery times of 1030s.

Additionally, twelve studies employ principles of progressive overload and periodisation, which align with the recommendations for advanced training.

Overall, while there is strong adherence to established training principles across the reviewed studies, some variations exist that reflect the specific objectives and populations targeted by each research effort.

Table 3.1 A summary of training variables including sets, repetitions, frequency and duration, utilised in the reviewed studies

Author	**Training variables**			
	Sets, reps, load	**Recovery times**	**Frequency**	**Duration**
Abade et al (217)	Weeks 1-7: 3 sets 10-8RM Weeks 8-14: 3 sets 8-6RM Weeks 15-20: 3 sets 4-6RM Eccentric-overload: 2 sets 6-8 reps Isometric planks: 3 sets 15 seconds	90s	1x per week	20 weeks
Cavaco et al (218)	Adaptation period: 3 sets 12 reps First station: 3 sets 6 reps, 85% 1RM Second station: 3 sets 6 reps at 85% 1-RM	180s	GCT1:1x per week GCT2: 2x per week	6 weeks
Chatzinikolau et al (220)	2-3 sets 6-14 reps, 60-90% 1RM	60-120s	4x per week	5 weeks
Christou et al (113)	Weeks 1-2: 2 sets 15 reps at 55-60% 1RM Weeks 3-4: 3 sets 15 reps at 55-60% 1RM Weeks 5-8: 2-3 sets 12 reps at 65-70% 1RM Weeks 9-12: 2-3 sets 10 reps at 70-75% 1RM Weeks 13-16: 2-3 sets 8 reps at 75-80% 1RM	120s-180s between sets 180-300s between exercises	2x per week	16 weeks
Ferley et al (219)	3 sets 6-12 reps at 60-90% 1RM	180-300s	1x per week	8 weeks

Ferrete et al (224)	1/4 Squat: Weeks 1-8: 2-3 sets 8 reps Weeks 9-16: 2-3 sets 6 reps Weeks 17-26: 4-6 sets 6 reps Deep squat: 2-3 sets 6 reps	60s	2x per week	26 weeks
Gonzalez-Garcia et al (225)	Weeks 1: 4 sets 12 reps at 60% RM Weeks 2-3: 4 sets 10 reps at 70% RM Weeks 4-5: 4 sets 8 reps at 80% RM Week 6: 4 sets 6 reps at 85% RM Week 7: 4 sets 4 reps at 90%	180s	2x per week	7 weeks
Gorostiaga et al (226)	4 sets a 5-exercise circuit Set 1: 12 reps at 40% 1RM Set 2: 10 reps at 50% 1RM Set 3: 6 reps at 80% 1RM Set 4: 3 reps at 90% 1RM	90s	2x per week	6 weeks
Harries et al (227)	Linear: Weeks 1-12: 10-4 reps at 60-88% daily max load Undulating: Session A: 10 reps at 60-70% daily max load Session B: 5 reps at 60-70% daily max load	120-180s	2x per week	12 weeks

Harries et al (228)	Linear: Weeks 1-12: 10-4 reps at 60-88% daily max load Undulating: Session A: 10 reps at 60-70% daily max load Session B: 5 reps at 60-70% daily max load	120-180s	2x per week	12 weeks
Ignajtovic (87)	Weeks 1-4: 3 sets 10 reps Weeks 5-8: 3 sets 12 reps Weeks 9-12: 3 sets 15 reps	10-30s	2x per week	12 weeks
Ignajtovic (88)	Weeks 1-4: 3 sets 10 reps Weeks 5-8: 3 sets 12 reps Weeks 9-12: 3 sets 15 reps	10-30s	2x per week	12 weeks
Johnson et al (229)	3 sets, undisclosed reps, undisclosed load Hang cleans 5 sets 3 reps	60-180s	3x per week	6 weeks
Keiner et al (123)	First 4 weeks: Technique training Next 8 weeks: 5 sets 10 reps Next block: 5 sets 6 reps Final block: 5 sets 4 reps Trunk/upper exercises: 3-5 sets 10 reps	180-300s	2x per week	104 weeks
Makhlouf et al (230)	Weeks 1-4: 3 sets 10 reps Weeks 5-8: 3 sets 6 reps Weeks 9-12: 3 sets 5 reps	90-120s	2x per week	12 weeks

McKinlay et al (231)	3 set 12 reps, <80% 1RM	60-90s between sets 120-180s between exercises	3x per week	8 weeks
Millar et al (232)	HT: 3-6 sets 3-8 reps, 30% of 3RM increasing by ~10% each week SQ: 3-6 sets 3-8 reps, 30% of 3RM increasing by ~10% each week Upper body: 2 sets 8 reps	120-300s	2x per week	6 weeks
Negra et al (233)	HVRT: Half-squat 4 sets 8-12 reps, week 1: 40% 1RM, week 2: 50% 1RM, week 3: 60% 1RM, week 4: 40% 1RM, Abdominal curl, back extension 6 sets 15 reps	120s	2x per week	12 weeks

Pangoulis et al (234)	Weeks 1-2: 3 sets 8 reps, body mass Nordics: 1 set 5 reps Planks: 3 sets 15s Weeks 3-4: 3 sets 8 reps, 2 kg med ball Nordics 2 sets 5 reps, Leg raises 3 sets 16 Weeks 5-6: 3 sets 8 reps 2-5kg med ball Nordics 2 sets 8 reps Knee to opposite elbow & up-downs, side planks 3 sets 16 reps Weeks 7-8: Continue with progressive difficulty	60-120s	3x per week	8 weeks
Ramalingham (221)	LP: Weeks 1-4: 2 sets 25RM, Weeks 5-8: 3 sets 20RM, Weeks 9-12: 3 sets 15RM DUP: Weeks 1-4: 2 sets 25RM, Weeks 5-12: Alternated between 3 sets 20RM and 3 sets 15RM.	60-120s	2x per week	12 weeks

Rodriguez Rosell (116)	Session 1: Squat 2 sets 8 reps Session 2-3: Squat 3 sets 8 rep Session 4-6: Squat 3 sets 6 reps Session 7: Squat 2 sets 6 reps Session 8-9: squat 3 sets 6 reps Session 10: Squat 2 sets 4 reps Session 11-12: Squat 3 set 4 reps	180s	2x per week	6 weeks
Ruivo (235)	Week 1-4: 4 sets 15 reps, 65% 1RM Week 5-8: 4 sets 8-12 reps, 70-80% 1RM Week 9-12: 4 sets 12 reps, 70-80% 1RM Week 13-16: 4 sets 6-12 reps, 70-80% 1RM	120s	3x per week	16 weeks
Saeterbakken (236)	4 sets 4-6 RM	60-120	2x per week	6 weeks
Sander et al (122)	4 weeks: Technique training 8 weeks: 5 sets 10 reps 4 weeks: 5 sets 6 reps 4 weeks: 5 sets 4 reps Trunk/upper extremities: 3-5 sets 10 reps	180-300s	2x per week	104 weeks

Santos & Janeira (237)	3 sets 10-12 RM	120-180s between sets 45-60s between exercises	1x per week	16 weeks
Smart & Gill (114)	4-5 sets, 6-10 reps, 6-10RM	120s	3x per week	15 weeks
Vassilis (238)	Week 1-2: 2 sets, 10-12 reps, 70% 1RM Week 3-4: 3 sets, 10-12 reps, 70% 1RM	60-90s	2x per week	4 weeks
Wong (117)	Weeks 1-4:10 exercises, 10 reps Weeks 5-8: 4 sets 6 reps 1-25KG	90-120s	2x per week	12 weeks
Zouita (239)	Sets undisclosed, 15-20 reps, 30-80% 1RM	Undisclosed	2-3x per week	12 weeks

Abbreviations: RM= repetition maximum, **reps** = repetitions

Study Categorisation

The categorisation or sorting of research on resistance training is a challenging task. Resistance training programmes involve many distinct variables, all of which can be adjusted or modified in some way to influence the stimulus and overall outcomes. The nature of these variables makes it difficult to pinpoint exactly which specific change a study may have made to investigate its effects. The author has categorised each paper based on its primary area of focus. For instance, while some studies may have aimed to compare frequency, they could also involve complex training in one study and traditional training in another. Alternatively, some research may examine the effects of resistance training combined with sport-specific training, but one paper might include both plyometrics and resistance training, while another uses only resistance training. To gain a clearer understanding of the current literature, the studies included in this review were analysed and categorised according to the aims being investigated. By sorting the studies into distinct categories, the goal was to identify the primary areas of focus, and the various methodologies employed by researchers. This categorisation provides a clearer overview of the existing research landscape and highlights the key variables being explored, offering valuable insights into current trends and future research needs

Training Intervention

Fifteen studies examined the addition of a resistance training program to sports specific training, or the comparison of a training program to a non-training or sports specific training control group. The included studies offered a variety of different training interventions and have a mixture of different areas of focus. This category has therefore been further divided into several subcategories to provide clarity. Seven studies utilised a standard resistance training program as their training group, four studies compared the effects of a complex training program, and four studies compared the effects of a specialised training program.

Traditional Resistance Training

A summary of the seven studies (113, 122, 123, 223, 226, 235, 239) utilising a standard resistance training program as the training group can be found in Table 3.2. Typically, the training programs consisted of a selection of upper and lower body exercises, performed as compound or in isolation, utilising barbells, dumbbells, and machine-based exercises. The studies did not incorporate any additional power-based exercises such as medicine balls throw, jumps, sprints etc.

Christou et al. (56) investigated the impact of a 16-week resistance training program combined with soccer practice on adolescent male soccer players. The group that participated in both strength and soccer training showed significantly greater improvements in leg press and bench press strength compared to the soccer-only and control groups. Additionally, the strength-soccer group experienced notable gains in jump height and sprint speed, while the other groups did not show significant changes. This suggests that combining resistance training with soccer enhances strength, jump performance, and speed more effectively than soccer training alone.

Gorostiaga et al. (91) examined the effects of a 6-week resistance training program on adolescent handball players. The strength training group saw significant increases in leg and upper body strength, particularly in leg extensors and flexors, while the handball-only group showed modest improvements in vertical jump height. The findings indicate that while resistance training boosts strength, it did not lead to improvements in explosive leg power, as reflected in the vertical jump results.

Ignjatovic et al. (88) explored the effects of a 12-week resistance training program on young basketball players. The experimental group demonstrated significant improvements in muscle strength, particularly in the bench press, along with gains in muscle power measured at various intensities. These improvements were greater than those observed in the control group, indicating the effectiveness of resistance training in enhancing both strength and power in young athletes.

Ruivo et al. (100) evaluated the effects of a 16-week strength training program on muscular endurance, strength, and body composition in adolescent soccer players. The study, which did not include a control group, found significant improvements in push-up repetitions and bench press strength. These results suggest that a structured strength training program, in addition to regular soccer practice, can effectively enhance overall fitness and performance in adolescent athletes. Keiner et al. (66) conducted a study to evaluate the long-term effects of strength training on change-ofdirection (COD) sprint performance in youth soccer players. Over two years, 112 athletes aged 13-18 were divided into a strength training group (STG), which combined strength training with regular soccer practice, and a control group (CG) that participated only in soccer training. The study found that the STG showed significantly greater improvements in COD performance compared to the CG. Furthermore, the STG demonstrated notable improvements in 1-repetition maximum (1RM) strength in both the back and front squats, with moderate to high correlations between strength levels and COD performance. The results suggest that long-term strength training positively affects COD abilities, and implementing such programs from an early age is recommended to enhance athletic performance in youth soccer players. Zouita et al. (104) conducted a study to investigate the effects of strength training on physical fitness and injury rates in elite young soccer players over one season. Fifty-two male soccer players aged 13-14 were divided into an experimental group (EG) and a control group (CG). The EG underwent a 12-week strength training program, including two to three sessions per week, in addition to their regular soccer training. Results showed that the EG demonstrated significant improvements in sprint performance, agility, and jumping ability compared to the CG. Furthermore, the injury rate was substantially lower in the EG, with only four injuries recorded, as opposed to 13 in the CG. The study concluded that strength training effectively improves performance and reduces injury risk in elite adolescent soccer players. Sander et al. (65) conducted a study to examine the effects of a two-year strength training programme on power performance in elite youth football players. The study involved 134 players from two youth training centres, divided into a strength training group (STG) and a control group (CG). The STG participated in a periodised strength training programme, including front and back squats, in addition to regular football training, while the CG only took part in football training. The results showed that the STG experienced significantly greater improvements in 1RM strength for both front and back squats, as well as enhanced sprint performance over 30 metres, compared to the CG. The study concluded that long-term strength training positively influences power performance, including sprint speed, in youth football players, suggesting that strength training should be integrated into football training programmes for optimal athletic development

Table 3.2 A summary of the studies utilising a Traditional Resistance training program

Author	**Sport**	**Participants**	**Independent variable and condition**
Christou *et al* (56)	Football/Soccer	**TG1:** n=9 13.8± 0.4yrs **TG2:** n=9 13.5 ± 0.9yrs **Control** n= 8 13.3 ± 0.7yrs	Strength training (**TG1**) vs Soccer training (**TG2**)
Gorostiaga et al (91)	Handball	**TG 1:** *n*= 9 15.1 ±0.7yrs. **TG 2:** *n*= 9 15.1 ±0.5yrs. **CG:** *n*= 4 14.8 ±0.4yrs.	Resistance training (**TG1**) Vs Handball training only (**TG2**)
Ignajtovic (88)	Basketball	**TG:** *n*= 23 15.7 □0.8yrs. **CG:** *n*= 23 15.9 □0.7yrs	Resistance training (**TG**) Vs Basketball training only (**CG**)
Keiner et al (66)	Football/Soccer	**STG 2:** *n*= 30 < 17yrs **CG 2:** *n*= 21 < 17yrs **STG 3:** *n*= 18 < 15yrs **CG 3:** *n*= 17 < 15yrs	Strength training (**STG**) Vs Control (**CG**)
Ruivo (100)	Football/Soccer	**TG:** *n*= 28 16.2 □1.1yrs	Resistance training (**TG**)
Sander et al (65)	Football/Soccer	**TG 1:** *n*= 13 17 yrs **CG 1:** *n*= 15 17 yrs **TG 2:** *n*= 30 15 yrs **CG 2:** *n*= 25 15yrs **TG 3:** *n*= 18 13 yrs **CG 3:** *n*= 33 13 yrs	Resistance training (**TG 1, 2, 3**) Vs Soccer training only (**CG 1, 2, 3**)
Zouita (104)	Football/Soccer	**TG:** *n*= 26 13-14 yrs **CG:** *n*= 26 13-14 yrs	Resistance training (**TG**) Vs Soccer training only (**CG**)

Abbreviations: TG= training group, **CG**= control group

Complex Training

Table 3.3 shows four studies had a training group which utilised complex training or training which was a combination of resistance, plyometric and/or sprint training (59, 60, 85, 89).The studies utilised a combination of exercises such as medicine ball throws, box jumps, bounds and sprints, which are all classified as explosive or ballistic power-based exercises.

Chatzinikolaou et al. (85) explored the effects of a 5-week complex training program, dividing participants into an experimental group (EG) and a control group (CG). The EG demonstrated significant improvements in strength and experienced smaller declines in endurance and repeated sprint ability, whereas the CG showed notable performance reductions.

Ferrete et al. (89) examined the impact of a 26-week combined strength and highintensity training program on young soccer players. Participants were divided into an experimental group (S) and a control group (C). The S group showed improvements in countermovement jump, endurance, and flexibility, while the C group experienced declines in these areas. A negative correlation was observed between sprint time and both jump and endurance performance in the S group.

Rodríguez-Rosell et al. (59) investigated the effects of a 6-week low-load, low-volume resistance training program combined with plyometrics in young soccer players. The strength training group (STG) improved in sprint performance, jump height, and estimated one-repetition maximum, while the control group showed no significant improvements. Wong et al. (60) conducted a study to investigate the effects of a 12week on-field combined strength and power training (CSPT) program on physical performance among under-14 soccer players. The study involved 51 male soccer players divided into experimental (n=28) and control (n=23) groups. The results indicated significant improvements in the experimental group in various performance measures, including vertical jump height, ball-shooting speed, sprint times (10m and 30m), and Yo-Yo Intermittent Endurance Run (YYIER) performance.

Table 3.3 A summary of the studies investigating Complex Training

Abbreviations: TG= training group, **CG**= control group

Author	**Sport**	**Participants**	**Independent variable and condition**
Chatzinikolau et al (85)	Football/Soccer	**TG** n= 12 14.3 ± 0.7yrs, **CG** n= 10 14.1 ± 0.6yrs,	Complex training (**TG**) Vs Control (**CG**)
Ferrete et al (89)	Football / Soccer	TG: n = 11 9.32 ± 0.25yrs CG *n*= 13 8.26 ± 0.33yrs	Strength training + plyometric + sprint training (**TG)** Vs Control (**CG**)
Rodriguez Rosell (59)	Football/Soccer	**TG:** *n*= 15 12.7 □0.5yrs **CG:** *n*= 15 12.8 □0.5yrs	Resistance training + plyometric training (**TG**) Vs Control (**CG**)
Wong (60)	Football/Soccer	**TG:** *n*= 28 13.5 □0.7yrs **CG:** *n*= 23 13.2 □0.6yrs	Resistance training + power training (**TG**) Vs Control (**CG**)

Specialised Resistance Training

Table 3.4 shows four studies that investigated the effects of specific types of resistance training methods on performance (87, 98, 99, 101). Studies in this category aimed to investigate the effects of a specific type or style of resistance training. For example, Ignjatovic et al. (87) focused on the effects of medicine ball training, incorporating various exercises aimed at enhancing upper-body strength and power, such as shotput throws, overhead throws, and side throws. The study highlighted significant improvements in medicine ball throw performance and gains in upper-body strength, particularly in the bench press and shoulder press.

Pangoulis et al. (99) examined the effects of an integrated neuromuscular training program, which combined resistance, plyometric, and balance training. The program included a variety of bodyweight exercises, medicine balls, and stability equipment like Bosu balls and rocker boards. The study found notable improvements in sprint times, squat strength, jump performance, and change of direction abilities.

Saeterbakken et al. (101) investigated a sling exercise training program focused on core stability and the lumbopelvic-hip complex. The exercises challenged balance and stability, resulting in enhanced neuromuscular coordination. The experimental group showed an increase in maximal throwing velocity, while the control group showed no significant change.

Negra et al. (98) explored high-velocity resistance training, with a focus on performing barbell half squats as quickly as possible. The program led to significant improvements in squat jump, standing long jump, sprint performance, and change of direction tests, while the control group saw no notable changes.

Table 3.4 A summary of studies investigating specialised Resistance Training methods

Author	Sport	Participants	Independent variable and condition
Ignajtovic (87)	Handball	**TG:** *n*= 11 **CG:** *n*= 10 16.9 □1.2yrs	Medicine ball training (**TG**) Vs Handball only training (**CG**)
Negra et al (98)	Football/Soccer	**TG:** *n*= 13 12.80 □0.25yrs **CG:** *n*= 11 12.74 □0.26yrs	High velocity resistance training (**TG**) Vs Control group (**CG**)
Pangoulis et al (99)	Football/Soccer	**TG:** *n*= 14 11.2 □0.5yrs **CG:** *n*= 14 11.4 □0.57yrs	Integrative neuromuscular strength training (**TG**) Vs Control group (**CG**)
Saeterbakken (101)	Handball	**TG:** *n*= 14 16.6 □3.1yrs **CG:** *n*= 10 16.5 □3.9yrs	Core strength training (**TG**) Vs Control group (**CG**)

Abbreviations: TG= training group, **CG**= control group

Exercise Selection

Table 3.5 shows four studies which focused on the comparison of a specific exercise. Three studies focused on the influence of force vectors by comparing two different exercises Back squat (vertical vector) and Hip thrust (horizontal vector) (82, 90, 97). Milar et al (97) found that both hip thrust and back squat exercises improved strength, sprinting, jumping, and kicking performance in female soccer players. But found no significant difference in performance when comparing both exercises. GonzalezGarcia (90) found the group performing hip thrusts had greater improvements in short sprint speed and the back squat group had greater improvements in count movement jump height. Abade et al. (82) found comparable improvements in vector-specific performance, with hip thrusts leading to greater gains in horizontal vector tasks like sprints and horizontal jumps, while back squats showed better results in vertical vector tasks such as vertical jumps. Ferley (84) had participants perform resistance training involving various leg exercises, along with plyometric sessions. The study compared two groups based on different treadmill training interventions: one using an incline (INC) and the other on a level surface (LEV). The results indicated that the INC group showed greater improvements in speed, agility, and power.

Table 3.5 A summary of studies comparing effects of different exercises

Author	Sport	Participants	Independent variable and condition
Abade et al (82)	Football/Soccer	**TG1**: *n*= 8 **TG2:** *n*= 8 **CG:** n= 8 16.56 ± 0.56yrs	Vertical training (back squat) Vs Horizontal training (Hip thrust)
Ferley et al (84)	Football/Soccer	**TG1**: Male n= 8 16.4 ± 1.1yrs Female n= 9 15.1 ± 1.1yrs **TG2**: Male n = 8 15.4 ± 0.9yrs Female n = 6 14.8 ± 1.1yrs, **CG:** Male n = 8 16.4 ± 1.5yrs Female n = 7 15.6 ± 0.5yrs	Incline treadmill sprints + strength + plyometric training (**TG1**) Vs Level treadmill sprints + strength + plyometric training (**TG2**)
Gonzalez-Garcia et al (90)	Football/Soccer	*n*= 24 16.82 ± 1.56yrs **TG1:** n= 8 **TG2:** n= 8 **CG:** *n* = 8	Hip thrust (**TG1**) Vs Back Squat (**TG2**)
Millar et al (97)	Football/Soccer	**TG1:** *n*= 6 15.7 ± 0.8yrs **TG2:** *n*= 8 15.3 ± 0.7yrs	Back squat + resistance training (**TG 1**) Vs Hip thrust + resistance training (**TG 2**)

Abbreviations: TG= training group, **CG**= control group

Effects of Training Frequency

Table 3.6 shows the only study to compare the effects of different resistance training frequencies. Cavaco et al. (83) examined the effects of complex training (CXT) on agility, sprinting, and the efficiency of crossing and shooting in youth soccer players. Sixteen participants were divided into three groups: one weekly CXT session (GCT1), two weekly CXT sessions (GCT2), and a control group (CG). While both experimental groups demonstrated improvements in sprinting and agility, these were not statistically significant compared to the control group. However, shooting efficiency improved significantly in the CXT groups, indicating that CXT can effectively enhance shooting skills in youth soccer players.

Table 3.6 A summary of studies investigating Resistance Training Frequency

Author	**Sport**	**Participants**	**Independent variable and condition**
Cavaco *et al* (83)	Football/Soccer	**TG 1:** *n*= 5 13.80 ± 0.45yrs. **TG 2:** *n*= 5 14.20 ± 0.45 yrs. **CG:** *n*= 6 14.20 ± 0.84yrs.	Complex training 1x per week (**TG 1**) Vs Complex training 2x per week (**TG 2**)

Abbreviations: TG= training group, **CG**= control group

Effects of Periodisation Models

Table 3.7 shows three studies which investigated the effects of different periodisation models (86, 92, 93). The periodisation models investigated were Linear periodisation (LP) and daily undulating periodisation (DUP). LP typically involves gradually increasing the intensity and decreasing the volume of training over time. This approach typically progresses through several phases including preparatory, hypertrophy, strength, power and peak/tapering.

DUP model involves frequently changing the training variables, such as intensity and volume, daily. Rather than following a linear progression, DUP alternates between different training focuses within the same week. Harries et al (93) took 16 male adolescent rugby players aged 15-18 years, divided into two groups LP (n=8) and DUP (n=8), The training lasted for 12 weeks, consisting of two supervised sessions per week. Both periodisation models effectively increased lower-body strength and improved sprinting performance, with daily undulating resistance training showing slightly superior results for sprinting improvements. Harries et al (92) compared the effectiveness of LP and DUP resistance training models on lower and upper body strength. 26 sub-elite adolescent rugby were divided into three groups: LP, DUP, and a control group. Both models were effective for improving upper and lower body maximal strength. No significant differences were found between the two models. Ramalingham et al (86) aimed to compare the effectiveness of LP and DUP in enhancing muscular endurance. Twenty male adolescent hockey players were randomly assigned to either the LP or DUP training group. Both the LP and DUP groups showed significant improvements in muscular endurance for the back squat and bench press. There were no significant differences in the overall improvements between the two groups

Table 3.7 A summary of studies comparing periodisation models

Author	**Sport**	**Participants**	**Independent variable and condition**
Harries et al (92)	Rugby union	**TG 1:** *n*= 8 16.8 1.0yrs **TG 2:** *n*= 8 17.0 1.1yrs **CG:** *n*= 10 15.5 1.0yrs	Linear periodisation (**TG 1**) vs Undulating periodisation (**TG 2**)
Harries et al (93)	Rugby union	**TG 1:** *n*= 8 16.8 1.0yrs **TG 2:** *n*= 8 17.0 1.1yrs **CG:** *n*= 10 15.5 1.0yrs	Linear periodisation (**TG 1**) vs Undulating periodisation (**TG 2**)
Ramalingham (86)	Field hockey	**TG 1:** *n*= 10 16.6 0.52yrs. **TG 2:** *n*= 10 16.5 0.53yrs	Linear periodisation (**TG 1**) Vs Daily undulating periodisation (**TG 2**)

Abbreviations: TG= training group, **CG**= control group

Effects of Training Sequence

Table 3.8 shows two studies which investigated the effects of training sequencing on performance measures (94, 95). Makhlouf et al. (95) investigated the effects of different sequences of concurrent strength and endurance training on performance variables in young male soccer players. The study involved 57 elite-level youth soccer players, divided into a control group (CG) and three experimental groups: strength before endurance (SE), endurance before strength (ES), and alternate days of strength and endurance (ASE). The study reported that combining strength and endurance training within a single session is more effective than training them on separate days. It also reported there were no notable differences in performance outcomes based on whether strength or endurance was performed first within a session (SE vs. ES). Both groups saw similar improvements in strength and endurance. Johnson et al (94) aimed to determine whether the exercise sequences in a resistance training program affects strength, speed, and agility outcomes in high school football players. 39 high school football players from two teams were divided into two groups. One group performed the traditional sequence (TRAD), while the other performed the circuit sequence (CIRC). Both groups completed an identical sixweek resistance training program, with the only difference being the sequence of exercises. The exercises included multi-joint lifts like hang cleans, bench presses, and squats. The study concluded that both traditional and circuit exercise sequences produce similar strength gains in high school football players. While there was a significant improvement in hang clean performance in the traditional group, overall results indicated that either sequence can be effectively used in resistance training programs.

Table 3.8 A summary of studies investigating Training Sequence

Author	**Sport**	**Participants**	**Independent variable and condition**
Johnson et al (94)	American football	**TG 1:** *n*= 16 16.0 ±2yrs **TG 2:** *n*= 23 16.0 ±1yrs	Circuit style training (**TG 1**) Vs Traditional sequence training (**TG 2**)
Makhlouf et al (95)	Football/Soccer	**TG 1:** *n*= 14 **TG 2:** *n*= 15 **TG 3:** *n*= 14 **CG:** *n*= 14 13.7 ± 0.5yrs	Soccer training only (**TG 1**) Vs Strength/Endurance (**TG 2**) Vs Endurance/Strength (**TG 3**)

Abbreviations: TG= training group, **CG**= control group

Supervised vs Unsupervised Training

Table 3.9 shows the only study to compare supervised vs unsupervised training. Smart and Gill (57) investigated the effects of a supervised versus an unsupervised offseason conditioning program on adolescent rugby union players' physical characteristics. The study involved 44 players (mean age 15.3 years) who completed a 15-week program, with the supervised group receiving guidance from a strength and conditioning coach and the unsupervised group training independently. The supervised group showed significantly greater improvements in strength measures, including chin-ups, bench press, and box squat.

Table 3.9 A summary of studies comparing supervised and unsupervised training

Author	Sport	Participants	Independent variable and condition
Smart & Gill (57)	Rugby union	**TG 1:** *n*= 27 15.4 ±1.4yrs **TG 2:** *n*= 17 15.1 ±1.3yrs	Supervised resistance training (**TG 1**) Vs Unsupervised resistance training (**TG 2**)

Abbreviations: TG= training group

Resistance training vs Plyometric training

Table 3.10 shows the only study to compare resistance training and plyometric training. McKinlay et al. (96) compared the effects of an 8-week resistance training (RT) program and plyometric training on muscle strength, explosiveness, and jump performance in young male soccer players aged 11-13. The study involved 41 participants divided into 3 groups resistance training group, plyometric training group, and a control group. Both training groups showed significant improvements in jump performance compared to the control group. Plyometric training resulted in a greater increase in squat jump performance compared to resistance training.

Table 3.10 A summary of studies comparing Resistance Training and Plyometric Training

Author	Sport	Participants	Independent variable and condition
McKinlay et al (96)	Football/Soccer	**TG 1**: *n*= 14 12.5 0.7yrs **TG 2**: *n*= 13 12.6 0.7yrs **CG**: *n*= 14 12.5 0.3yrs	Resistance training (**TG 1**) vs Plyometric training (**TG 2**)

Abbreviations: TG= training group, **CG**= control group

Effects of Detraining/ De-loading

Table 3.11 shows two studies which investigated the effects of detraining or de-loading periods on measures of performance. In periodised training plans, a detraining period refers to a planned phase where the intensity and volume of training are significantly reduced, or training is temporarily ceased altogether. Vassilis et al. (103) found that a 4-week detraining period followed by a 4-week strength training program did not significantly affect lower limb strength or anthropometric characteristics in elite youth soccer players, suggesting better maintenance of training benefits in youth due to neural adaptations. Santos & Janeira (102) demonstrated that both detraining and reduced training effectively maintain explosive strength in adolescent male basketball players, with regular basketball practice alone being sufficient to sustain previously gained strength improvements

Table 3.11 A summary of studies investigating the effects of de-training and/or de-loading

Author (year)	Sport	Participants	Independent variable and condition
Santos & Janeira (102)	Basketball	**TG1:** *n*= 7 1415yrs **TG2:** *n*= 8 14-15yrs	Detraining group (**TG 1**) Vs Reduced training group (**TG 2**)
Vassilis (103)	Football/Soccer	**TG:** *n*= 13 15.1 0.3yrs	Detraining group (**TG**)

Abbreviations: TG= training group

3.10 DISCUSSION

One of the objectives of this review was to evaluate whether the literature has explored key training variables and to determine if the findings support the guidelines established by the NSCA and UKSCA. The results of this review show that evidence and research regarding the specific training variables necessary for an effective resistance training program are lacking. The following section will focus on studies that have specifically examined the training variables outlined in these organisational guidelines

Choice and Order of Exercise

The UKSCA recommends introducing free weights once basic bodyweight exercises are mastered, while the NSCA suggests multi-joint movements can be introduced early with light loads. Both stress the importance of controlled movement and advise full-body workouts, starting with large muscle groups and multi-joint exercises before moving to smaller, single-joint movements. More challenging exercises, such as weightlifting or plyometrics, should be done early in the session to avoid fatigue and maintain good technique (1, 33). However, there are no specific recommendations made by wither organisation, regarding order or choice of exercise.

According to the current review of literature three studies have investigated the manipulation of exercise selection within resistance training interventions. However, these studies often narrow their scope to comparisons between specific exercises, notably the back squat versus the hip thrust (82, 90, 97). While these comparisons are valuable, they leave unanswered questions regarding the broader impacts of varied exercise selection within a full training session.

These studies aimed to determine which exercise more effectively enhances lower body strength and power. The studies found that while each exercise has its merits, the back squat and hip thrust target different aspects of lower body musculature and mechanics, suggesting that each can be beneficial depending on the specific performance goals of the athlete.

While these studies provide valuable insights, their focus on single exercise comparisons limits their applicability. The exclusive examination of back squats versus hip thrusts does not address how a comprehensive training session incorporating multiple exercises affects overall training outcomes. The complexity of a full resistance training session, which typically includes a variety of exercises targeting different muscle groups and movement patterns, remains underexplored. This is significant as it does not reflect the multifaceted nature of practical training programs used by strength and conditioning professionals. None of the reviewed studies extensively investigate how a full training session comprising various exercises impacts performance outcomes. Understanding the synergistic effects of multiple exercises within a training program is crucial for optimising training protocols and achieving balanced athletic development. There were a further two studies which investigated order or sequence of exercise, Makhlouf et al. (95) was the sole study to specifically investigate the sequencing of resistance training in conjunction with technical sports training. The study examined the effects of two different training sequences: strength training followed by endurance training and endurance training followed by strength training. Johnson et al. (94) examined the impact of exercise order by comparing two training methods: a traditional approach, where all sets of one exercise are completed before moving to the next, and a circuit style, where one set of each exercise is performed sequentially before repeating the circuit until all sets are completed. The study found that both training methods produced similar strength gains in high school football players, with the traditional method having a slight advantage for the hang clean. However, neither method improved speed or agility. Both studies do investigate the order or sequence of training and exercise. Johnson et al (94) does This study is particularly valuable for strength and conditioning coaches who often face time constraints when designing training programs. The findings suggest that circuit-style training can offer an efficient alternative by reducing recovery times between exercises without compromising strength gains. By performing sets sequentially and then repeating the circuit, coaches could make training time more efficient while still achieving comparable improvements in strength, as observed with the traditional training method. This approach can be especially useful in environments where equipment availability and session duration are limited, allowing for more efficient use of time while maintaining the effectiveness of the resistance training program.

Makhlouf et al. (95) focused on long-term performance outcomes; it did not address the potential short-term effects of concurrent training sequencing. Understanding how the order of resistance and technical training sessions affects subsequent training sessions in the short term is crucial. For instance, performing a high-intensity resistance training session immediately before a technical training session might impair technical skill execution due to fatigue. Conversely, technical training performed before resistance training might affect the quality and intensity of the strength session. These short-term interactions could have significant implications for training planning and overall athletic development

Training Intensity and Volume

Both the UKSCA (33) and the NSCA (1) recommend a gradual progression of volume and intensity in youth resistance training. For volume, the UKSCA suggests starting with 1–2 sets of 6–12 repetitions, increasing to 2–4 sets as experience grows. Similarly, the NSCA advises beginning with 1–2 sets of 10–15 repetitions, progressing to 2–3 sets of 6–10 repetitions for more advanced individuals.

In terms of intensity, the UKSCA advocates starting with low-to-moderate loads (≤60% 1RM) and progressing to 80% 1RM for more experienced youth. The NSCA recommends starting with lighter loads (50-70% 1RM for strength, 30-60% 1RM for power), increasing to 70-85% 1RM as competency improves (1, 33). From the literature analysed in the study only x papers investigated load or volume changes as part of their intervention. Rodriguez-Rossell (59) investigated sessions of full squat exercises with a low load of 45-58% 1RM combined with jumps and sprints over a 6week preseason period. The paper does not directly compare the training load or volume with an alternative load, volume, or another experimental group performing a standard load or volume. Although the authors describe the volume as "low," the selected volume (2-3 sets of 4-8 repetitions) aligns with the guidelines set by position statements on youth resistance training. Furthermore, only 3 out of the 12 sessions in the program utilized the lower volume of four repetitions, which raises questions about the consistency of the "low volume" description.

Training Frequency

Current position statements from the NSCA (1) and UKSCA (33), recommend 2-3 resistance training sessions per week as optimal for developing strength in youth athletes. These guidelines suggest that while one session per week can help maintain strength levels, it is insufficient for significant strength gains. Despite these recommendations, empirical evidence directly comparing the effects of different frequencies in resistance training alone is sparse

Only one paper (83), manipulated and directly compared training frequency. This study explored the effects of complex training sessions conducted once versus twice per week on the agility, sprinting ability, and shooting efficiency of youth soccer players. The study's complex training intervention, which combined resistance training, plyometrics, and sprint exercises, demonstrated significant improvements in performance outcomes with increased frequency. However, this raises the question of how frequency may alter the effectiveness traditional resistance training, which focuses solely on strength development without the added components of plyometrics and sprints.

Investigating the effects of training frequency on resistance training only is crucial. Understanding the impact of training frequency on resistance training is vital for several reasons. First, youth athletes often have demanding schedules with multiple sports and academic commitments, making it essential to determine the most efficient training frequency for optimal results. Second, coaches and practitioners could benefit from evidence-based guidelines that specify how often youth athletes should engage in resistance training to maximise strength gains while preventing overtraining. Future research should aim to fill this gap by conducting studies that manipulate and compare different frequencies of resistance training sessions in youth athletes.

Rest Intervals

Both the NSCA (1) and UKSCA (33) recommend rest intervals of approximately 1 minute for most youth during moderate-intensity exercises but suggest increasing rest periods to 2–3 minutes as the intensity and complexity of exercises rise. Both organisations agree on the necessity of individualising rest intervals based on the specific needs of the young athlete and emphasise the importance of maintaining proper technique and avoiding excessive fatigue to reduce injury risk. The current review of literature did not find any studies which directly compared rest intervals in youth resistance training.

Repetition Velocity

Both the UKSCA (33) and NSCA (1) share a similar philosophy that youth training should begin with moderate velocities for technical development and progress to higher velocities for power and neuromuscular adaptations. The UKSCA emphasises the intention to move explosively, even when the actual movement speed might be limited by heavier loads, while the NSCA takes a broader approach, recommending different velocities across exercises to optimise training outcomes. However, neither organisation offers any specific guidelines on how repetition velocity should be measured or prescribed. The literature analysed in this review revealed that only one study investigated the effects of repetition velocity (98). The study took Twenty-four prepubertal male soccer players were divided into two groups: a control group (CG) that followed regular soccer training for 5 sessions per week, and an experimental group that replaced 2 soccer training sessions with 2 high-velocity resistance training (HVRT) sessions, combining 3 soccer and 2 HVRT sessions per week. The HVRT program involved exercises such as half-squats and core conditioning (e.g., abdominal and back extension exercises), using low-to-moderate loads (40-60% of 1 repetition maximum) performed at high movement velocities. This program lasted for 12 weeks with two HVRT sessions each week concluded that high velocity resistance training, when combined with regular soccer training, enhances maximal strength, jumping ability, sprint performance, and change of direction ability in prepubescent soccer players. While this study offers valuable insights into the benefits of HVRT for prepubescent soccer players, it is important to acknowledge several limitations. First, the study did not measure or quantify specific movement velocities during the exercises. Instead, participants were instructed to lift with the intent to move as quickly as possible, leaving uncertainty about the actual velocities achieved and the degree of consistency across participants.

Second, the study did not compare the effects of different velocities. Without comparing HVRT with training performed at moderate or slower speeds, the findings only indicate that high-velocity training may be effective, without establishing its relative efficacy compared to other velocity-based training methods. Finally, since no comparisons were made with other forms of resistance training, the study does not offer information on how HVRT compares in effectiveness to alternative training approaches. As a result, while the study shows that HVRT can improve strength, sprint, and jump performance, it does not provide clear guidance on the optimal velocity prescription or dosage for resistance training. This limits the ability to determine the best training method for youth athletes aiming to improve performance.

3.11 CONCLUSION

This literature review has highlighted there is a lack of evidence in the research on resistance training for youth athletes in team sports, particularly concerning key training variables outlined by the UKSCA and NSCA. While these organisations provide important guidelines, there is limited evidence that directly examines the manipulation of variables such as volume, load, frequency, and recovery in youth populations. Existing studies often fail to provide conclusive comparisons or control for influencing factors, making it difficult to draw definitive conclusions.

The complexity of resistance training, where multiple variables interact, makes it challenging to isolate the effects of any single factor. Adjustments to one variable, for example load, often require changes to others, such as repetitions and recovery, complicating research designs and limiting their applicability to real-world settings.

Practitioners rely on the UKSCA and NSCA guidelines to design effective training programmes, but current research does not fully validate these recommendations in practical contexts like youth sports academies. In such environments, youth athletes often contend with unique challenges, including limited time, developmental differences, and the competing demands of training and education. The research that does exist is often inconclusive or does not fully reflect the complexity of these practical settings, making it difficult to ascertain whether the recommended approaches produce the desired outcomes in everyday practice.

This review highlights the need for further investigation into all aspects of the guidelines, particularly the key training variables they emphasise. More rigorous and focused studies are necessary to assess the effectiveness of these recommendations, not only in controlled environments but also in the day-to-day context of sports academies. Until such research is conducted, practitioners may find it challenging to implement these guidelines with full confidence.

CHAPTER 4

Investigating the effects of 1 vs 2 sessions of resistance training per week in youth footballers: a preliminary study

4.1 ABSTRACT

Current guidelines recommend two to three weekly resistance training sessions to optimise strength gains in youth athletes. Previous research has yielded mixed results regarding the effects of training frequency across various performance measures. While some studies suggest greater strength improvements with increased training frequency, others report minimal differences. This study investigates the effects of once versus twice-weekly resistance training sessions on strength, power, and speed in youth footballers.

The participants consisted of 26 male youth footballers, aged 12–14 years, who were divided into two groups: one group trained once per week (RT1), and the other trained twice per week (RT2) over an 8-week period. Both groups were prescribed a wholebody resistance training routine alongside regular football training. Pre- and postintervention testing measured isometric mid-thigh pull (IMTP) for strength, countermovement jump (CMJ) for power, and 10 m and 20 m sprints for speed. Data were analysed using a repeated measures analysis of variance (ANOVA) to assess changes over time within and between groups.

Both groups demonstrated significant improvements in lower body strength, with RT2 showing greater gains in IMTP force ($F(1,19) = 8.254$, $p = .010$, $\eta p^2 = .303$) compared to RT1. However, no significant differences were observed between the groups in CMJ height ($F(1,19) = 0.285$, $p = .599$, $\eta p^2 = .015$), 10 m sprint speed ($F(1,19) = 0.319$, $p = .579$, $\eta p^2 = .017$), or 20 m sprint speed ($F(1,19) = 0.089$, $p = .769$, $\eta p^2 = .005$). This suggests that while increasing training frequency may lead to greater strength gains, it does not significantly affect power or sprint speed. Attendance variability, particularly in the RT2 group, limited the ability to fully assess the effects of training frequency on

all performance outcomes.

4.2 NTRODUCTION

The effectiveness of resistance training prescription relies heavily on the successful manipulation of several key variables, including, loading, sets, repetitions (240-243) and Frequency (244, 245). Each of these variables, when manipulated, can significantly influence the physiological and performance adaptations achieved (242). Training frequency, which typically refers to the number of resistance training sessions performed within a training week (1, 33), is a particularly interesting variable to consider. Research indicates that the optimal frequency needed may vary depending on the desired outcome, such as hypertrophy, strength, or power (241, 245, 246).

Position statements from the NSCA (1) UKSCA (33) and CSEP (34) recommend a frequency of two to three sessions per week. A meta-analysis conducted by Lesinski et al. (55) reported no significant difference for gains in muscular strength or measures of performance between training two or three times per week. Also suggesting one session per week may only be sufficient to maintain strength levels. Of the n=43 studies analysed by the authors, only three studies (218, 247, 248) utilised a single session of resistance per week protocol within their investigations. Therefore, the effectiveness of single sessions per week should be concluded with caution.

The study by Alves et al. (113) investigated the effects of complex and contrast training (CCT) on sprinting, vertical jump, and agility abilities in youth footballers. Two experimental groups were created: one group performed CCT once per week, and the other group trained twice per week, with a control group following only regular soccer training. The results showed that both groups improved in sprint performance and squat jump ability. However, there were no significant changes in countermovement jump or agility performance in either group. The study concluded that CCT is an effective method for increasing speed and muscle power in soccer players, though it may not significantly improve agility or vertical jump performance. The frequency of training did not have a notable effect on the overall results.

Cavaco et al. (83) investigated the short-term effects of complex training (CXT) on agility with the ball, speed, youth soccer players. Participants were divided into three groups: one group performed one weekly CXT session, another performed two weekly CXT sessions, and a control group did not engage in CXT. The study found no significant improvements in speed or agility performance and no significant differences between the one-session and two-session groups. This suggests that the frequency of training did not significantly impact these performance outcomes.

In terms of strength, Faigenbaum et al. (109) observed that chest press strength improved by 4% in the one-day-per-week group compared to 12% in the two-daysper-week group, and leg press strength improved by 14% in the one-day-per-week group compared to 25% in the two-days-per-week group. These findings suggest that more frequent training sessions lead to more significant strength gains, particularly for lower body exercises.

However, DeRenne et al. (112) found that improvements in strength were greater with one day per week of resistance training, showing a 6% increase in bench press and a 9.87% increase in pull-ups, compared to a 4.92% increase in bench press and a 4.75% decrease in pull-ups with two days per week. Both groups in this study exhibited a decrease in lower body strength, with group 1 showing a 1.29% decrease and group 2 a 0.55% decrease.

Across the studies, frequency of training, whether once or twice per week, has varying impacts depending on the type of performance measure being examined. For speed and agility, as seen in both Alves et al. (113) and Cavaco et al. (83), the frequency of training did not lead to significant differences in outcomes. In contrast, strength gains were more pronounced with increased frequency in the studies by Faigenbaum et al. (109), but DeRenne et al. (112) presented conflicting evidence. These mixed findings highlight that optimal training frequency may depend on the specific fitness component being targeted, with strength possibly benefiting more from higher frequencies, while speed and agility may require different approaches

The existing literature offers mixed insights on training frequency and strength development, but generally supports the guidelines that training twice per week is optimal for strength gains. Faigenbaum et al. (109) demonstrated that twice-weekly training led to more consistent and significant strength gains, especially for lower body exercises, aligning with guidelines that recommend more frequent training for optimal strength development.

Conversely, DeRenne et al. (112) found that some upper body exercises, such as the bench press and pull-ups, saw greater improvements with one day per week of resistance training. However, this study also confirmed that more frequent training was necessary for consistent lower body strength gains. In summary, while some variability exists, particularly for upper body exercises, the evidence supports the conclusion more frequent training, especially for lower body strength, results in greater gains. The present study aims to examine the effects of training frequency, defined as the number of resistance training sessions performed per week. However, it is important to acknowledge that frequency cannot be fully separated from training dose in this context. While efforts were made to standardise session content, it was not possible to match training volume and load precisely across participants. As a result, any increase in frequency may also lead to an increase in total training dose, which could influence the outcomes observed.

This limitation is consistent with previous research in youth resistance training (218, 244, 247, 248), where higher frequency groups typically performed greater total training volume. Despite this, the term "training frequency" remains widely used in both academic and applied settings. While not entirely precise, it reflects how coaches and practitioners commonly describe and prescribe training.

The training week of a professional athlete can already be congested with sportspecific training sessions, midweek and weekend fixtures/competitions, and planned recovery sessions. Striking the right balance between providing an effective resistance training stimulus and avoiding overtraining is crucial. This challenge is even more pronounced in youth and academy-level sports, where the available time for training is further limited (127). For instance, in academy football, players typically have two or three comprehensive training sessions each week, usually scheduled after school hours and lasting between resistance training two and three hours. These sessions primarily focus on sport-specific skills, directed by technical coaching staff, despite resistance training is recognised for its importance in enhancing performance among youth athletes, (1, 33) technical training is given precedence.

Salter (71) highlighted concerns over the lack of structured strength and conditioning within youth football. The author comments that up to 97% of training time in some youth academies can be skills-based. Salter (71) further suggests that several barriers ultimately reduce the influence of strength and conditioning practices within football academies, such as a lack of understanding and knowledge among coaching staff, and persistent myths related to resistance training in youth and adolescents (e.g., it being dangerous, negatively affecting growth, or leading to injuries and fatigue). Additionally, available training time is a significant barrier. Younger players in academies often do not have the same amount of training time during the week as professional adults. Obstacles such as school commitments, travel arrangements, and reliance on parents limit the amount of training that can be achieved within a week.

Considering the practical difficulties highlighted earlier in the thesis, identifying a 'minimally effective dose' of training frequency would be highly beneficial. The present study reflects the realities of academy football, where decisions regarding training frequency are often influenced by limited time, fixture schedules, and logistical constraints. Although frequency is the primary variable of interest, accompanying changes in training dose must also be considered, as both factors may contribute to performance outcomes. Nevertheless, examining training frequency in this context remains important, as it reflects the decisions coaches are required to make and provides meaningful insight into how variations in weekly resistance training exposure may impact athlete development in applied settings. The primary aim of the current study is to compare the effects of once weekly vs twice weekly resistance training sessions on measures of strength, power and speed in youth footballers.

4.3 METHODS

Participants

Male academy football players aged were recruited to participate in this study. An u13s (n= 13). An u14s team (n= 13) Each participant had regularly engaged in resistance training for ≤ 6 months and were familiar with the exercises conducted in the resistance training sessions. Participant characteristics are shown in Table 4.1. Participants were given full details of the study procedures and informed of the risks and benefits of the study before any data collection. Each participant completed a physical activity readiness questionnaire (PARQ). Participants provided personal and parental, or guardian written informed consent before participation. All participants were free from injury and deemed eligible for participation by their club's medical staff. Ethical approval was granted by University of Essex. Maturity offset was calculated using the Moore et al. (57) simplified regression equation: maturity offset = –7.999994 + (0.0036124 × [Age × Height]), which provides an estimate of years from peak height velocity (PHV). Based on the resulting offset values, participants were classified as pre-, circa-, or post-PHV. Group 1 had a mean maturity offset of –0.61 ± 0.33 years, while Group 2 had a mean offset of +0.05 ± 0.44 years.

Table 4.1 Participant characteristics

	RT1	**RT2**
N	13	13
Age (years)	13.0 ± 0.23	13.8 ± 0.23
Height (cm)	156.7 ± 7.32	160.8 ± 7.41
Weight (kg)	54.1 ± 7.43	54.6 ± 6.64
Maturity Offset	-0.61 ± 0.33	0.05 ± 0.44

Procedure

The resistance training intervention took place over and 8-week period during the competitive phase of the season.

The under 13s team (RT1) were assigned one whole-body resistance training program (Routine A) and trained once per week. The under 14s team (RT2) and were assigned two whole body resistance training programs (Routine A and B) and trained twice per week, full details of Routine A and B are shown in Table 3.3. Both teams performed Routine A on a Tuesday at the same time. RT2 performed Routine B on a Thursday. Resistance training took place either before or after football training, authors had no control over times of football training. Both teams maintained their regular schedule of football training of two sessions per week

Testing of isometric mid-thigh pull, countermovement jump and 10 m and 20 m sprints took place before and after the 8-week training intervention.

All testing was conducted on the same day in the following sequence: the 10 m and 20 m sprints were assessed first, followed by the counter movement jumps After a 60 min rest period, the isometric mid-thigh pull was measured.

Lower Body Muscular Strength

High levels of muscular force are essential for actions such as sprinting, jumping, tackling, and kicking, all of which are critical to overall performance in the sport of football (138, 158). The Isometric Mid-Thigh Pull (IMTP) test is recognised as a valid and reliable method for evaluating lower limb muscular force (249). Isometric mid-thigh pull (IMTP) was performed on a portable cable pull apparatus (Takei A5002, Fitness Monitors, Wrexham, United Kingdom). The handle was positioned midway up the thigh. Participants were then instructed to pull as hard as possible and drive their feet into the floor until they were instructed to stop, each attempt lasted 5s. Participants completed a total of three attempts each, with a 2 min recovery between each attempt (191). The units measured by the apparatus was kilogram-force (kgf). The largest value obtained from the 3 attempts was used for analysis.

Lower Body Muscular Power

Lower body muscular power and jumping ability are key factors influencing performance in football (158, 167). A valid and reliable method for assessing lower body muscular power is through Countermovement Jump (CMJ) testing (167, 250). Countermovement jump (CMJ) measured using a Just Jump (Probotics, Alabama, USA) jump mat. CMJ was performed with hands on hips and straight legs during the flight phase. Each participant performed 3 jumps, with a recovery of 60s between jumps. Flight time was then converted into jump height using the formula; $h = t^2g/8$, where h is jump height (m), t is flight time (s) and g is the gravity acceleration (9.81 m/s^2) (251, 252). The highest value for jump height from each participant was then recorded for analysis. In addition to raw countermovement jump (CMJ) height, peak muscle power (PMP) was also estimated to provide a more comprehensive assessment of lower-limb explosive capacity. PMP was calculated using a validated predictive equation developed by Gomez-Bruton et al. (253), which accounts for both vertical jump height and body mass. This equation is specifically designed for youth populations and has demonstrated strong predictive accuracy:

Power (W)=54.2×Jump Height (cm)+34.4×Body Mass (kg)−1,520.4Power (W)=54.2× Jump Height (cm)+34.4×Body Mass (kg)−1,520.4

Peak power values were computed individually using each participant's recorded CMJ height and body mass for both pre- and post-tests. The difference scores (Post – Pre) were then used to evaluate absolute reliability, consistent with procedures for other performance metrics.

Linear Sprint Speed

Acceleration and short distance sprint speed are important physiological factors in football (158, 254). A valid and reliable method for assessing linear speed and acceleration is by measuring 10-meter and 20-meter sprint times (119, 254). Testing took place on an indoor artificial (3G) surface, participants were instructed to wear football boots to ensure adequate traction. Sprint time was measured using timing gates (Brower Timing Systems, Utah, USA). Timing gates were set at 10 m and 20 m intervals to allow measurements for each distance to be taken from one sprint effort. Participants began from a standing start. Each participant completed three total sprint efforts, with a 120s recovery period between each effort. The shortest time recorded was then converted from time (s) to speed (m/s) to be used for analysis.

Resistance Training Intervention

Two different resistance training routines (Routine A and B) were constructed based upon training recommendations by the UKSCA (33) NSCA (1) CSEP (34). RT 1 and RT 2 both performed routine A once per week, RT2 also performed routine B once per week in addition, details of resistance training prescribed to each group are shown in tabl3 4.2. Participants performed each exercise with a self-selected load. All sessions were supervised by at least two qualified strength and conditioning coaches. A register of participant attendance to each resistance training session was taken throughout the intervention, full details of session attendance are shown in Table 4.

Table 4.2 Details of the resistance training routines

	Routine A	
Exercise	**Sets & Repetitions**	**Recovery (s)**
Back Squats	3 sets 8 repetitions	90 s
Press ups	3 sets 8 repetitions	90 s
Romanian Deadlift	3 sets 8 repetitions	90 s
Dumbbell rows	3 sets 8 repetitions e/a	90 s
	Routine B	
Exercise	**Sets & Repetitions**	**Recovery (s)**
Hex bar Deadlift	3 sets 8 repetitions	90 s
Pull ups	3 sets 8 repetitions	90 s
Split squats	3 sets 8 repetitions e/l	90 s
Dumbbell Shoulder press	3 sets 8 repetitions	90 s

Abbreviations: e/a = each arm, **e/l** = each leg

4.4 DATA TREATMENT

The aim of this study was to compare the effects of once versus twice-weekly resistance training sessions on strength, power and speed in youth academy footballers.

To achieve this, pre- and post-intervention measures were compared across two groups: a once-weekly training group (RT1), a twice-weekly training group (RT2).

The independent variable in this study was training frequency, which had two conditions, Condition 1 where participants were prescribed resistance training once per week, and Condition 2 where participants were prescribed resistance training twice per week. The dependent variables were the pre and post outcomes of Force, power and sprint speed.

The differences in mean values for all dependent variables across the two time points and between the different groups were analysed using a repeated measures analysis of variance (ANOVA). The main effect (Time) can determine whether there are any statistically significant differences between the means of repeated measurements within the same participants (i.e. pre-training vs. post-training) introducing group as a between-subjects factor and interpreting the size and significance of the time x group interaction effect can determine whether there are differences in response over time between independent treatment groups.

For each outcome (dependent variable) the ANOVA model included time as the withinsubjects factor with two levels (pre-training and post-training). Group was included as the between-subjects factor (two levels once-weekly or twice-weekly resistance training). We calculated the main effect of time to assess whether there was a significant difference in the outcome from pre-training to post-training. Where there was a significant main effect for time, the time x group interaction effect was calculated to determine whether the change from pre-training to post-training differed significantly between the groups.

4.5 RESULTS

Force

Figure 4.1 shows the mean pre and post training values. The main effect for time was significant, showing force increased significantly from pre-test to post-test, ($F_{(1,19)}$ = 145.50, P = <.001). There was a significant time x group interaction effect, ($F_{(1,19)}$ = 8.254, P = .010, ηp^2=.303), suggesting that RT2 experienced a significantly greater improvement in force compared to the RT1. Table 4.3 shows the mean difference and percentage change from pre and post values.

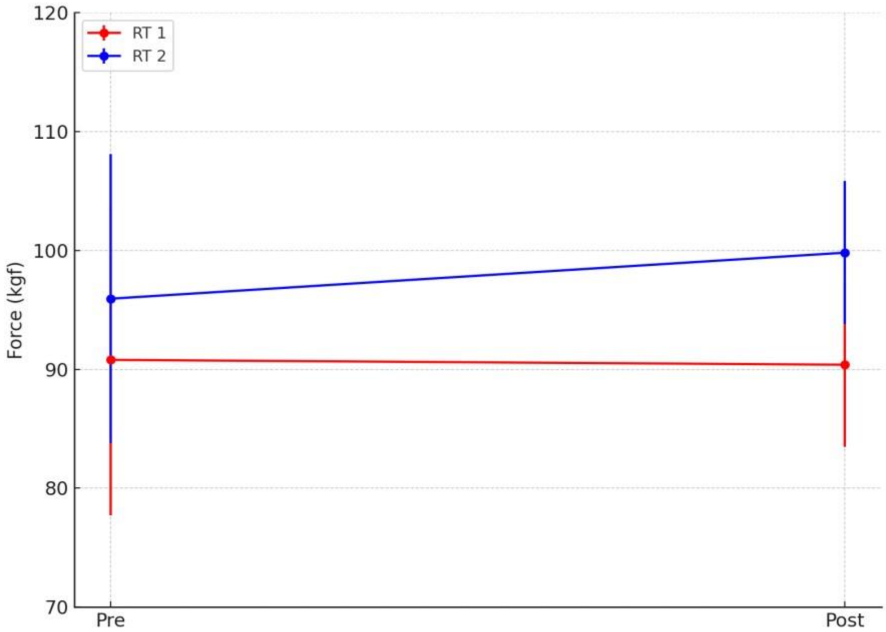

Figure 4.1 Mean Force (kgf) for RT 1 and RT 2 pre and post training intervention. Error bars represent standard deviations.

Counter movement jump (CMJ)

Figure 4.2 shows the mean pre and post training values. The main effect for time was significant ($F_{(1,19)}$ = 7.69, P = .012, ηp^2=.288). Showing that CMJ height increased from pre-test to post-test. The time x group interaction was not significant ($F_{(1,19)}$ = 0.285, P= .599, ηp^2=.015). Indicating no difference in CMJ improvement between groups.

Table 4.3 shows the mean difference and percentage change from pre and post values.

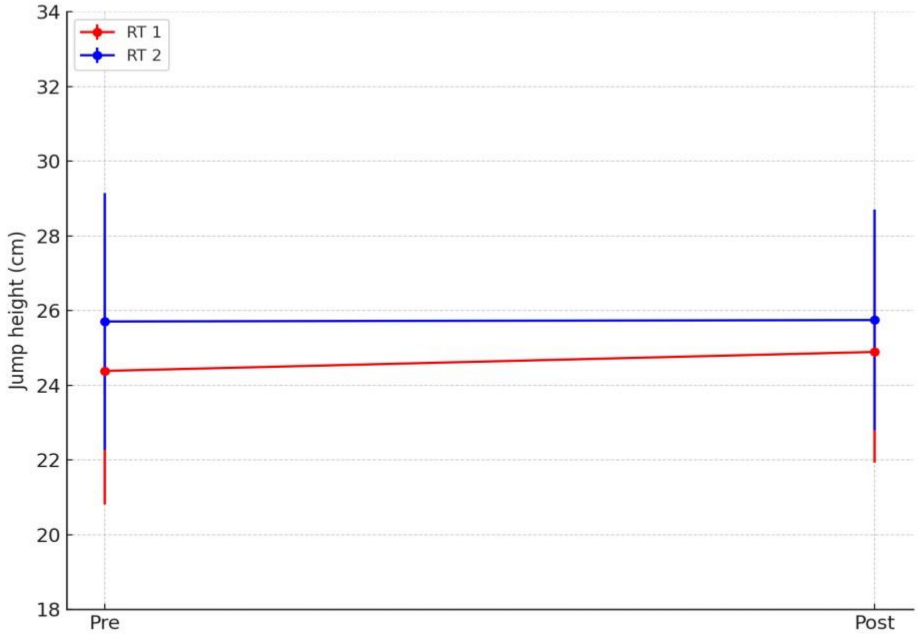

Figure 4.2 Mean jump height (cm) for RT 1 and RT 2 pre and post training intervention. Error bars represent standard deviations.

Peak Power

Figure 4.3 shows the mean pre and post training values. The main effect for time was significant ($F_{(1,24)}$ = 54.998, P < .001, ηp^2 = .696), showing that power increased from pre-test to post-test. The time × group interaction was not significant ($F_{(1,24)}$ = 0.247, P= .624, ηp^2 = .010), indicating no difference in power improvement between groups. Table 4.3 shows the mean difference and percentage change from pre and post values.

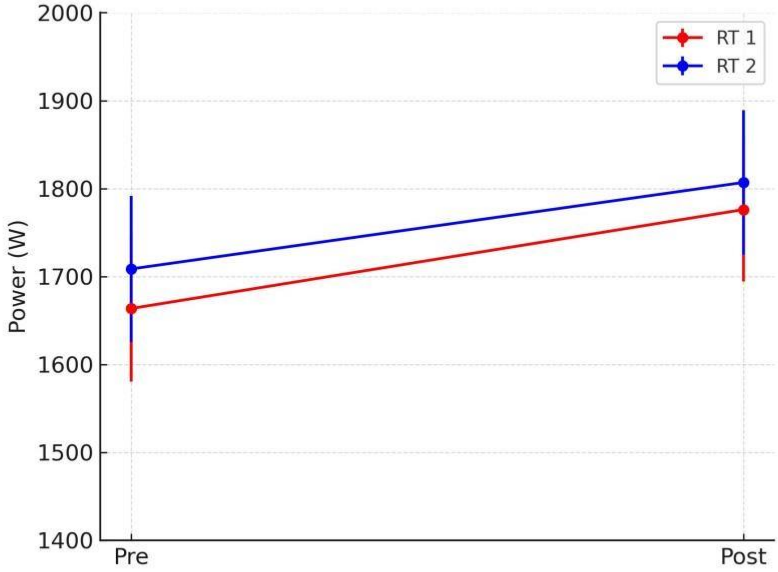

Figure 4.3 Mean Peak power (W) for RT 1 and RT 2 pre and post training intervention. Error bars represent standard deviations

10 m sprint

Figure 4.4 shows the mean pre and post training values for 10 m Sprint speed. The main effect for time was not significant ($F_{(1,19)}$ = 1.53, P =.232, ηp^2=.074) and there was no significant time x group interaction effect ($F_{(1,19)}$ = 0.319, P = .579, ηp^2=.017). Table 4.3 shows the mean difference and percentage change from pre and post values

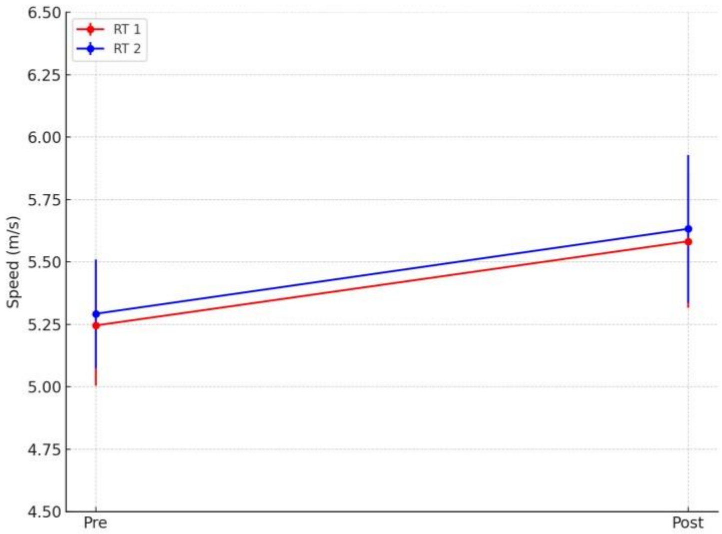

Figure 4.4 Mean 10 m sprint speed (m/s) for RT 1 and RT 2 pre and post training intervention. Error bars represent standard deviations.

20 m sprint

Figure 4.4 shows the mean pre and post training values. The main effect for time was not significant ($F_{(1,19)}$ = 0.478, P =.498, ηp^2=.025), and no significant time x group interaction effect. ($F_{(1,19)}$ = 0.089, P = .769, ηp^2=.005). Table 4.3 shows the mean difference and percentage change from pre and post values.

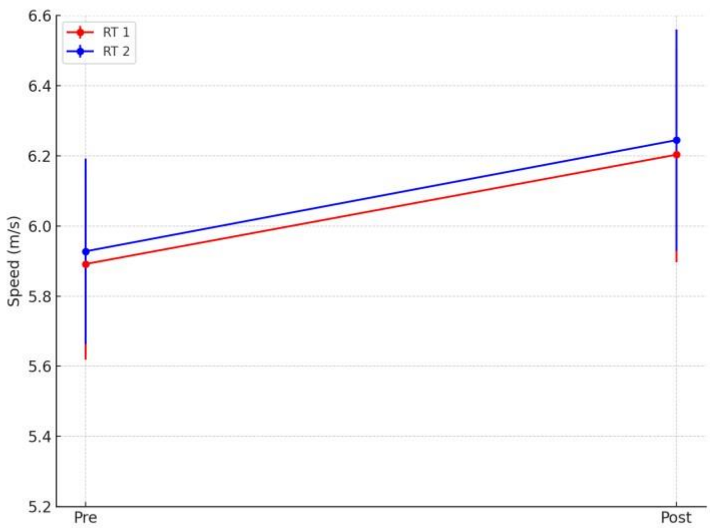

Figure 4.4 Mean 20 m sprint speed (m/s) for RT 1 and RT 2 pre and post training intervention. Error bars represent standard deviations.

Table 4.3 Mean Standard Deviation, Mean difference, Confidence Intervals and Percentage Change values for RT1 and RT2 pre and post intervention.

	Pre-Training Mean (SD)	**Post-Training Mean (SD)**	**Mean difference (95% CI)**	**Percentage change**
Once per week (RT 1)				
(n= 13)				
Force (IMTP [kgf])	88.21	94.29	6.08	6.89 %
	(±13.53)	(±12.97)	(-30.67, 42.83)	
Jump height (CMJ [cm])	24.84	25.78	0.94	3.78%
	(±4.08)	(±4.05)	(-10.33, 12.21)	
Peak Power (CMJ [W])	1663.60	1776.08	112.48	6.76%
	(±272.49)	(±266.13)	(62.26, 162.70)	
Speed (10 m [m/s])	5.25	5.28	0.03 m/s (-0.64, 0.70)	0.57%
	(±0.28)	(±0.2)		
Speed (20 m [m/s])	5.86	5.88	0.02 m/s (-0.76, 0.80)	0.34%
	(±0.31)	(±0.25)		
Twice per week (RT 2)				
(n= 13)				
Force (IMTP [kgf])	89.12	99.00	9.88	11.09%
	(±6.15)	(±5.99)	(-6.94, 26.70)	

Jump height (CMJ [cm])	24.83 (±3.36)	25.46 (±3.24)	0.63 (-8.52, 9.78)	2.54%
Peak Power (CMJ [W])	1708.59 (±324.56)	1806.94 (±322.94)	98.35 (48.13, 148.57)	5.76%
Speed (10 m [m/s])	5.57 (±0.29)	5.68 (±0.31)	0.11 (-0.71, 0.93)	1.97%
Speed (20 m [m/s])	6.26 (±0.31)	6.32 (±0.28)	0.06 (-0.76, 0.88)	0.96%

Abbreviations Force – measured by isometric mid-thigh pull, Kgf = kilogram force, CMJ **-** Countermovement jump height, Peak power – measured in (W) watts 10 m sprint time (s) converted to speed (m/s), 20 m sprint time (s) converted to speed (m/s).

4.6 DISCUSSION

The primary aim of this study was to compare the effects of once-weekly versus twiceweekly resistance training sessions on measures of strength, power, and speed in youth footballers. We hypothesized that participants engaging in twice-weekly resistance training (RT2) would exhibit significantly greater improvements in these performance metrics compared to those training once per week (RT1). The results of our investigation provide partial support for this hypothesis, revealing differences in the effectiveness of training frequency across the various performance variables assessed. The findings are discussed in reference to the hypothesis below. It is important to consider these findings in the context of participants' attendance, or lack thereof, in both conditions, with particular emphasis on the twice-weekly resistance training condition (RT2)

Lower Body Muscular Force

The analysis revealed that training both once and twice per week resulted in significant increases in lower body muscular force from pre- to post-intervention. However, twice per week showed a more substantial improvement (11%) compared to the once per week (6.8%). Statistical analysis confirmed that twice per week experienced significantly greater gains in force than the once per week. suggesting that increasing training frequency would increase strength gains. However, when examining the practical significance of these results, neither training group (RT1 or RT2) demonstrated performance changes that exceeded the MDC_{95} thresholds in any of the measured outcomes. For IMTP, mean increases of +6.08 kgf (RT1) and +9.88 kgf

(RT2) fell well below the MDC_{95} threshold of 29.32 kgf, indicating that observed strength gains, while statistically significant, may not reflect true physiological improvements beyond measurement error.

These findings are in line with previous literature which demonstrated that two days of resistance training per week resulted in a 12% increase in chest press strength and a 25% increase in leg press strength, compared to a 4% and 14% increase, respectively, with one day per week (109). In contrast to this DeRenne et al (112) found a decrease in lower body strength (1.29% decrease for one day/week vs. 0.55% decrease for two days/week), but an increase in bench press strength (6% vs. 4.92%) and pull-ups (9.87% vs. a 4.75% decrease) which was more pronounced from training 1 day per week. The findings from the present study support the guidelines which suggest two sessions per week are optimal for increase strength in youth athletes (1, 33).

Lower Body Muscular Power

Both training frequencies showed modest improvements from pre- to postintervention. Training once per week improved CMJ height from 24.84 cm (±4.08) to 25.78 cm (±4.05), a gain of 3.7%, while the twice-per-week group improved from 24.83 cm (±3.36) to 25.46 cm (±3.24), a gain of 2.5%. In percentage terms, RT1 showed a 6.76% improvement in peak power output, while RT2 improved by 5.76%, further highlighting that both training protocols yielded similar, modest gains without clear evidence of a frequency-based advantage. Although both groups exhibited improvements, the difference in CMJ height and peak power between the training frequencies was not statistically significant. Similarly, improvements in countermovement jump height (RT1: +0.94 cm; RT2: +0.63 cm) and peak power output (RT1: +112.48 W; RT2:

+98.35 W) did not exceed their respective MDC_{95} values (2.25 cm for CMJ and 121.82 W for power), suggesting that observed changes may be attributed to measurement variability or reflect a limited training effect. This suggests that, while both training frequencies positively impacted jump performance, the additional training session per week did not confer a significant advantage. Lesinksi et al (55) also reported no significant differences in jump performance based on training frequency. This suggests that while resistance training positively affects vertical jump performance, the frequency of training sessions does not significantly alter the magnitude of improvement. Alves et al (113) reported a significant increase in squat jump performance for a group that trained once per week (12.6%) and a group that trained twice per week (9.63%). However, neither group showed significant improvements in CMJ. Most importantly the study found no significant difference between the groups that trained once per week and those that trained twice per week in terms of improvements in SJ and CMJ.

Linear Sprint Speed

The sprint performance results showed minimal changes from pre- to post-intervention for both 10 m and 20 m sprints across both training frequencies. Training once per week led to a 0.5% increase in 10 m sprint speed, improving from 5.25 m/s (±0.28) to 5.28 m/s (±0.2). Training twice per week showed a 1.9% improvement, increasing from 5.57 m/s (±0.29) to 5.68 m/s (±0.31). For the 20 m sprint, training once per week resulted in a slight improvement of 0.3%, from 5.86 m/s (±0.31) to 5.88 m/s (±0.25).

Twice-weekly training showed a 0.9% increase, from 6.26 m/s (±0.31) to 6.32 m/s (±0.28). Despite these improvements, statistical analysis did not reveal any significant changes in sprint speed for either training frequency, there was also no significant difference between training frequencies for either sprint distance. Importantly, changes in sprint speed over both 10 m and 20 m distances fell below the MDC_{95} thresholds reported earlier in the thesis. This indicates that the observed improvements are likely within the bounds of measurement error and may not represent true physiological adaptations. These results suggest that the sprint performance of youth footballers may not be significantly influenced by the frequency of resistance training alone, possibly due to the need for more specific sprint training to observe substantial improvements. Previous research has also suggested this, Lesinski et all (55) did not find a strong, consistent relationship between training frequency and improvements in sprint speed. This suggests that factors such as training intensity, exercise selection, and overall program design may be more influential than frequency alone. A study by Cavaco et al. (83) found improvements in 15m sprint performance among youth soccer players. The group that trained once per week Improved by 4.78%, while the group that trained twice per week improved by 5.38%. Despite these improvements, there were no statistically significant differences between the one-session and twosessions-per-week groups. This is also surprising as this study involved a dedicated sprint training protocol as part of the intervention.

In summary, the findings of this study do suggest an importance of training frequency in enhancing lower body strength, with RT2 yielding greater improvements compared to RT1. These findings agree with the existing literature (109, 112). However, the benefits of increased frequency on power (as measured by CMJ) and sprint speed were not as pronounced. Which is in contrast with existing literature (83, 113) These would seem to align with the existing literature and guidelines which suggest that two sessions per week is more beneficial than resistance training once per week (1, 33, 55, 109) however it is of note that literature investigating effects of training frequency in youth do not report actual volume of resistance training completed and only report what was prescribed.

4.7 Limitations

One of the notable limitations of this study is the non-matched nature of the participant groups. The participants were not randomised or matched based on key characteristics such as baseline strength, power, sprint speed, age, height, weight, or training history prior to being assigned to the different training frequency groups. This lack of randomisation or matching may have introduced significant baseline differences between the groups, which could confound the results. For instance, if one group had inherently stronger or more athletic individuals, the observed differences in outcomes might reflect these pre-existing disparities rather than the effects of the training frequency itself.

Such baseline differences can make it challenging to attribute changes in performance metrics purely to the intervention,

Another important consideration in this study is the potential impact of maturation status on the participants' performance outcomes. Maturation can significantly influence strength, power, and speed development in youth athletes, and it is welldocumented that athletes of the same chronological age can vary widely in their stage of physical maturity (111, 255). In the present study, the U13 and U14 teams were not separated based on their maturation status but rather by their chronological age as is common in youth sports settings. The maturity offset data provides important context for interpreting the training responses observed in the RT1 and RT2 groups.

Participants in the RT2 group displayed a mean maturity offset of +0.05 ± 0.44 years, placing them, on average, at or near their predicted peak height velocity (PHV). In contrast, the RT1 group demonstrated a mean offset of –0.61 ± 0.33 years, indicating a biologically less mature cohort. Given that the standard error of estimate (SEE) for the Moore-2 method is ±0.54 years (57) the group difference of 0.66 years exceeds the expected margin of error and supports the interpretation that RT2 was biologically more advanced than RT1.

These developmental differences may have contributed to the performance outcomes observed. Biological maturity is positively associated with neuromuscular coordination (37, 70), muscle mass (35, 76), and strength development (38, 76), which could partially explain why the RT2 group demonstrated significantly greater improvements in isometric mid-thigh pull (IMTP) performance compared to RT1. Participants closer to or beyond PHV typically exhibit accelerated gains in strength and power due to hormonal and musculoskeletal adaptations (35, 70, 74) which may have enhanced the training response in RT2. Although both groups improved in countermovement jump (CMJ) performance, the lack of a significant group × time interaction suggests that this measure may have been less sensitive to maturational status, or that other factors such as training attendance or exercise specificity played a greater role.

It is also important to consider that while RT1 participants were, on average, pre-PHV, their proximity to the SEE boundary suggests some individuals may have been nearing PHV. This intra-group variability adds complexity to interpreting training responses, particularly in studies involving early adolescents. Taken together, the maturity offset differences highlight a potential confounding variable that may have influenced strength outcomes in particular. Future studies should consider selecting or matching participants based on biological maturity to reduce the impact of developmental differences on training comparisons.

The primary aim of the present study was to manipulate training frequency (sessions per week), reflecting a practical concern within academy football environments where time constraints and fixture congestion often result in the reduction of strength and conditioning opportunities. This design was intended to represent real-world conditions, where practitioners must optimise limited training time to maintain or improve the physical qualities of youth athletes.

Although training frequency was the variable intentionally manipulated, it is important to acknowledge that changes to frequency also resulted in a corresponding change to training dose. Training dose, typically defined as the total volume-load accumulated over a given period (sets × repetitions × load), plays a significant role in mediating resistance training outcomes (256, 257). In this study, both groups completed similar per-session volumes; however, the RT2 group completed two distinct resistance training sessions each week, each with a different exercise focus. Consequently, the RT2 group not only performed a greater total weekly training volume but was also exposed to a broader variety of training stimuli compared to the RT1 group, who completed a single program once per week. This methodological feature aligns with designs in the existing literature. Of the four key studies reviewed (218, 244, 247, 248) none equated total training volume between frequency conditions. In each case, participants in the higher-frequency groups accumulated a greater overall training dose.

In the current study participants in RT1 were scheduled to complete one session per week (eight total), while RT2 participants were scheduled for two sessions per week (sixteen total). However, actual attendance deviated from the prescribed plan. Participants in RT1 completed an average of 6.4 sessions, while RT2 participants completed an average of 6.75 sessions. This resulted in only an 8.3% greater total training volume for RT2 compared to RT1, a substantial reduction from the intended 100% increase. In effect, both groups received a very similar overall training dose, which likely limited the differentiation in performance outcomes between conditions. While real-world constraints in academy football often prevent strict volume-matching, particularly when session adherence is inconsistent, Matching weekly training dose across groups, for example, by distributing the same total volume across one or two sessions, would allow for a more accurate assessment of frequency as an isolated variable. Without such control, it remains difficult to determine whether observed differences in performance are driven by frequency, dose, variation in training stimuli, or the interaction between these factors.

While the limitations present challenges from a research perspective, they also underscore the practical realities of youth sports training, where such factors are often unavoidable. In real-world settings, training groups are typically organised by chronological age or perceived talent rather than by maturation status. This means that athletes at different stages of biological maturity often train together within the same team, reflecting common practices in youth sports.

The current study, therefore, provides valuable insights into the effects of resistance training frequency in a real-world context, where training is not adjusted based or on maturation status or baseline characteristics but is instead structured according to age group or talent level. This approach mirrors the actual conditions under which youth athletes are typically trained, where teams are set based on chronological age or, in some cases, by an athlete's talent, such as when a player is advanced enough to compete in an older age group.

The findings offer practical relevance for coaches and trainers who work within these constraints, providing evidence that can inform training decisions in youth sports settings. Furthermore, any training prescriptions recommended from the findings would have to be implemented in this exact type of setting, where such constraints and variables are naturally present.

There was significant attendance issues observed in this study, shown in Table 3.5. The comparison between the once-weekly (RT1) and twice-weekly (RT2) resistance training groups did not accurately reflect the intended evaluation of 2 versus 1 resistance training sessions per week. Ideally, the RT2 group should have received twice the total training load compared to the RT1 group. However, this did not occur as planned, primarily due to the inconsistent attendance among participants in the RT2 group.

In the RT1 group, participants were scheduled for a total of 8 sessions, and most participants (n = 8) attended 6 sessions (75%), with attendance ranging from 75% to

100%. This relatively consistent attendance meant that the RT1 group received nearly the full intended training load. In contrast, the RT2 group was scheduled for a total of 16 sessions, but attendance was much more variable. Most participants attended fewer than half of the scheduled sessions, with 4 participants attending 6 sessions (31.25%) and another 4 participants attending 7 sessions (43.75%). The lowest attendance recorded was 5 sessions (31.25%).

When considering only the actual number of training sessions attended, without factoring in the percentage of desired training load, the RT2 group received approximately 8.33% more total training load compared to the RT1 group. This calculation is based solely on the number of sessions attended by participants in each group over the 8-week period. Despite the RT2 group being scheduled for twice as many sessions, the difference in training load between the two groups was modest due to the lower attendance rates in the RT2 group. Therefore, while the RT2 group did receive a slightly higher training load than the RT1 group, it was not nearly as substantial as intended. This lack of treatment fidelity can explain the absence of significant differences in performance outcomes between the groups and limits the study's ability to draw accurate conclusions about the effects of different training frequencies.

Table 4.4 Attendance values for RT1 and RT2

Participant	RT 1 Attendance (%)	RT 2 Attendance (%)
1	6 (75)	8 (50)
2	7 (87.5)	7 (43.75)
3	6 (75)	6 (37.5)
4	7 (87.5)	8 (50)
5	6 (75)	7 (43.75)

6	7 (87.5)	6 (37.5)
7	6 (75)	7 (43.75)
8	6 (75)	5 (31.25)
9	6 (75)	6 (37.5)
10	6 (75)	7 (43.75)
11	7 (87.5)	8 (50)
12	6 (75)	6 (37.5)
13	8 (100)	5 (31.25)

4.8 Conclusion

In conclusion, the low attendance in the RT2 group reduced the intended differential training exposure between the groups, effectively rendering the planned comparison more similar to a study of two groups both engaging in once-weekly resistance training. This undermines the ability to draw clear conclusions about the impact of increased training frequency. Therefore, the author has decided it appropriate to run another similar study to try to address this limitation and attempt to gather a more accurate and robust dataset to analyse.

CHAPTER 5

Investigating the effects of 1 vs 2 sessions of resistance training per week in youth footballers

5.1 ABSTRACT

Current guidelines recommend two to three weekly resistance training sessions to optimise strength gains in youth athletes, but limited research has directly compared one versus two sessions per week. This study investigates the effects of once versus twice-weekly resistance training sessions on strength, power, and speed in youth footballers.

The participants consisted of 23 male youth footballers, aged 12–14 years, who were divided into three groups: a control group that performed no resistance training, a once-weekly training group (RT1), and a twice-weekly training group (RT2). The intervention took place over an 8-week period. Pre- and post-intervention testing measured isometric mid-thigh pull (IMTP), countermovement jump (CMJ) and 10 m and 20 m sprints. Data were analysed using analysis of variance (ANOVA) to assess changes across the groups. Both RT1 and RT2 showed significant improvements in lower body strength compared to the control group ($F(1,9) = 42.912$, $p < .001$ for RT1; $F(1,9) = 36.445$, $p < .001$ for RT2), but no significant difference in strength gains between RT1 and RT2 ($F(1,9) = 0.278$, $p = .605$). No significant differences were found between the groups for CMJ height ($F(1,9) = 0.160$, $p = .694$) or 10 m sprint speed

(F(1,9) = 0.452, p = .506). However, RT2 showed a significant improvement in 20 m sprint speed compared to the control group (F(1,9) = 7.118, p = .014), with no significant difference between RT1 and RT2 (F(1,9) = 0.676, p = .416). Attendance variability, especially in RT2, limited the ability to fully assess the effects of twiceweekly training.

These findings suggest that while resistance training, even once per week, can improve strength, training frequency may have limited impact on power and speed outcomes in youth footballers.

5.2 INTRODUCTION

In the previous chapter, the study was designed to investigate whether once-weekly resistance training (RT1) was more effective than twice-weekly resistance training (RT2) in improving key performance metrics such as strength, lower body power, and linear speed in youth footballers. However, the study did not successfully meet this aim due to several critical limitations.

Poor participant attendance, particularly in the RT2 group, significantly compromised the intended comparison between training frequencies. While RT2 was scheduled for 16 sessions (double the RT1 group's 8 sessions), actual attendance was low and inconsistent. Most RT2 participants completed fewer than half of their sessions, with four attending only 6 (31.25%) and another four attending 7 (43.75%). In contrast, RT1 attendance was more consistent, with most participants completing 6 out of 8 sessions (75%). As a result, RT2 received only about 8.33% more total training load than RT1, falling well short of the planned doubling. This minimal difference in actual exposure limited the ability to evaluate the true impact of twice-weekly training.

Additionally, the study lacked a control group, which is essential for establishing a baseline to measure the true effects of the resistance training interventions. The absence of a control group made it difficult to discern whether the observed improvements were genuinely due to the training itself or if they could be attributed to external factors such as natural growth, maturation, or other confounding variables (111). A control group would have provided a critical reference point, allowing for a clearer determination of whether changes in performance metrics were the result of the training regimen or simply part of the participants' natural development over time (258).

Another significant limitation was the non-matching of participants, who were drawn from different age groups without consideration of key characteristics such as baseline strength, power, sprint speed, age, height, weight, or training history. This lack of randomisation or matching may have introduced significant baseline differences between the groups, potentially confounding the study’s results. For instance, participants from different age groups, such as U13 and U14, were not separated based on their maturation status but rather by their chronological age. This is important because maturation can significantly influence the development of strength, power, and speed, with older or more physically mature athletes likely to respond differently to the resistance training protocols compared to their less mature peers (255).

One of the most significant limitations encountered was the issue of attendance, particularly within the group assigned to twice-weekly resistance training sessions. As discussed in the previous study, this is an inherent challenge in academy football and youth sports more broadly, as well as in research involving human participants.

Attendance cannot be fully controlled, but it will continue to be recorded and reported to provide transparency. This will allow readers to interpret the results within the appropriate context, which is something that has not been done in previous research, particularly those who are measuring effects of training frequency (83, 109, 112, 113). Previous literature has only reported results based upon what was prescribed but don't account for what was carried out by participants, which would theoretically have a significant impact upon the results obtained and the conclusions drawn from them. If attendance again proves to be a significant issue, statistical methods will be employed to account for these differences, ensuring the results are as reliable as possible. Further details on how attendance will be addressed, if necessary, are provided in the data treatment section of this chapter.

Similarly, the variability in participant characteristics, such as age, maturation, and baseline performance, cannot be realistically controlled within the context of this study. As discussed in the previous chapter, this reflects the real-world applicability of the research, where youth sports teams are rarely separated based on maturation or baseline characteristics. While this limitation remains, the present study will aim control for it by performing covariate analysis to statistically control for baseline differences between participants. This approach will help mitigate the impact of these differences on the study's outcomes, allowing for a more accurate assessment of the training interventions. The specific procedures for this statistical treatment will be detailed in the data treatment section of this chapter.

A key methodological Improvement In the present study Is the Inclusion of a control group. This addition is crucial as it strengthens the study by providing a baseline against which the effects of the resistance training interventions can be accurately measured. The presence of a control group allows for a clearer determination of whether observed changes in performance metrics are truly attributable to the training regimen itself or if they might be influenced by external factors such as natural growth, maturation, or other confounding variables (255, 258).

Given the attendance issues noted in the previous chapter, similar challenges may affect the current study. If participation is again low, the inclusion of a control group will still allow assessment of whether training once per week improves athletic performance. While poor attendance may limit conclusions about whether two sessions are superior to one, the study can still offer valuable insights into the effectiveness of a minimal resistance training dose, an outcome highly relevant to realworld settings where consistent participation is often difficult. The current literature and guidelines suggest that once-weekly resistance training is sufficient for maintaining, but not necessarily improving, athletic performance (1, 33, 55). Previous research, as discussed by Kadlec et al. (124), highlights a significant concern in meta-analyses that contribute to these current guidelines and practices. These meta-analyses often fail to report the effects of experimental groups compared to control groups, which can lead to potentially misleading conclusions about the efficacy of training interventions. By including a control group in the present study, this research addresses the issue highlighted by Kadlec et al. (124), ensuring that the comparison between the experimental and control groups is clearly established. This approach provides stronger evidence to support or refute the claim that once-weekly training is only beneficial for maintenance and not for improvement.

In the previous chapter a review of four key studies that examined the effects of resistance training frequency in youth populations (218, 244, 247, 248) demonstrated that none of these studies matched training dose across frequency conditions. In each case, the higher-frequency group completed a greater total volume of training, making it difficult to isolate frequency as the sole explanatory variable.

This shows a methodological issue, while frequency is often treated as an independent training variable, in practice it is rarely manipulated in isolation. Consequently, performance changes attributed to frequency may also reflect underlying increases in training dose, particularly when volume-load is not controlled. In the current study, this distinction is especially relevant for interpreting the effects of once-weekly versus twice-weekly resistance training, as differences in outcome measures may be influenced by both the distribution and magnitude of the training stimulus. Despite this limitation, training frequency remains a meaningful and relevant variable to study. In real-world environments like academy football, coaches must often decide how many resistance training sessions can realistically be delivered within a week. Exploring the effects of different weekly training frequencies, even when dose is not fully controlled, offers valuable insight into practical programming decisions. Given the limitations identified in the previous chapter, the author deems it necessary to repeat the study to better achieve the aims originally set out. The initial study faced challenges, particularly in participant attendance and baseline variability, which hindered the ability to draw clear and reliable conclusions about the effectiveness of different resistance training frequencies.

5.3 METHODS

Participants

23 Male academy football players aged were recruited to participate in this study. An u13s (n= 11). An u14s team (n= 12) Each participant had regularly engaged in resistance training for ≤ 6 months and were familiar with the exercises conducted in the resistance training sessions. A separate control group (CG) (n= 13) were recruited from an under 13s team of a local football club. Details of anthropometric data can be seen in Table 5.1. Participants were given full details of the study procedures and informed of the risks and benefits of the study before any data collection. Each participant completed a physical activity readiness questionnaire (PARQ). Participants provided personal and parental, or guardian written informed consent before participation. All participants were free from injury and deemed eligible for participation by their club's medical staff. Ethical approval was granted by University of Essex.

Maturity offset was calculated using the Moore et al. (57) simplified regression equation: maturity offset = –7.999994 + (0.0036124 × [Age × Height]), which provides an estimate of years from peak height velocity (PHV). Based on the resulting offset values, participants were classified as pre-, circa-, or post-PHV. RT2 had a mean maturity offset of +0.29 ± 0.52 years. RT1 and the Control Group had mean offsets of –0.49 ± 0.42 years and –0.74 ± 0.49 years, respectively.

Table 5.1 Participant characteristics

	RT1	RT2	Control
N=	11	12	13
Age (years)	13.1 (±0.25)	14.2 (±0.28)	13.1 (±0.34)
Height (cm)	157.5 (±7.43)	161.4 (±8.12)	152.8 (±8.15)
Weight (kg)	45.6 (±6.78)	49.0 (±7.23)	47.3 (±8.71)
Maturity Offset (yrs)	-0.49 (±0.42)	0.29 (±0.52)	-0.74 (±0.49)

Procedure

The resistance training intervention took place over and 8-week period during the competitive phase of the season. The under 13s team (RT1) were assigned one whole-body resistance training program (Routine A) and trained once per week. The under 14s team (RT2) and were assigned two whole body resistance training programs (Routine A and B) and trained twice per week, full details of Routine A and B can be seen in Table 5.2. Both teams performed Routine A on a Tuesday at the same time. RT2 performed Routine B on a Thursday. Resistance training took place either before or after football training, authors had no control over times of football training. Both teams maintained their regular schedule of football training of two sessions per week. The control group performed football training twice per week and no resistance training.

Testing of 10 m and 20 m sprints, countermovement jump, and isometric mid-thigh pull took place before and after the 8-week training intervention.

All testing was conducted on the same day in the following sequence: the 10 m and 20 m sprints were assessed first, followed by the counter movement jumps After a 60 min rest period, the isometric mid-thigh pull was measured.

Lower Body Muscular Strength

High levels of muscular force are essential for actions such as sprinting, jumping, tackling, and kicking, all of which are critical to overall performance in the sport of football (138, 158). The Isometric Mid-Thigh Pull (IMTP) test is recognised as a valid and reliable method for evaluating lower limb muscular force (249). Isometric mid-thigh pull (IMTP) was performed on a portable force platform PS-2141 (PASCO, California, USA) sampling at 1000Hz. Ground reaction force data was collected using SPARKvue PS-2400 version 3.1.3 software (California, USA). The bar was positioned so as to mimic the position of the second pull during a power clean exercise. Once the participant was in place the force trace was reset to zero to account for body mass. Participants were then instructed to pull as hard as possible and drive their feet into the force platform until they were instructed to stop, each attempt lasted 10s. Participants completed a total of three attempts each, with a 2 min recovery between each attempt. The largest peak force value was used for analysis.

Lower Body Muscular Power

Lower body muscular power and jumping ability are key factors influencing performance in football (158, 167). A valid and reliable method for assessing lower body muscular power is through Countermovement Jump (CMJ) testing (167, 250).

Countermovement jump (CMJ) was collected using a portable force platform PS-2141 (PASCO, California, USA) sampling at 1000Hz. Jump height (cm) data was collected using SPARKvue PS-2400 version 3.1.3 software (California, USA). CMJ was performed with hands on hips and straight legs during the flight phase. Each participant performed 3 jumps, with a recovery of 60s between jumps. Flight time was then converted into jump heigh using the formula; $h = t^2g/8$, where h = jump height (m), t = flight time (s) and g is the gravity acceleration (9.81 m/s^2) (251, 252). The highest value for jump height from each participant was then recorded for analysis. In addition to raw countermovement jump (CMJ) height, peak muscle power (PMP) was also estimated to provide a more comprehensive assessment of lower-limb explosive capacity. PMP was calculated using a validated predictive equation developed by Gomez-Bruton et al. (253), which accounts for both vertical jump height and body mass. This equation is specifically designed for youth populations and has demonstrated strong predictive accuracy:

$$\text{Power (W)}=54.2\times\text{Jump Height (cm)}+34.4\times\text{Body Mass (kg)}-1{,}520.4$$
$$\text{Power (W)}=54.2\times\text{Jump Height (cm)}+34.4\times\text{Body Mass (kg)}-1{,}520.4$$

Peak power values were computed individually using each participant's recorded CMJ height and body mass for both pre- and post-tests. The difference scores (Post – Pre) were then used to evaluate absolute reliability, consistent with procedures for other performance metrics.

Linear Sprint Speed

Acceleration and short distance sprint speed are important physiological factors in football (158, 254). A valid and reliable method for assessing linear speed and acceleration is by measuring 10 m and 20 sprint times (119, 254). Testing took place on an indoor artificial (3G) surface, participants were instructed to wear football boots to ensure adequate traction. Sprint time was measured using timing gates (Brower Timing Systems, Utah, USA). Timing gates were set at 10 m and 20 m intervals to allow measurements for each distance to be taken from one sprint effort. Participants began from a standing start. Each participant completed three total sprint efforts, with a 120s recovery period between each effort. The shortest time recorded was then converted from time (s) to speed (m/s) to be used for analysis.

Resistance Training Intervention

Two different resistance training routines (Routine A and B) were constructed based upon training recommendations by the UKSCA (33) NSCA (1) CSEP (34) full details of each training program can be found in table 2. RT 1 and RT 2 both performed routine A once per week, RT2 also performed routine B once per week in addition. Participants performed each exercise with a self-selected load, the range of loads used are noted in Table 5.2. All sessions were supervised by at least 2 qualified strength and conditioning coaches.

Table 5.2 Details of resistance training routine A and B

Routine A							
Exercise	**Sets**	**Reps**	**Recovery (s)**	**Load (range)**		**RPE range**	
				RT1	**RT2**	**RT1**	**RT2**
Squats	3	10	90	14-25kg	16-30kg	7-9	7-9
Pull ups	3	10	90	B/W		6-8	
Romanian Deadlifts	3	10	90	18-30kg	18-30kg	7-9	7-9
Press ups	3	10	90	B/W		7-8	
Planks	3	20s hold	60	B/W		5-6	

Routine B

Exercise	Sets	Reps	Recovery (s)	Load (range)	RPE range
Hex Bar Deadlift	3	10	90	25-40kg	7-9
Inverted Rows	3	10	90	B/W	6-8
Lunges	3	10	90	10-16kg	7-9
DB shoulder press	3	10	90	8-14kg	7-8
Dead bugs	3	10	60	B/W	5-6

Abbreviations B/W = Bodyweight, **RPE** = Rate of perceived exertion, **DB** = Dumbbells,

Table 5.3 Attendance values and percentages for each participant

Participant	RT 1 (n= 11) Attendance: n (%)	RT 2 (n= 12) Attendance: n (%)
1	7 (87.5)	4 (25)
2	7 (87.5)	4 (25)
3	7 (87.5)	9 (56.25)
4	5 (62.5)	9 (56.25)
5	3 (37.5)	8 (50)
6	8 (100)	7 (43.75)
7	7 (87.5)	9 (56.25)
8	4 (50)	8 (50)
9	5(62.5)	2 (12.5)
10	2 (25	5 (31.25)
11	7 (87.5)	9 (56.25)
12		2 (12.5)

5.4 DATA TREATMENT

The aim of this study was to compare the effects of once versus twice-weekly resistance training sessions on strength, power and speed in youth academy footballers.

To achieve this, pre- and post-intervention measures were compared across three groups: a once-weekly training group (RT1), a twice-weekly training group (RT2), and a non-training control group.

The independent variable in this study was training frequency. The conditions were a control group that performed no resistance training, Condition 1 where participants engaged in resistance training once per week, and Condition 2 where participants engaged in resistance training twice per week. The dependent variables were the change in outcomes (Force, jump height, 10 m and 20 m sprint speed), which was quantified as the difference between post-training and pre-training values. An example for Force is detailed below.

$$\Delta Force(N) = Force\ post\ training(N) - Force\ pre\ training(N)$$

This calculation was applied to all other outcomes including Jump height, 10 m and 20 m Sprint speed.

The differences in the mean changes among the three groups can be tested using Analysis of Variance (ANOVA). ANOVA is suitable for determining whether there are any statistically significant differences between the means of three or more independent groups. Analysis of Covariance (ANCOVA) was employed. ANCOVA allows for the adjustment of these initial differences by including the pre-training values as covariates in the model, helping to isolate the true effect of the intervention on the dependent variables.

The same analysis approach was applied to each dependent variable. For example, in the analysis of Force, the dependent variable was the ΔForce (N). To test the hypothesis that there were differences in the mean change for each factor by resistance training group, the factor 'Group' was introduced. The group variable had three conditions: Control, RT1 (once-weekly resistance training), and RT2 (twiceweekly resistance training). To adjust for between-group differences in pre-training means, Force pre-training(N) was introduced as a covariate.

To test for the effects of attendance the factor attendance was introduced as a covariate to control for its potential impact on the outcomes.

5.5 RESULTS

Lower Body Muscular Force

Figure 5.1 shows the adjusted means and standard error values, and Table 5.4 shows the values for change in force across the three experimental groups. Adjusting for session attendance as a covariate ($F_{(1, 12)} = 2.61$, $P = .130$, $\eta p^2 = .167$).

The mean difference between RT 1 and the control group was 315.98 (95% CI [183.62, 448.34], $P < .001$). Similarly, the mean difference between RT 2 and the control group was 282.69 (95% CI [171.25, 394.14], $P < .001$). The mean difference between RT 1 and RT 2 was 33.29 (95% CI [-97.66, 164.23], $P = .605$), which was not statistically significant.

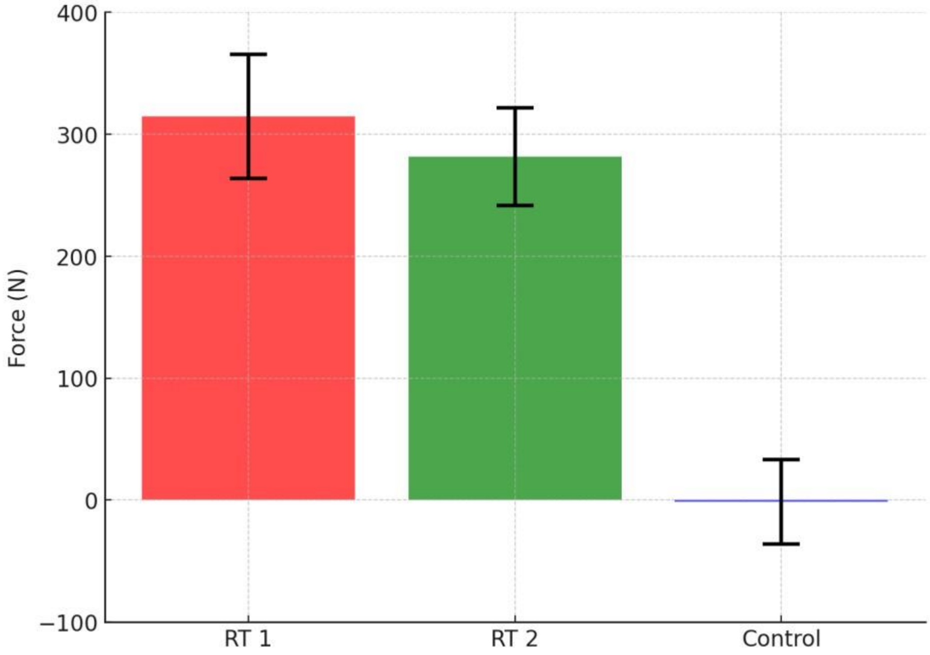

Figure 5.1: Adjusted mean change in Force (N) for youth academy footballers receiving different resistance training frequencies. Bars represent adjusted means, with error bars indicating standard errors.

Lower Body Power

Figure 5.2 shows the adjusted means and standard error values and Table 5.4 shows the values for change in counter movement jump height across the three experimental groups. Attendance was not significant covariate on the change in CMJ height ($F_{(1, 12)}$ = 0.060, P = .809, partial ηp^2 = .004). The mean difference between RT 1 and the control group was -0.35 (95% CI [-4.24, 3.54], P = .856). The mean difference between RT 2 and the control group was 1.02 (95% CI [-2.96, 5.00], P = .604). The mean difference between RT 1 and RT 2 was 1.37 (95% CI [-5.56, 2.83], P = .509), which was not statistically significant.

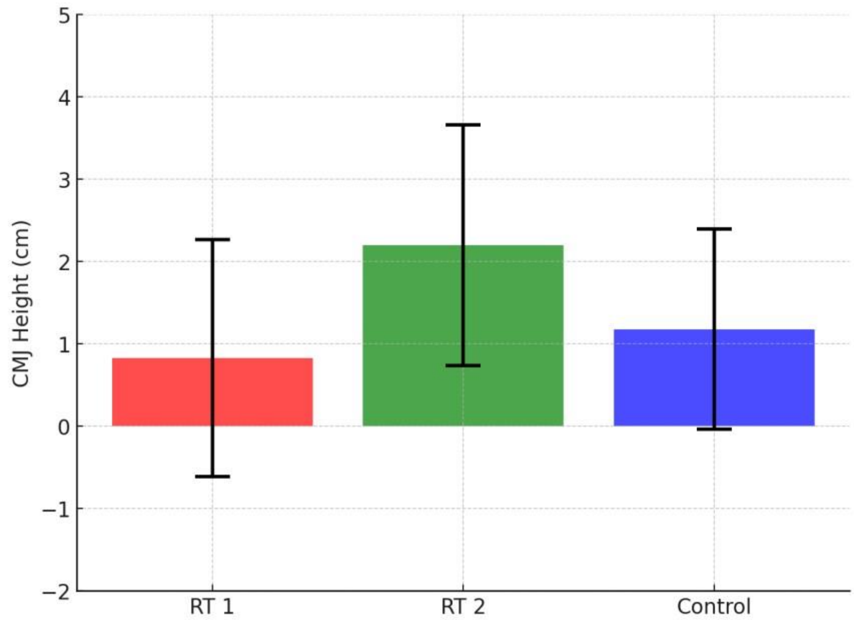

Figure 5.2: Adjusted mean change in CMJ height (cm) for youth academy footballers receiving different resistance training frequencies. Bars represent adjusted means, with error bars indicating standard errors.

Peak Power

Figure 5.3 shows the adjusted means and standard error values and Table 5.4 shows the values for change in power output across the three experimental groups. Attendance was not a significant covariate on the change in power ($F_{(1, 14)}$ = 0.017, P = .898, partial ηp^2 = .001). The mean difference between RT 1 and the control group was 36.61 W (95% CI [-127.26, 200.48], *P* = 1.000). The mean difference between RT 2 and the control group was 138.37 W (95% CI [-6.60, 283.33], *P* = .065). The mean difference between RT 1 and RT 2 was -101.75 W (95% CI [-215.90, 12.39], *P* = .093), which was not statistically significant.

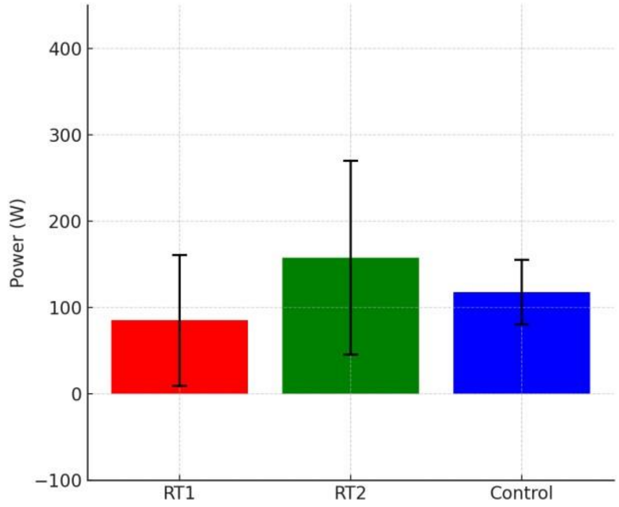

Figure 5.3. Adjusted mean change in Peak power (W) for youth academy footballers receiving different resistance training frequencies. Bars represent adjusted means, with error bars indicating standard errors.

Linear Sprint Speed

Figures 5.4 and 5.5 show the adjusted means and standard error values and Table 5.4 shows the values for change in 10 m and 20 m sprint speeds across the three experimental groups. Attendance was not a significant covariate on the change in 10 m sprint speed, ($F_{(1, 12)}$ = 0.805, p = .387, ηp^2 = .063). The mean difference between RT 1 and the control group was -0.18 (95% CI [-0.38, 0.01], *P* = .573). The mean difference between RT 2 and the control group was -0.10 (95% CI [-0.32, 0.12], *P* = .179). The mean difference between RT 1 and RT 2 was -0.08 (95% CI [-0.37, 0.21], *P* = .506), which was not statistically significant. Attendance was not a significant covariate on change in 20 m sprint speed ($F_{(1, 12)}$ = 0.317, p = .583, ηp^2 = .024). The mean difference between RT 1 and the control group was -0.24 (95% CI [-0.38, -0.13], *P* = .416). The mean difference between RT 2 and the control group was -0.32 (95% CI [-0.47, -0.17], *P* = .014). The mean difference between RT 1 and RT 2 was 0.07 (95% CI [-0.11, 0.26], *P* = .416), which was not statistically significant.

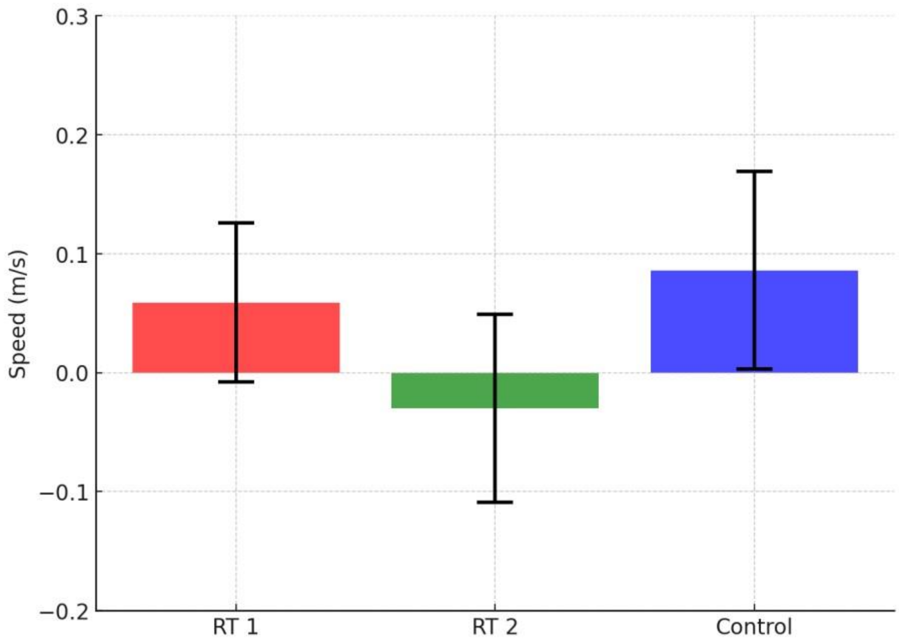

Figure 5.4: Adjusted mean change in 10m sprint speed (m/s) for youth academy footballers receiving different resistance training frequencies. Bars represent adjusted means, with error bars indicating standard errors.

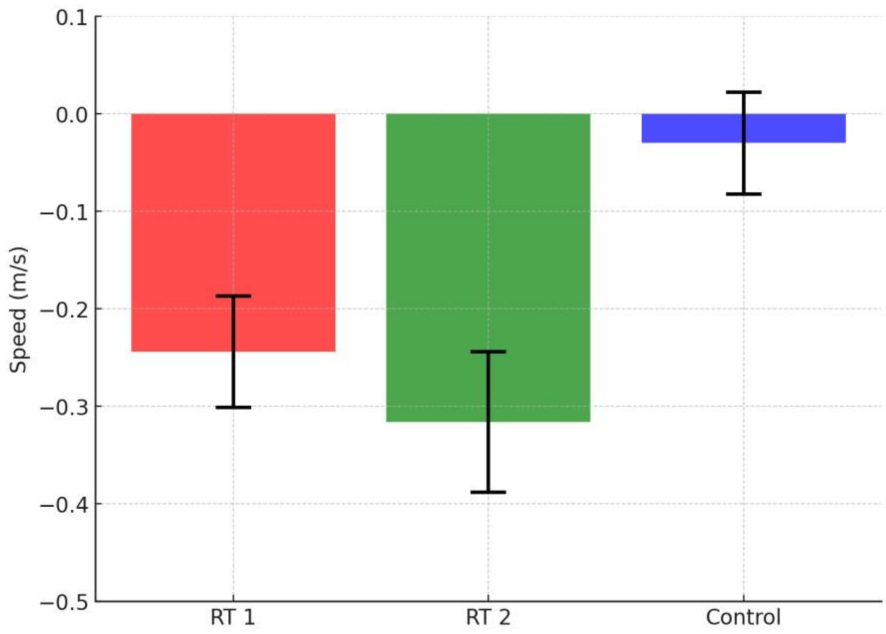

Figure 5.5: Adjusted mean change in 20m sprint speed (m/s) for youth academy footballers receiving different resistance training frequencies. Bars represent adjusted means, with error bars indicating standard errors.

Table 5.4 Means and standard deviation for pre and post intervention and change for all three intervention groups.

	Pre-Training Mean (SD)	Post-Training Mean (SD)	Δ (Post – Pre) Mean (SD)
Control (n= 13)			
Force (IMTP [N])	685.37 (±131.85)	949.38 (±225.04)	283.59 (±145.18)
Jump heigh (CMJ [cm])	41.90 (±5.69)	42.33 (±6.67)	1.39 (±5.14)
Peak Power (CMJ [W])	2194.97 (±397.49)	2312.61(±405.83)	117.64 (±134.48)
Speed (10 m sprint [m/s])	5.41 (±0.33)	5.21 (±0.29)	-0.23 (±0.36)
Speed (20 m sprint [m/s])	6.20 (±0.35)	5.86 (±0.25)	-0.31 (±0.16)
Once per week (RT 1) (n= 11)			
Force (IMTP [N])	657.86 (±136.22)	705.38 (±131.37)	296.41 (±74.89)
Jump height (CMJ [cm])	41.25 (±6.44)	42.49 (±5.12)	0.78 (±4.15)
Peak Power (CMJ [W])	2285.48 (±455.9)	2351.89 (±446.04)	85.2 (±227.26)
Speed (10 m sprint [m/s])	5.39 (±0.23)	5.44 (±0.41)	-0.23 (±0.26)
Speed (20 m sprint [m/s])	6.14 (±0.31)	6.25 (±0.38)	-0.26 (±0.15)
Twice per week (RT 2) (n= 12)			
Force (IMTP [N])	931.78 (±185.22)	961.11 (±258.45)	275.05 (±182.13)
Jump height (CMJ [cm])	41.14 (±5.59)	43.52 (±7.74)	2.00 (±6.18)
Peak Power (CMJ [W])	2469.39 (±378.8)	2635.31 (±527.9)	157.69 (±335.8)
Speed (10 m sprint [m/s])	5.14 (±0.23)	5.29 (±0.35)	-0.24 (±0.48)
Speed (20 m sprint [m/s])	5.78 (±0.22)	5.95 (±0.27)	-0.38 (±0.15)

Abbreviations Force (N) – maximal force of the lower limb musculature by isometric mid-thigh pull (IMTP) Countermovement Jump (CMJ) – measured as jump height (cm), Peak Power – measured from CMJ and converted into (W), 10 m and 20 m sprint - measured as time (s) to run 10 m or 20 m then converted to speed (m/s)

5.6 DISCUSSION

The aim of this study was to evaluate the effects of once-weekly versus twice-weekly resistance training sessions on measures of strength, power, and speed in youth footballers. It was hypothesised that participants undergoing twice-weekly resistance training (RT2) would demonstrate significantly greater improvements in these performance metrics compared to those training once per week (RT1). Additionally, this study aimed to assess whether a single resistance training session per week would provide measurable benefits over no training at all.

Lower Body Muscular Strength

High levels of muscular force are crucial for enhancing athletic performance in team sports, as it is strongly linked to improved force-time characteristics like the rate of force development (RFD) and external mechanical power. These characteristics are vital for executing fundamental movements in team sports, such as jumping, sprinting, and changing direction. Research suggests that athletes with greater muscular strength tend to perform better in these sport-specific tasks, primarily because they can generate higher levels of force more quickly, leading to improved overall athletic performance (29).

The findings indicate that both training frequencies experienced significant increases in lower body strength compared to the control group, as measured by the isometric mid-thigh pull (IMTP). Specifically, the mean increase in force for once per week was significantly greater than that of the control group. Twice per week also demonstrated a significant improvement in strength over the control group However, when comparing the once and twice per week directly, the difference in strength gains was not statistically significant. Importantly, only the RT1 group exceeded the minimum detectable change (MDC_{95}) threshold for IMTP force (+296.41 N vs. MDC_{95} = 287.62 N), suggesting a likely true improvement in maximal strength. While the control group showed a comparable increase (+283.59 N) and RT2 slightly less (+275.05 N), both remained below the MDC threshold, indicating that these changes may fall within the bounds of measurement variability. These results suggest that while resistance training is effective in enhancing strength, and importantly training only once per week is significantly more effective than no training at all. This contrasts with existing literature and guidelines which have previously suggested that one session of resistance training per week may only offer strength maintenance benefits and would not be enough to substantially increase strength levels (1, 33, 55, 109). The findings also show that two sessions per week did not provide significant increases in strength levels when compared to a single session per week. This is in contrast with existing literature which found Chest press strength increased by just 4% in the group training once per week, whereas the group training twice per week saw a 12% improvement. Similarly, leg press strength improved by 14% in the once-per-week group, compared to a 25% increase in the twice-per-week group (109).

Lower Body Muscular Power

Explosive muscular power and the rate of force production underpin most athletic movements. Increases in strength and power following resistance training (RT) in both pre-adolescents and adolescents are typically attributed to neuromuscular adaptations, such as improved motor unit recruitment and coordination, rather than hypertrophy (125). Consequently, changes in jumping performance are widely regarded as a proxy for improvements in sports performance (125).

In this study, there were no statistically significant differences in CMJ height between groups. Neither training once (RT1) nor twice (RT2) per week produced significant improvements compared to the control, nor was there a significant difference between RT1 and RT2. These findings suggest that the training frequencies used did not meaningfully influence jump height over the intervention period.

This contrasts with previous literature. A meta-analysis by Harries et al. (125) reported a Z-score of 1.95, indicating that RT improves CMJ height in youth athletes. More pronounced effects were found when RT was combined with plyometric training (Z = 2.69), which may explain the lack of significant gains in the present study, where only RT was used. Alves et al. (113) also reported slightly greater jump height improvements with twice-weekly training compared to once per week.

However, analysis of CMJ-derived peak power suggests a more favourable response in the RT2 group. Although no group exceeded the MDC_{95} for CMJ height (2.25 cm), RT2 achieved the largest gain (+2.00 cm). Importantly, peak power in RT2 increased by +157.69 W, exceeding the MDC_{95} of 121.82 W, indicating a likely true improvement in lower-body power. This gain approached statistical significance compared to the control group (P = .065) and was greater than the RT1 group, though not significantly so (P = .093). RT1 and control groups showed smaller, sub-threshold changes.

Overall, while CMJ height remained unchanged, the RT2 group demonstrated a meaningful improvement in power output, emphasising the value of including kinetic variables alongside jump height when evaluating training outcomes in youth athletes

Linear Sprint Speed

Linear sprint speed is a critical attribute required for success in team sports like football (125) Greater levels of force and strength are closely linked to faster sprint times, particularly due to their influence on acceleration and ground contact time. Athletes with higher strength can produce greater forces more quickly, leading to faster acceleration and increased speed over short distances (259). For sprint speed, the analysis revealed minimal changes across the training frequencies. In the 10 m sprint, neither once nor twice per week showed statistically significant improvements compared to the control group. Similarly, there was no significant difference between once and twice per week. However, all groups did exceed the MDC_{95} threshold for 10 m sprint velocity (0.13 m/s), with changes ranging from –0.23 to –0.24 m/s, suggesting that although not statistically significant, these reflect real improvements in shortdistance speed. In the 20 m sprint, training twice per week demonstrated a statistically significant improvement compared to the control group, while training once per week did not. The RT2 group also showed the largest absolute change (–0.38 m/s), matching the MDC_{95} threshold of 0.38 m/s, further suggesting a potentially meaningful improvement. However, the comparison between once and twice per week did not yield a statistically significant difference. These results suggest that while there may be some benefit to twice per week training for longer sprints, overall, the frequency of resistance training did not have a substantial impact on sprint speed.

These findings suggest that neither training frequency resulted in significant improvements in sprint performance over either distance. These findings are consistent with other literature for example, in a meta-analysis by Lesinski et al (55) found that there were only small improvements on linear speed in youth athletes participating in resistance training, reporting a weight mean effect score (SMD_{wm}) of 0.58, suggesting a small effect. Furthermore, literature has suggested that improving linear speed is multi-factorial (55, 125), it involves the combination of resistance training and some form of explosive training such as plyometrics and also sprint specific training involving drills and technical work (260). However previous literature which investigated effects of training frequency contrast with the present study. Cavaco et al. (83) observed more pronounced improvements in sprint performance and agility with a higher training frequency.

Attendance

In the RT1 group, participants were expected to attend 8 resistance training sessions over the 8-week period, while those in the RT2 group were expected to attend 16 sessions. However, the actual attendance varied significantly. In RT1, the mode was 7 (87.5%) with 5 participants attending these many sessions. The attendance in this group ranged from 2 sessions (25%) to 8 sessions (100%), reflecting a broad spectrum of adherence.

In RT2, the mode was 9 (56.25%), with 5 participants attending these many sessions. However, the attendance in this group ranged from 2 sessions (12.5%) to 9 sessions (56.25%), with most participants attending fewer than 60% of the total possible sessions. This low level of attendance in RT2, where participants were expected to attend 16 sessions, indicates that many participants received a training stimulus more akin to a once-weekly regimen, rather than the intended twice-weekly schedule. RT2 did still receive slightly more training than RT1 (12.37%).

While this attendance pattern is documented in the current study, it is important to note that previous research in this area has not typically recorded or reported on participant attendance in such detail. Studies directly comparing the effects of 1 versus 2 resistance training sessions per week (83, 109, 112, 113) have reported the outcomes of the prescribed training regimens rather than the actual sessions attended by participants. As a result, there is limited information available on whether the attendance issues observed in the current study are common in this type of research or whether they represent an anomaly.

The absence of detailed attendance reporting in previous studies makes it difficult to determine whether the attendance variability observed in this study is a typical challenge in similar research settings (83, 109, 112, 113). Thus, while the current findings are valuable, they should be interpreted with caution, as the lack of attendance data in previous literature prevents a clear comparison and understanding of how attendance might have influenced the outcomes in those studies.

This variability in attendance from RT 2 suggests the distinction between once-weekly and twice-weekly training frequencies was blurred. As a result, the intended comparison between training frequencies was compromised, and the efficacy of the twice-weekly regimen may not be accurately reflected in the outcomes. This is a repeat of what happened in the preliminary study and was ultimately why the author chose to repeat this study again.

In the context of research on resistance training interventions, maintaining fidelity is crucial to the validity and interpretation of the study's outcomes. Reporting participant attendance is an essential aspect of this fidelity (261), as attendance would directly impact the extent to which participants are exposed to the training stimulus. This is something which is commonplace and expected in the world of medical research, both the Consolidated standards of reporting trials (CONSORT) and consensus on exercise reporting template (CERT) expect research utilising exercise protocols to report both the recording and values of attendance or adherence to the exercise treatments prescribed (262, 263). The failure to report attendance in research undermines the ability to fully understand the relationship between the intervention and its outcomes, as it leaves open the possibility that observed effects may be due to differences in training exposure rather than the intervention itself.

To the best of the authors knowledge this is the first study to report attendance when investigating resistance training frequency Unfortunately, it has been noted that many studies in this subject do not adequately report participant attendance (83, 109, 112, 113), which can lead to over or underestimation of the intervention's true effects. Reporting attendance is not only a matter of transparency but also of good scientific practice (129, 130). It allows for a more nuanced interpretation of the data and provides context for the observed outcomes, ensuring that conclusions drawn from the research are both accurate and reliable. As such, the inclusion of attendance data should be considered a standard practice in studies involving training interventions to enhance the integrity of the research findings.

The inconsistent training observed in this study is the same limitation observed in the study previously reported in this thesis. While this limitation complicates the ability to draw definitive conclusions, both studies highlight the significant challenge of training schedules in a real word setting. Showing that it can often be chaotic and unpredictable. This reality makes it difficult to consistently implement optimal training frequencies. Having now undertaken two interventions over a combined 16 weeks, it becomes clear that even with the best intentions of prescribing an optimal dose of two session per week, this may not be achievable outside of a controlled environment. Understanding the minimum amount of training required to elicit positive adaptations becomes particularly crucial in such unpredictable environments. By focusing on the minimal dose, strength coaches can design training programs that are more adaptable to the inevitable inconsistencies in attendance, ensuring that athletes still achieve meaningful improvements in performance despite the challenges posed by fluctuating training schedules.

While training frequency was the variable explicitly manipulated in the present study, increasing from one to two sessions per week also resulted in a higher total training dose. Both groups performed the same training protocol during each session; thus, the two-session group effectively received twice the prescribed weekly volume. Consequently, the greater improvements observed in this group may have been influenced by the increased dose rather than training frequency alone. Training dose, calculated through the combination of sets, repetitions, and load, serves as a primary driver of resistance training adaptation and influences neuromuscular, hypertrophic, and performance outcomes (256, 257).

This confounding of frequency and dose is consistent with previous research (218, 244, 247, 248), where none of the studies matched training volume between conditions. In all cases, the higher-frequency groups accumulated a greater total training dose, limiting the extent to which frequency could be isolated as an independent factor. Of the reviewed studies, only Faigenbaum et al. (244) explicitly acknowledged the potential for differences in dose to influence training outcomes, highlighting the need for careful consideration of this issue in future research. In the current study, it remains plausible that the performance improvements observed in the RT2 group were driven, at least in part, by the increased exposure to training volume.

While the group was prescribed two sessions per week over an eight-week intervention (totaling 16 sessions), attendance data indicated that RT2 participants completed an average of 12.7 sessions, compared to 6.7 sessions for RT1, who were prescribed eight sessions in total. This resulted in an approximate 12.4% greater total training volume for the RT2 group. Although this increase was substantially less than the intended doubling of volume, the realised difference in dose may have meaningfully contributed to the superior improvements observed in strength and speed performance measures.

While real-world constraints in academy football often prevent strict volume-matching, particularly when session adherence is inconsistent, future studies aiming to isolate the effects of training frequency could control for total dose. Strategies should include equating weekly training volume between groups by adjusting per-session load or setrepetition schemes, ensuring that frequency is the only variable manipulated.

Further Limitations

Maturity offset estimates showed developmental differences between groups that may have influenced the observed training responses. RT2 had a mean maturity offset of +0.29 ± 0.52 years suggesting that they were at or near peak height velocity (PHV). In comparison, RT1 had a mean offset of –0.49 ± 0.42 years, and the control group showed the lowest maturity at –0.74 ± 0.49 years. Although the maturity offset values fall within the standard error of estimate of ±0.54 years for the Moore-2 calculation (57), it is still important to acknowledge the differences in biological maturity between groups, as these may have contributed to variations in performance outcomes

This maturational advantage may have contributed to the significant improvements in 20m sprint speed observed in RT2 but not in RT1 or the control group. As adolescents approach and pass through PHV, they experience rapid gains in neuromuscular efficiency, muscle mass, and stride length (37, 70), all of which can enhance sprint performance. The RT2 group's greater biological maturity may have facilitated a more pronounced adaptive response to sprint and strength training stimuli compared to less mature peers (70, 74). However, it is noteworthy that, despite these maturational differences, no significant differences were observed between RT1 and RT2 in IMTP or CMJ performance. This may reflect the limited actual training frequency achieved by RT2 due to low attendance or suggest that biological maturity alone was not the primary determinant of performance gains in these measures.

While biological maturity may have partially influenced the sprint outcomes, the general improvements in IMTP strength across both training groups suggest that resistance training, even at lower frequencies, can be effective in early- to midadolescent athletes regardless of maturity status. Nonetheless, the maturity-related variation between groups should be acknowledged as a potential confounding variable, particularly when interpreting differences in responsiveness to to training stimulus. Future studies may benefit from dividing groups by biological age or including maturity offset as a covariate to better isolate training effects.

5.7 PRACTICAL APPLICATIONS

Based on the findings of this study, it is reasonable to suggest that strength coaches working in environments with poor attendance, or frequently altered schedules can still achieve performance improvements with minimal training frequency. Specifically, if attendance is low or sessions are rescheduled, a single training session per week can still provide a sufficient stimulus to improve athletic performance. This finding is particularly important for youth sports, where maintaining consistent attendance can be challenging. Strength coaches can take confidence in knowing that, even when circumstances prevent the ideal frequency of training, a once-weekly session remains a viable option for promoting athletic development. Further research could benefit from extending the duration of the intervention to encompass an entire season. This would provide a clearer picture of how attendance fluctuates over time and how these fluctuations may impact the overall effectiveness of resistance training. By examining attendance patterns over a longer period, a deeper understanding can be obtained, of how inconsistent attendance influences the cumulative training stimulus and ultimately the outcomes of the program.

CHAPTER 6

Comparing the effects of Traditional resistance training versus Functional resistance training on athletic performance in youth footballers

6.1 ABSTRACT

Current guidelines on youth resistance training do not provide specific recommendations regarding exercise selection, and the existing literature has primarily focused on complex training programs or comparisons between specific exercises rather than full training modalities. This study investigates the effects of traditional versus functional resistance training modalities on strength, power, speed, and change of direction in youth footballers. 22 male youth footballers, aged 13-14 years, were recruited into three groups: a traditional training group (TTG), a functional training group (FTG), and a control group (CG). TTG and FTG performed two resistance training routines per week alongside regular football practice over an 8week period. Traditional utilised bilateral, sagittal plane exercises, while functional training employed a mixture of unilateral, multi-planar movements. Pre- and posttesting assessed isometric mid-thigh pull (IMTP), countermovement jump (CMJ), 10 m and 20 m sprints and 505 change of direction test for a. Data were analysed using ANCOVA

to assess changes between the groups. Traditional training demonstrated significant improvements in lower body strength ($F(2,29) = 5.60$, $p = .009$, $\eta p^2 = .278$) compared to the control group. Functional training showed greater gains in CMJ height ($F(2,29) = 3.63$, $p = .039$, $\eta p^2 = .200$) and change of direction speed ($F(2,41) = 18.939$, $p < .001$, $\eta p^2 = .566$). However, there were no significant differences between traditional and functional training in 10 m or 20 m sprint performance. Attendance variability limited the ability to fully evaluate the long-term effects of the training programs. These findings suggest that while traditional training is more effective for enhancing strength, functional training may offer greater benefits for power and agility.

Both modalities have benefits that can be applied to optimise training outcomes for youth footballers.

6.2 INTRODUCTION

The NSCA (1) and UKSCA (33) agree that youth resistance training should prioritise technical competency, ensuring that exercises are performed with proper technique to prevent injury and support long-term development. Both organisations emphasise a gradual progression from simpler exercises to more complex multi-joint exercises as the participants skills improve. They also recommend structuring training sessions so that more complex exercises and larger muscle groups are trained first, when the athlete is less fatigued (1, 33).

However, the guidelines do not provide any specific details into exercise selection. Exercise selection in the context of resistance training refers to the process of choosing specific exercises to achieve desired training outcomes. This includes the decision to use movements such as compound, isolation, bilateral and unilateral (10, 264, 265). This is an important variable to consider as exercise selection can influence overall adaptation to training (10, 131).

One modality of resistance training is commonly referred to as “Traditional training” utilises movements rooted in primary patterns push, pull, hinge, squat that establish the groundwork for overall muscular development and performance (29). This modality will often utilise bilateral training movements such as the back squat, deadlift, bench press, and pull-ups. For clarity and consistency in this study, the term "traditional resistance training" will be used to denote this modality.

Among strength and conditioning professionals, traditional training often emerges as the preferred modality (266-268). It’s effectiveness in elevating athletic performance is well-documented, with research showing its positive impact on muscular strength (158), lower limb muscular power (266) linear running speed (266, 269) and change of direction ability (270). When considering bilateral movements like squats and deadlifts, coaches often favour these for their potential to be performed with a higher magnitude of load, thereby significantly increasing force production (260, 266, 271). This is underscored by findings that indicate almost double the loading capacity in bilateral squats as opposed to unilateral variants like the rear foot elevated split squat (272). These movements offer the advantage of stability and the capacity to manage greater loads, which can accelerate strength gains (259).

Functional training has received increasing attention in recent years and has gained popularity within both athletic and general fitness populations (273-275). It represents a departure from traditional strength training approaches, which have historically focused on the development of maximal force production through bilateral, linear exercises such as the squat, deadlift, and bench press (276-278). While these conventional methods are effective for building foundational strength, they may not fully address the complex, multi-faceted demands of athletic performance, which often involve asymmetrical, multi-directional, and reactive movement tasks (273, 279-281).

Functional training is fundamentally based on the idea that strength and power should be developed to mirror the biomechanical, neuromuscular, and coordination demands of sport-specific movements a principle known as dynamic correspondence (282). This principle suggests that training should mirror the direction, velocity, and muscular coordination of sporting actions to maximise performance improvements (282, 283). This can also include the use of multi-joint, multi-planar, and often unilateral exercises performed under conditions that challenge balance, proprioception, and movement control (280, 284).

Functional training literature (273) suggests that strength and conditioning programmes should not aim to replicate sport-specific skills directly but rather focus on enhancing the fundamental physical capacities that underpin effective movement in sport (273). This model favours unilateral and multi-directional loading patterns over traditional bilateral lifts and promotes a concept he describes as "sports-general" training an approach built on the recognition that most sports share common movement demands, such as jumping, sprinting, and cutting (273).

One framework that has attempted to operationalise this principle is the force-vector theory. This theory proposes that aligning the direction and amplitude of force application in training with the primary direction of force required in sport can enhance transfer (283). This evolution toward vector- and direction-specific training has been the focus of some recent research. Studies have reported improvements in sprint acceleration following resistance training interventions that include the hip thrust exercise (285, 286). This has been attributed to the biomechanical characteristics of the hip thrust, which applies resistance in a horizontal direction and primarily targets the gluteal musculature. It is suggested that this horizontal force orientation may more closely reflect the posteriorly directed ground reaction forces observed during the early phases of sprinting. As a result, the hip thrust is hypothesised to elicit neuromuscular adaptations that are more specific to the demands of horizontal movement, potentially offering greater transfer to sprint performance compared to vertically loaded exercises such as the back squat (286, 287).

Cooley et al. (288) reported that laterally resisted split squats may better target frontal plane force production critical for movements like cutting and change of direction. Applying lateral rather than vertical resistance, as in traditional squats, appears to enhance recruitment of stabilising and propulsive musculature for side-to-side movements. This aligns more closely with the biomechanical demands of change of direction tasks, where force must be generated and absorbed in the frontal plane.

While direction-specific loading has gained traction through research supporting horizontal and frontal plane resistance exercises (285, 286, 288), the underlying assumptions of force-vector theory have not gone unchallenged. Recent work by Fitzpatrick et al (289) raised concerns regarding the theory's reliance on external, global reference frames to define force direction. They argued that force application should instead be considered in relation to the athlete's own orientation and movement mechanics. In their study, training with hip thrusts did not produce greater improvements in horizontal jump performance than vertically loaded exercises, despite predictions based on vector alignment.

Despite its rising popularity the term functional training has often been criticised for its lack of clarity. Siff (290) argues that functionality should not be defined by the surfacelevel appearance of an exercise such as whether it is performed on one leg or an unstable surface but by its actual relevance to performance outcomes. From this perspective, functional training is not a discrete category of exercises but a training principle, whereby the selection of methods is guided by their ability to improve taskspecific outcomes, including sport performance or rehabilitation goals. La Scala Teixeira et al. (279) reinforce this by suggesting that the term functional training may be better replaced with descriptors such as integrated neuromuscular training **or** movement-specific strength training**,** which more accurately reflect the training's intent to coordinate multiple physical and neural systems under conditions similar to sport. Although the terminology surrounding functional training remains debated, the underlying principle consistently centres on enhancing an athlete's ability to perform sport-relevant movements. Rather than focusing solely on developing absolute strength, functional training aims to improve physical qualities such as coordination, balance, and force production in ways that are transferable to the unilateral, multi-directional, and dynamic conditions encountered in sport.

Despite ongoing debate regarding its definition, classification, and scientific utility, functional-style training and its various iterations have gained increasing popularity within strength and conditioning practices (273, 279, 280, 285, 288, 291). Strength and conditioning practices have increasingly shifted away from traditional barbellbased resistance training towards the incorporation of unilateral, multi-planar, and directionally specific exercise modalities (280, 284) with the aim of enhancing sportspecific performance. Although the inherent variability and task-specific nature of functional training make it challenging to systematically evaluate, for the purposes of this study, exercises that have attracted considerable interest in both the scientific literature and applied settings will be incorporated. These include the barbell hip thrust, unilateral squat variations, and multi-directional lunge patterns.

When designing training programs for youth or novice athletes, a pragmatic approach often favours traditional training as the starting point (14). These movements tend to offer a more stable environment for initiating strength development, providing an ideal starting point for novice athletes due to their inherent stability and ease of execution. By simplifying the recruitment of stability muscles, it establishes a solid foundation enabling athletes to safely and effectively generate force (14). Additionally, coaching bilateral movements is comparatively straightforward. The stability and symmetry inherent in these lifts make them particularly accessible and quickly understandable for beginners. While mastering technique remains crucial, the lesser demand for control and stability in bilateral training allows for effective performance even with minimal coaching intervention (14).

The transition to functional training movements, which demand higher control in less stable positions, presents specific challenges. As strength increases, so does the risk of adopting potentially harmful positions or movements, such as increased spinal flexion, hip flexion, and internal pelvic rotations, which may lead to increased injury risk, particularly with higher loads (292-294). Functional training movements inherently require more time since each limb must be trained separately. This doubled time commitment not only impacts the duration of training sessions but also influences cumulative fatigue a crucial factor when considering the overall training load on developing athletes (267). Therefore, for beginners, it may be advantageous to prioritise bilateral training until proper techniques are established.

To the best of the authors knowledge there are four studies which have investigated different training modalities in youth populations (271, 272, 276, 295). Although the modalities utilised are not identical to the one proposed in this study, they are similar in that they compare functional training exercises and traditional training exercises. Keiner et al. (154) examined the effects of different training methods on elite adolescent soccer players. Traditional strength training (STG) produced the greatest improvements across all performance metrics, including maximal strength, squat jump height, sprint speed, and change of direction. In comparison, the plyometric and sprint training group (PSTG) saw limited improvements, particularly in strength and sprint performance. While PSTG showed some gains in jumping and agility, these were less pronounced than in STG. The functional training group (FTG), which focused on stability, core, and bodyweight exercises, showed the least improvement across all measures. The study concluded that traditional strength training is the most effective method for improving strength and power in elite youth soccer players, with plyometric/sprint and functional training offering comparatively limited benefits. Stern et al. (141) compared bilateral and unilateral exercises in elite youth soccer players over six weeks. The bilateral group improved overall lower-body strength and sprint speed, especially in bilateral strength tests. The unilateral group showed greater gains in single-leg strength, rear foot elevated split squats (RFESS), and single-leg jump performance. They also outperformed in the 505 change of direction test, highlighting the specificity of unilateral training for agility-focused tasks. While both approaches were effective, bilateral training better enhanced general strength and speed, whereas unilateral training improved single-leg power and movement efficiency (141).

Zhao et al. (155) studied bilateral (BL) vs. unilateral (UL) leg press training in adolescent rugby players over five weeks. Both groups improved bilateral strength, but the UL group saw greater gains in unilateral strength. However, neither group showed significant improvements in vertical jump or sprint performance, suggesting that short-term strength gains may not translate to enhanced athletic performance.

Speirs et al. (142) investigated unilateral (rear elevated split squats) and bilateral (back squats) training in academy rugby players over five weeks. Both groups achieved similar improvements in lower-body strength, 40-meter sprint speed, and change of direction. The findings suggest that either method can be effectively used to enhance key performance metrics in youth athletes.

There is evidence that the following modalities can improve physical performance outcomes in youth athletes; Traditional strength training enhances strength, jump, sprint, and change of direction (154) as does sprint and plyometric training154). Unilateral exercises improve single-leg strength (141, 142, 155). Bilateral exercises improve bilateral strength (141, 142, 155).

There are a very limited number of studies comparing training modalities. Studies do investigate the addition or comparison of specific exercises (141, 142, 155), or comparison of multiple training modalities (154). The functional training program by Keiner et al. (154) lacks the progression in load and complexity typically seen in longterm strength and conditioning programs. The reliance on low-intensity mini-band and bodyweight exercises limits adaptation, as it doesn't progressively challenge performance outcomes like strength or power. Moreover, the exercises seemed primarily aimed at stability and injury prevention, such as lateral walks, planks, and bridging. While valuable in certain phases of training, a long-term program would adopt a more balanced approach, incorporating movements that directly enhance strength and power, key performance indicators in sports like soccer. These studies add important scientific information to the evidence supporting the application of resistance training in youth; however, they do not provide ecologically valid comparison of different training modalities and how these might improve physical performance.

The existing research on youth resistance training lacks direct comparisons between full training programmes that utilise different modalities. Specifically, regarding the comparison of traditional resistance training and functional resistance training programmes, without the inclusion of plyometric or sprint training or the comparison or addition of a single exercise. It would be beneficial to focus solely on resistance training, comparing comprehensive programmes consisting of multiple exercises commonly prescribed by strength and conditioning practitioners. This research could provide valuable insights for strength coaches, helping them understand the potential differences between traditional and functional training approaches and allow them to optimise valuable training time.

Therefore, this study will employ two complete training programs one with traditional resistance training exercises and the other with functional training exercises. With the aim to compare the effects of traditional training versus functional training on measures of strength, power, speed and change of direction in youth footballers.

6.3 METHODS

Participants

An under 14s male academy football squad (n=22) was recruited to participate in this study. Each participant had regularly engaged in resistance training for ≤ 6 months and were familiar with the exercises conducted in the resistance training sessions. A separate control group (CG) (*n*= 11) were recruited from an under 14s team of a local football club and had no resistance training experience. Participant characteristics are shown in Table 6.1. Participants were given full details of the study procedures and informed of the risks and benefits of the study before any data collection. Each participant completed a physical activity readiness questionnaire (PARQ). Participants provided personal and parental, or guardian written informed consent before participation. All participants were free from injury and deemed eligible for participation by their club's medical staff. Ethical approval was granted by University of Essex.

Maturity offset was calculated using the Moore et al. (57) simplified regression equation: maturity offset = –7.999994 + (0.0036124 × [Age × Height]),
which provides an estimate of years from peak height velocity (PHV).

TTG had a mean maturity offset of +0.09 ± 0.41 years. FTG and Control had mean offsets of +0.25 ± 0.37 years and +0.14 ± 0.51 years, respectively.

Table 6.1 Participant characteristics

	TTG	FTG	Control
N=	11	11	11
Age (years)	13.8 (±0.29)	13.7 (±0.24)	13.7 (±0.36)
Height (cm)	162.1 (±9.74)	165.7 (±7.1)	164.4 (±8.05)
Weight (kg)	48.7 (±8.18)	51.7 (±6.43)	52.7 (±6.81)
Maturity Offset (yrs)	0.09 (±0.41)	0.25 (±0.37)	0.14 (±0.51)

Abbreviations TTG = Traditional training group, **FTG** = Functional training group

Procedure

The 8-week resistance training intervention took place during the competitive phase of the season.

Participants were randomly assigned to one of two groups. A traditional training group (TTG) *n*= 11 or a functional training group (FTG) *n*= 11. Both TTG and FTG groups were assigned two resistance training routines, shown in Table 6.2. Both groups performed each routine once per week (routine A on Tuesday and routine B on Thursday). Both groups trained at the same time, sessions were performed either before or after football training, however the authors had no control of session sequence. The control group (CG) performed two sessions per week of football training with no resistance training.

Testing of 10 m and 20 m sprints, countermovement jump (CMJ), and isometric midthigh pull (IMTP) were taken before and after the 8-week training intervention. All testing was conducted on the same day in the following sequence: the 10 m, 20 m sprints were assessed first, followed by the 505 change of direction test. After a 60 min rest period, counter movement jumps and then isometric mid-thigh pull was measured.

Lower Body Muscular Force

High levels of muscular force are a crucial are inherent in the sport of football (138, 158). A valid and reliable method for testing lower limb muscular force is by Isometric Mid-thigh pull (IMTP) test (249). IMTP testing was performed on ForeDecks FDlite force platforms at 1000Hz sampling frequency (ForceDecks, Vald performance, Australia) and data was analysed using ForceDecks software (ForceDecks, Vald erformance, Australia). The bar was positioned to mimic the position of the second pull during a power clean exercise. Once the participant was in place the force trace was reset to zero to account for body mass. Participants were then instructed to pull as hard as possible and drive their feet into the force platform until they were instructed to stop, each attempt lasted 10 seconds. Participants completed a total of 3 attempts each, with a 120s recovery between each attempt. The largest peak force value was used for analysis.

Lower Body Muscular Power

Lower body muscular power and jumping ability are important determinants of performance in football (158, 167). A valid and reliable way to assess lower body muscular power is with counter movement jump (CMJ) testing (167, 250). CMJ were recorded using ForeDecks FDlite force platforms at 1000Hz sampling frequency (ForceDecks, Vald performance, Australia) and data was analysed using ForceDecks software (ForceDecks, Vald erformance, Australia) CMJ was performed with hands on hips and straight legs during flight phase. Each participant performed 3 jumps, with a recovery of 60s between jumps. The highest value for jump height was recorded for analysis. In addition to raw countermovement jump (CMJ) height, peak muscle power

(PMP) was also estimated to provide a more comprehensive assessment of lowerlimb explosive capacity. PMP was calculated using a validated predictive equation developed by Gomez-Bruton et al. (253), which accounts for both vertical jump height and body mass. This equation is specifically designed for youth populations and has demonstrated strong predictive accuracy:

Power (W)=54.2×Jump Height (cm)+34.4×Body Mass (kg)−1,520.4Power (W)=54.2× Jump Height (cm)+34.4×Body Mass (kg)−1,520.4

Peak power values were computed individually using each participant's recorded CMJ height and body mass for both pre- and post-tests. The difference scores (Post – Pre) were then used to evaluate absolute reliability, consistent with procedures for other performance metrics.

Linear Sprint Speed

Acceleration and short distance sprint speed are an important physiological consideration in football (158, 254). A valid and reliable way to assess linear speed and acceleration is by measuring 10 m and 20 m sprint times (119, 254).

Testing took place on an indoor artificial (3G) surface, participants were instructed to wear football boots to ensure adequate traction. Time was measured using a photogate timing system (Brower Timing Systems, Utah, USA). Gates were placed at 10 m and 20 m intervals and timings for 10 m and 20 m sprints were obtained from each sprint attempt. Each participant completed three total sprint attempts, with a 120 s recovery between each attempt. The shortest time recorded was then converted from time (s) to speed (m/s) to be used for analysis.

Change of Direction Speed

A 505 change of direction test was conducted as a reliable and valid test of change of direction speed (194) and serves as an assessment of multidirectional speed and unilateral power (20, 296) which is an important quality in team sports. The 505 test was set out in accordance with previous literature (194, 195, 197) a diagram of the test is shown in Figure 5.1. A photogate timing system (Brower Timing Systems, Utah, USA) was used to record 3 attempts on each leg. Photogates were placed 10 m from the start line. Testing procedure was performed as per previous literature (195). A researcher was placed at the turning line to ensure that the participants foot had crossed the line and that the correct foot was used to make the turn. If either of these conditions were violated, then the test was null, and the participant was instructed to attempt again.

Six total attempts were recorded, three turns using the right foot and three using the left foot, the order of which was randomised among subjects. From these results the shortest time of each foot was taken and then combined before analysis to give a combined effect on change of direction speed.

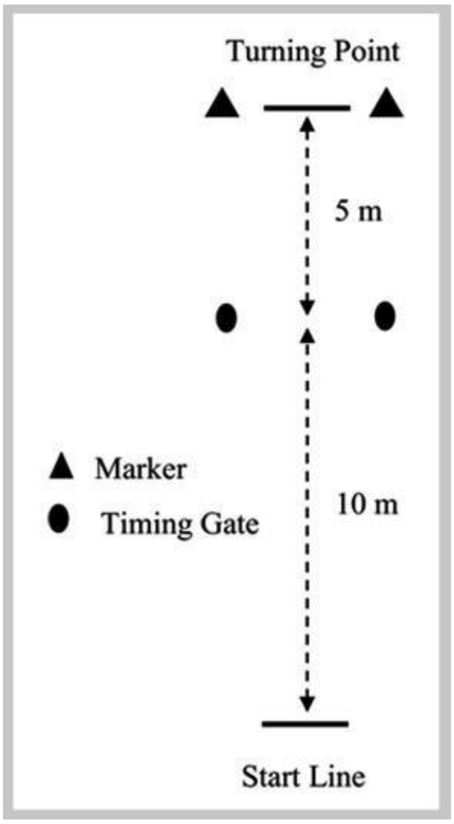

Figure 6.1 Diagram of 505 change of direction procedure Source: Nimphius et al, 2016

Resistance Training Intervention

TTG group was assigned a two whole body training programs (Routine A and B) consisting of traditional barbell and dumbbell exercises, which were performed bilaterally and in the sagittal plane. FTG group was also assigned two whole body training programs (Routine A and B) consisting of a mixture of Unilateral, Bilateral and multiplanar exercises. Participants of both experimental groups were all familiar with resistance training (≤6 months experience) and were deemed competent with basic exercise techniques (i.e. squats, deadlifts, presses, pulls). According to the guidelines from the UKSCA (33) and the NSCA (1) this would suggest the participants were of novice-intermediate experience therefore volume and loading were prescribed to reflect the guidelines. Each exercise was performed using a self-selected load based on the participant's perceived effort. Participants were instructed to select a resistance that allowed them to complete the prescribed number of repetitions while reaching a moderate-to-high level of intensity, typically corresponding to an RPE (Rate of Perceived Exertion) of 7–9 on the Borg CR-10 scale. Participants were already familiar with the use and interpretation of RPE through previous training experience, and this was reinforced during initial sessions.

Loads were adjusted over time based on individual feedback and performance, participants were encouraged to increase resistance when the RPE for a given exercise dropped below the target range, or when the exercise could be completed with little effort.

The range of actual loads used by participants and full details of the exercise programs, including structure and exercise selection, are presented in Table 6.3. All training sessions were supervised by a minimum of two qualified strength and conditioning coaches, who monitored technique, ensured adherence to loading protocols, and verified participant effort levels. Attendance records are provided in Table 6.2.

Table 6.2 Attendance values and percentages for each participant

Participant	**TTG** Attendance (%)	**FTG** Attendance (%)
1	12 (75)	11 (65.75)
2	16 (100)	13 (81.25)
3	15 (93.75)	13 (81.25)

4	13 (81.25)	15 (93.75)
5	13 (81.25)	12 (75)
6	12 (75)	14 (87.5)
7	11 (65.75)	10 (62.5)
8	11 (65.75)	13 (81.25)
9	13 (81.25)	16 (100)
10	9 (56.25)	16 (100)
11	16 (100)	15 (93.75)

Table 6.3 Description of resistance training routine A and routine B for both groups

Traditional training group (TTG)									
Routine A					Routine B				
Exercise	**Volume**	**Recovery**	**Load (range)**	**RPE (range)**	**Exercise**	**Volume**	**Recovery**	**Load (range)**	**RPE (range)**
Back squat	3 sets 8 reps	90s	25-40kg	7-8	Hex bar deadlift	3 sets 8 reps	90s	30-50kg	8-9
Pull ups	3 sets 8 reps	90s	B/W	6-8	Bench press	3 sets 8 reps	90s	B/W	6-8
RDL	3 sets 8 reps	90s	20-32.5kg	6-8	Front squat	3 sets 8 reps	90s	20-30kg	7-8
DB shoulder press	3 sets 8 reps	90	6-12kg	6-9	Barbell row	3 sets 8 reps	90s	20-30kg	6-7

Functional training group (FTG)									
Routine A					Routine B				
Exercise	**Volume**	**Recovery**	**Load (range)**	**RPE (range)**	**Exercise**	**Volume**	**Recovery**	**Load (range)**	**RPE (range)**
RFE split squat	3 sets 8 reps (each leg)	90s	B/W – 20kg	6-7	Hip thrust	3 sets 8 reps	90s	40-60kg	7-9
SA landmine press	3 sets 8 reps (each arm)	90s	5-10kg	6-8	Ring press ups	3 sets 8 reps	90s	B/W	7-9
SL RDL	3 sets 8 reps (each leg)	90s	10-20kg	6-9	Multi direction lunges	3 sets 6 reps (each leg)	90s	10-20kg	7-8
SA pulldowns	3 set 8 reps (each arm)	90s	10-22.5kg	6-8	SA DB rows	3 set 8 reps (each arm)	90s	12.5-18kg	6-8

Abbreviations: **RDL**= Romanian deadlift, **DB** = Dumbbells, **Reps** = Repetitions, **B/W** = Bodyweight, **RFE** = Rear foot elevated, **SA** = Single arm, **SL** = Single leg.

6.4 DATA TREATMENT

The aim of this study was to compare the effects of traditional versus functional resistance training on lower body muscular force, lower body muscular power, sprint speed, and change of direction speed in youth academy footballers. To achieve this, pre- and post-training measures were compared across three groups: a traditional training group (TTG), a functional training group (FTG), and a non-training control group.

The independent variable in this study was training modality. The conditions were a control group, condition 1 where participants engaged in traditional training and condition 2 where participants engaged in functional training. The primary dependent variables were the changes in outcomes (force, jump height,10 m and 20 m sprint speed and change of direction speed), which were quantified as the differences between post-training and pre-training values. An example for force is detailed below.

$$\Delta Force(N) = Force\ post\ training(N) - Force\ pre\ training(N)$$

This calculation was applied to all other outcomes including force, jump height,10 m and 20 m sprint speed and change of direction speed.

To analyse the mean differences in multiple dependent variables simultaneously across the three groups, an Analysis of Covariance (ANCOVA) was employed. ANCOVA allowed for the adjustment of baseline differences by including pre-training measures of each dependent variable as covariates, thereby isolating the effect of the training interventions. The ANCOVA tested for overall differences among the TTG, FTG, and CG groups across all dependent variables while controlling for pre-training scores. If the ANCOVA indicated a significant overall effect, subsequent univariate ANOVAs were to be conducted for each dependent variable to identify which specific variables contributed to the group differences.

The same analytical approach was applied to each set of dependent variables. For example, in the analysis of lower body muscular force, the dependent variable was the Δ Force (N). To test the hypothesis that there were differences in the mean changes across the training groups, the factor 'Group' was introduced, which had three levels: Control, TTG (traditional training group), and FTG (functional training group). Pre-training values of force were included as covariates to adjust for between-group differences in pre-training means, ensuring that the observed differences in posttraining outcomes could be attributed to the intervention.

ANCOVA was conducted for the other dependent variables, lower body muscular power, sprint speed, and change of direction speed using their respective pre-training values as covariates. Effect sizes were calculated using Hedges' g to account for small sample sizes. This was based on the mean differences between groups, pooled standard deviations, and corrected for sample size bias. Interpretation followed conventional thresholds: small (g = 0.2), moderate (g = 0.5), and large (g = 0.8)

6.5 RESULTS

Force

Unadjusted mean values for each group are shown in Table 6.4. TTG had a significantly greater increase in force compared to the Control group, with a mean difference of 132.85 N (95% CI [44.64, 221.07], P = .004). The difference between FTG and the Control group was not statistically significant, with a mean difference of 65.83 N (95% CI [-45.96, 177.62], P = .238). The difference between TTG and FTG was not significant, with mean difference of 67.02 N (95% CI [-13.97, 148.00], P = .101). Figure 6.2 shows the adjusted mean values for change in force across the three experimental groups. Adjusting for pre-training force as a covariate, ($F_{(1,29)}$=0.218, P = .644, ηp^2= .007) there was a statistically significant main effect for group on ΔForce, ($F_{(2,29)}$ = 5.60, P = .009, ηp^2= .278). In isometric mid-thigh pull (IMTP) force, the TTG group showed a moderate-to-large improvement compared to Control (g = 0.75), while FTG showed a small-to-moderate effect (g = 0.37).

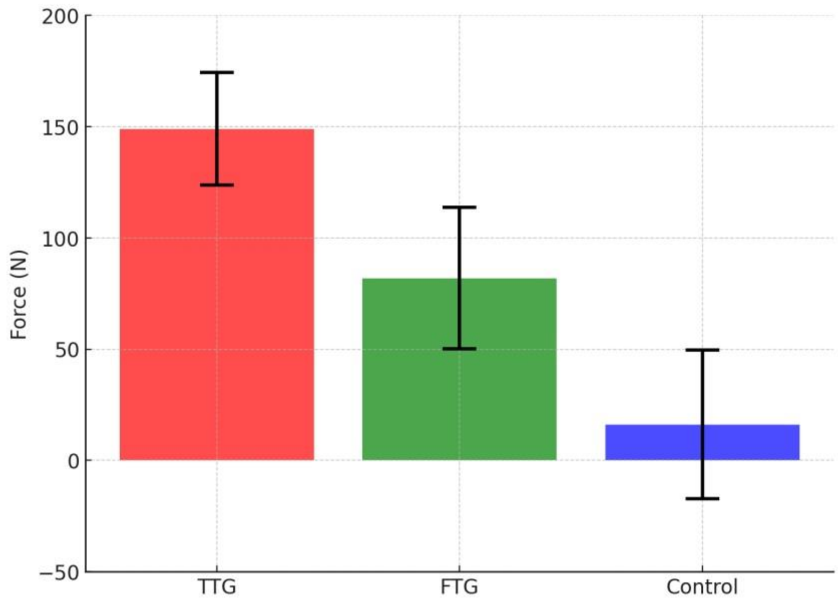

Figure 6.2 Adjusted mean change in Force (N) for youth academy footballers receiving different resistance training modalities. Bars represent adjusted means, with error bars indicating standard errors.

Counter movement jump

Unadjusted mean values for each group are shown in Table 6.4. TTG had a significantly different in ΔCMJ compared to the Control group, with a mean difference of 2.057 cm (95% CI [0.442, 3.672], *P* = .014). The difference between FTG and the Control group was not statistically significant, with a mean difference of 1.432 cm (95% CI [-0.855, 3.720], *P* = .210). The difference between TTG and FTG was statistically significant, with a mean difference of -2.057 cm (95% CI [-3.672, -0.442], *P* = .014).

Figure 6.3 shows the adjusted mean values for change in counter movement jump (CMJ) across the three experimental groups. Pre-training CMJ was not a significant covariate, ($F_{(1,29)}$ = 0.221, p = .642, ηp^2= .008). There was a significant main effect for group on ΔCMJ, ($F_{(2,29)}$=3.63, *P* = .039, ηp^2= .200). For countermovement jump (CMJ) height, FTG demonstrated a small improvement relative to Control (g = 0.35), whereas TTG showed negligible change (g = –0.04).

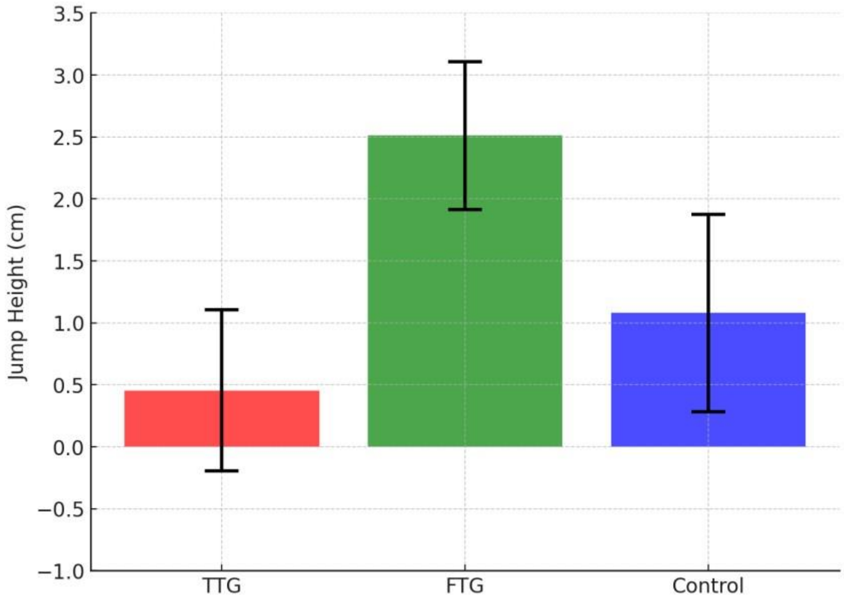

Figure 6.3 Adjusted mean change in CMJ height (cm) for youth academy footballers receiving different resistance training modalities. Bars represent adjusted means, with error bars indicating standard errors.

Peak Power

Unadjusted mean values for each group are shown in Table 6.4. The difference in ΔPower between FTG and the Control group was not statistically significant, with a mean difference of 138.365 W (95% CI [-6.604, 283.334], *P* = .065). The difference between TTG and the Control group was also not statistically significant, with a mean difference of -36.611 W (95% CI [-200.478, 127.255], P = 1.000). The difference between FTG and TTG did not reach statistical significance, with a mean difference of 101.754 W (95% CI [-12.387, 215.895], P = .093). In CMJ peak power, TTG showed a small effect (g = 0.28) and FTG a trivial effect (g = 0.04) compared to Control. Figure 6.4 shows the adjusted mean values for change in power output across the three experimental groups. Pre-training power output was not a significant covariate, ($F(1,29)$ = 1.101, P = .303, ηp^2 = .037). There was a significant main effect for group on ΔPower, ($F_{(2,29)}$ = 4.526, P = .019, ηp^2 = .238).

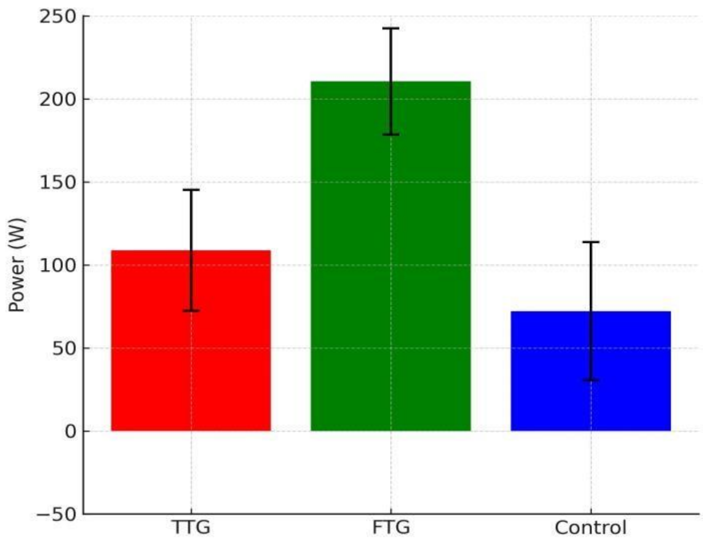

Figure 6.4 Adjusted mean change in Peak Power (W) for youth academy footballers receiving different resistance training modalities. Bars represent adjusted means, with error bars indicating standard errors.

10 m sprint speed

Unadjusted mean values for each group are shown in table 6.4. TTG did not have a significantly different Δ10 m sprint speed compared to the Control group, with a mean difference of -0.027 seconds (95% CI [-0.252, 0.199], P = .810). The difference between FTG and the Control group was not statistically significant, with a mean difference of -0.116 seconds (95% CI [-0.385, 0.154], P = .387). The difference between TTG and FTG was not statistically significant, with a mean difference of 0.089 seconds (95% CI [-0.117, 0.294], P = .384). Figure 6.5 shows the adjusted mean values for change in 10 m sprint speed across the three experimental groups. Pretraining 10 m sprint time was not a significant covariate, ($F_{(1,29)}$=0.337, P = .566, ηp^2= .011). There was no significant main effect for group on Δ10 m sprint speed, ($F_{(2,29)}$=0.492, P = .616, ηp^2= .033). TTG displayed a small negative effect in 10m speed compared to Control (g = –0.19), and FTG a moderate negative effect (g = –0.56), suggesting limited sprint adaptations.

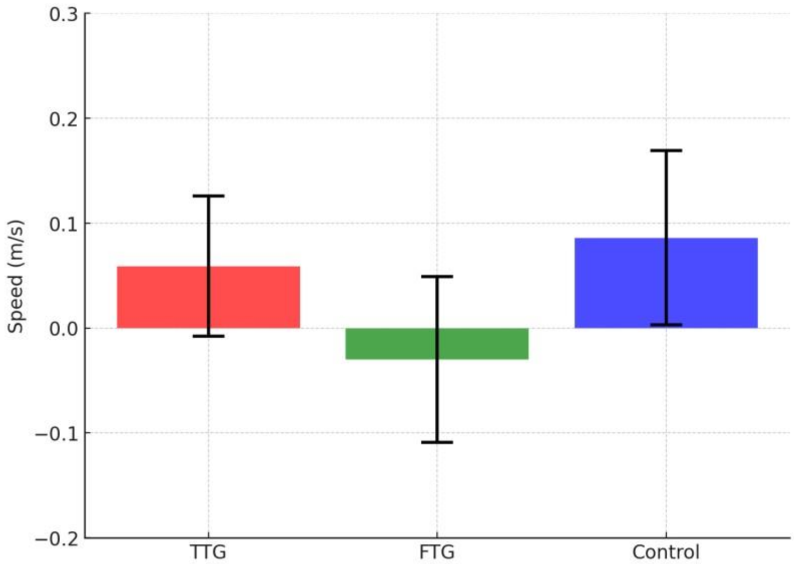

Figure 6.5 Adjusted mean change in 10 m sprint speed (m/s) for youth academy footballers receiving different resistance training modalities. Bars represent adjusted means, with error bars indicating standard errors.

20 m sprint speed

Unadjusted mean values for each group are shown in Table 6.4. TTG did not have a significantly different Δ20 m sprint speed compared to the Control group, with a mean difference of 0.068 seconds (95% CI [-0.103, 0.239], *P* = .422). The difference between FTG and the Control group was not statistically significant, with a mean difference of -0.013 seconds (95% CI [-0.204, 0.178], *P* = .889). The difference between TTG and FTG was not statistically significant, with a mean difference of 0.081 seconds (95% CI [-0.077, 0.239], *P* = .303). Figure 6.6 shows the adjusted mean values for change in 20 m sprint speed across the three experimental groups. Pretraining 20 m sprint speed was not a significant covariate, ($F_{(1,29)}$=0.123, *P* = .729, ηp^2= .004). There was no statistically significant main effect for group on Δ20 m sprint speed, ($F_{(2,29)}$ = 0.674, *P* = .517, ηp^2= .044). For 20m sprint speed, TTG achieved a small positive effect (g = 0.23), while FTG showed no difference (g = 0.00) compared to Control.

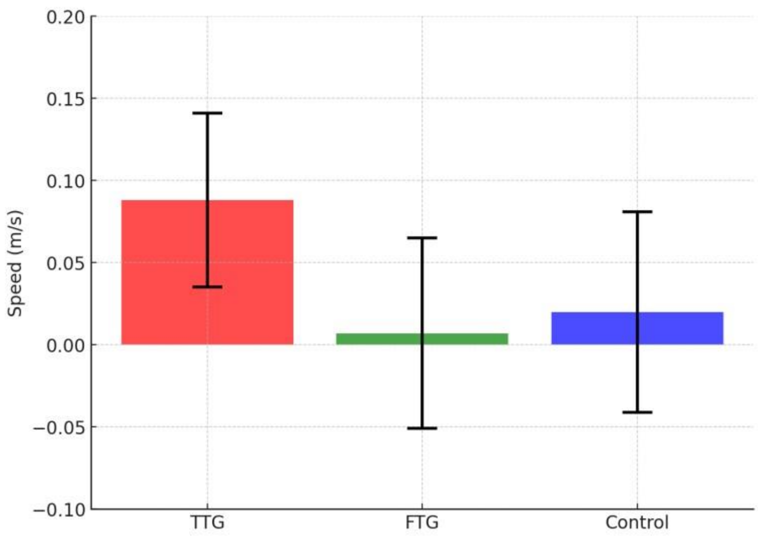

Figure 6.6 Adjusted mean change in 20 m sprint speed (m/s) for youth academy footballers receiving different resistance training modalities. Bars represent adjusted means, with error bars indicating standard errors.

505 change of direction speed

Unadjusted mean values for 505R and 505L for each group are shown in Table 6.4 FTG had a significantly greater improvement in agility compared to the Control group, with a mean difference of 0.220 seconds (95% CI [0.137, 0.304], *P* = <.001). The difference between TTG and the Control group was not statistically significant, with a mean difference of 0.013 seconds (95% CI [-0.062, 0.087], *P* = .725). FTG improvement was significantly greater than the TTG, with a mean difference of 0.207 m/s (95% CI [0.130, 0.284], *P* = <.001). Figure 6.7 shows the adjusted mean values for change in 505R speed and figure 6.8 shows the values for change in 505L speed across the three experimental groups. Adjusting for pre-test 505 scores as a covariate, ($F_{(1,41)}$ =2.227, *P* = .146, *ηp*2= .051), there was a statistically significant main effect for group on Δ505, ($F_{(2,41)}$ = 18.939, *P* = <.001, *ηp*2= .566). TTG showed a moderate positive effect on 505 left-side COD speed (g = 0.97), and FTG showed a large effect (g = 1.56), indicating meaningful improvements in COD ability.

For right-side COD, TTG and FTG also showed moderate (g = 0.55) and large (g = 1.08) effects, respectively.

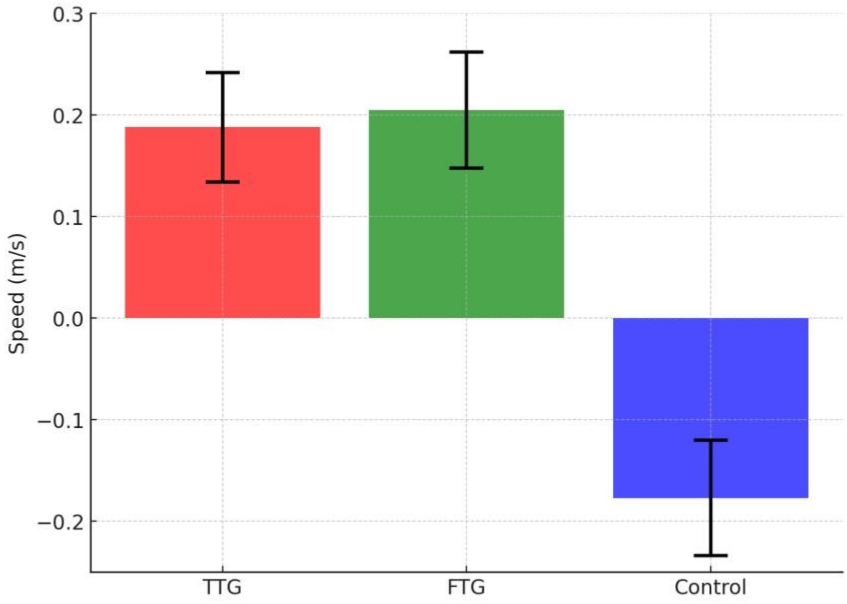

Figure 6.7 Adjusted mean change in 505R change of direction speed (m/s) for youth academy footballers receiving different resistance training modalities. Bars represent adjusted means, with error bars indicating standard errors.

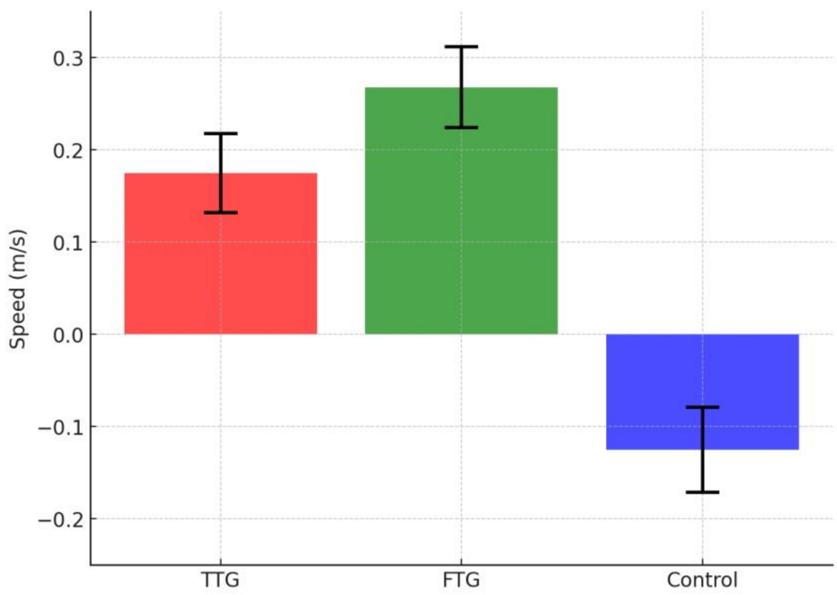

Figure 6.8 Adjusted mean change in 505L change of direction speed (m/s) for youth academy footballers receiving different resistance training modalities. Bars represent adjusted means, with error bars indicating standard errors.

Table 6.4 Mean, Standard Deviation and Change in pre and post training values for TTG, FTG and Control groups.

	Pre-Training Mean (SD)	Post-Training Mean (SD)	Δ (Post – Pre) Mean (SD)

Control (n=11)			
Force (IMTP [N])	771.50 (107.26)	777.42 (141.08)	5.92 (0.27)
Jump height (CMJ [cm])	39.23 (4.41)	40.04 (5.04)	0.81 (0.63)
Peak Power (CMJ [W])	1533.07 (373.37)	1621.44 (395.82)	88.36 (100.0)
Speed (10 m sprint [m/s])	5.08 (0.25)	5.19 (0.32)	0.11 (0.07)
Speed (20 m sprint [m/s])	5.68 (0.34)	5.69 (0.40)	0.01 (0.06)
COD (505L [m/s])	0.24 (0.14)	3.75 (0.25)	-0.09 (0.10)
COD (505R [m/s])	3.86 (0.27)	3.74 (0.29)	-0.12 (0.14)
Traditional training TTG (n=11)			
Force (IMTP [N])	1133.45 (237.49)	1283.55 (239.73)	150.10 (2.24)
Jump height (CMJ [cm])	25.38 (5.13)	26.00 (4.55)	0.62 (0.58)
Peak Power (CMJ [W])	1733.25 (392.155)	1934.62 (413.68)	201.37 (101.53)
Speed (10 m sprint [m/s])	5.46 (0.26)	5.52 (0.28)	0.06 (0.02)
Speed (20 m sprint [m/s])	6.07 (0.34)	6.16 (0.39)	0.09 (0.05)
COD (505L [m/s])	4.01 (0.16)	4.18 (0.12)	0.16 (0.17)
COD (505R [m/s])	3.97 (0.24)	4.16 (0.16)	0.19 (0.25)
Functional Training FTG (n=11)			
Force (IMTP [N])	1389.91 (297.12)	1481.00 (330.21)	91.09 (3.19)
Jump height (CMJ [cm])	27.20 (5.45)	29.82 (5.86)	2.62 (0.41)
Peak Power (CMJ [W])	2419.53 (267.02)	2521.12 (330.40)	101.58 (105.71)
Speed (10 m sprint [m/s])	5.69 (0.30)	5.64 (0.38)	-0.05 (0.08)

Speed (20 m sprint [m/s])	6.27 (0.33)	6.28 (0.39)	0.01 (0.06)
COD (505L [m/s])	4.07 (0.12)	4.31(0.16)	0.24 (0.14)
COD (505R [m/s])	4.10 (0.11)	4.26 (0.17)	0.15 (0.18)

Abbreviations- Force (N) – maximal force of the lower limb musculature by isometric mid-thigh pull (IMTP) **Countermovement Jump** (CMJ) – measured as jump height (cm), **Peak power** – measured as jump height then converted into (W) **10 m and 20 m sprint** - measured as time (s) to run 10 m or 20 m then converted to speed (m/s) **505L, 505R** - measured as time (s) to complete the 505- change of direction (COD) on both left (L) and right (R) side test converted to speed (m/s).

6.6 DISCUSSION

This study aimed to compare the effects of traditional resistance training versus functional resistance training on various performance measures, including lower body muscular force, lower body muscular power, sprint speed, and change of direction speed in youth academy footballers. The results provide important insights into how different training modalities can influence athletic performance in youth athletes.

Lower Body Muscular Force

Muscular force is an important determinant performance in team sports, players with higher force production and the ability to generate higher levels of force more rapidly (RFD) are associated with better overall athletic performance (29).

Traditional resistance training (TTG) resulted in a clear improvement in lower body muscular strength compared to the control group, with a 13.2% increase in force that was statistically significant. Functional resistance training (FTG) led to a 6.6% improvement, though this was not statistically significant when compared to the control group's 0.8% increase. When comparing traditional and functional training, traditional methods appeared more effective in enhancing lower body strength.

However, it is important to note that while both experimental groups showed improvements, changes in isometric mid-thigh pull (IMTP) force did not exceed the minimum detectable change (MDC_{95}) thresholds. Specifically, the FTG's gain of 91.09 N remained below this threshold, and changes in the TTG also fell short of MDC_{95}. The control group showed no meaningful changes in any performance measures, further confirming that observed improvements in the intervention groups, while encouraging, may not definitively reflect true physiological adaptations.

Effect size analysis supported these findings, with the TTG demonstrating a moderateto-large effect (Hedges' g = 0.75) compared to the control group, indicating a potentially meaningful improvement in strength. The FTG showed a small-to-moderate effect (g = 0.37), suggesting more modest gains. Although the changes fell below the MDC threshold, the magnitude of these effects, particularly in the TTG, suggests the intervention may have produced practical, if not statistically definitive, benefits for lower body force development.

Previous literature supports the idea that both unilateral and bilateral training can significantly improve lower-body strength. Speirs et al. (272) found a 9.2% increase in rear foot elevated split squat (RFESS) strength in a unilateral training group and a 10.5% increase in back squat strength in a bilateral group, with both groups experiencing approximately a 5% improvement in the opposing exercise. Stern et al. (271) also reported substantial gains, with bilateral training improving back squat strength by 26.01% and RFESS strength by 23.34%, while unilateral training resulted in a 33.29% increase in RFESS strength. However, these studies assessed strength via performance in the specific exercises being trained, suggesting that a learning effect may have contributed to the improvements.

By contrast, the present study utilised the isometric mid-thigh pull (IMTP) to assess lower limb force production test that is less likely to be influenced by specific exercise familiarity and thus offers a more general measure of strength. The findings suggest that traditional bilateral exercises, such as the hex bar deadlift and back squat, which allow for heavier external loading, provide a more robust stimulus for strength development than the lighter loads used in functional exercises like the RFE split squat and single-leg RDL (132). For instance, participants in the TTG performed hex bar deadlifts with 30–50 kg and back squats with 25–40 kg. In contrast, FTG participants used notably lighter loads, RFE split squats with 0–20 kg and single-leg RDLs with 10–20 kg, potentially explaining the more modest strength gains observed.

Lower Body Muscular Power

When assessing lower body muscular power using countermovement jumps (CMJ), traditional resistance training did not result in a noticeable difference compared to the control group. In contrast, functional training led to a significant improvement in CMJ performance when compared to the control group. Additionally, when comparing traditional training to functional training, functional methods were shown to be more effective in enhancing jump height. This is further supported by effect size analysis, where the functional training group (FTG) demonstrated a small improvement in CMJ height relative to the control (Hedges' g = 0.35), while the traditional training group (TTG) showed a negligible effect (g = –0.04), reinforcing the greater effectiveness of functional approaches in this context.

While there was a significant overall effect of group on the change in peak power output, further analysis revealed that none of the differences between individual groups reached statistical significance. However, the functional training group demonstrated a clear trend toward greater improvements in peak power when compared to both the traditional training and control groups. These trends are reflected in effect size estimates, where TTG showed a small effect for peak power improvement (g = 0.28), and FTG demonstrated a trivial effect (g = 0.04) compared to the control.

These findings suggest that functional resistance training may offer more practical benefits for developing muscular power, even if the statistical comparisons between groups did not reach conventional significance levels.

These interpretations are supported by the observed changes in performance relative to the minimum detectable change (MDC_{95}) thresholds. In the FTG, CMJ height improved by 2.62 cm, surpassing the MDC_{95} of 2.25 cm, indicating a likely real gain in vertical jump ability. However, their peak power increase of 101.58 W did not exceed the MDC_{95} threshold of 121.82 W, suggesting a more modest effect on power output. Conversely, the TTG demonstrated a substantial improvement in peak power output (+201.37 W), exceeding the MDC_{95}, although their improvement in jump height did not surpass the threshold for a meaningful change. The control group showed no changes that exceeded MDC_{95} in either variable, indicating that any observed differences were likely due to measurement variability.

A meta-analysis by Liao et al. (297) compared the effects of unilateral and bilateral resistance training on jump performance. The meta-analysis revealed that unilateral resistance training had a significantly greater impact on improving unilateral jump performance, with a large effect size of 0.89 ($p < 0.0001$). Bilateral resistance training demonstrated only a trivial effect on bilateral jump performance, with a pooled effect size of -0.12, which was not statistically significant ($p = 0.79$). These findings suggest that while bilateral training might increase overall strength, it does not effectively translate into enhanced jump performance as unilateral training does

Furthermore, literature has reported that traditional-style (bilateral) training tends to produce better performance in bilateral jumps, such as squat jumps and CMJs (141), while functional training-style (unilateral) training typically yields better results in unilateral jump tests, like single-leg jumps and single-leg broad jumps (154). This suggests that the specific training modality used should ideally correspond to the type of performance being tested, with each approach being most effective for improving outcomes in similar types of exercises. There is no clear explanation for the results observed in this study. It is possible that the engagement of stabilising muscles during functional training played a role, as movements like jumps do require substantial neuromuscular coordination (141).

Sprint Speed

Higher levels of force and strength are strongly associated with faster sprint times, particularly through their impact on acceleration and ground contact time. Stronger athletes can generate greater forces more rapidly resulting in quicker acceleration and higher speeds over short distances. This capability is essential in team sports like soccer, rugby, and hockey, where linear speed often plays a critical role in successful performance during plays that require rapid bursts of acceleration (29). A systematic review and meta-analysis conducted by Seitz et al (260) reported that increases in lower-body strength. Specifically, the analysis found resistance training led to a 3.11% improvement in sprint performance, it also suggested a practical relevance for athletes who rely on high levels of speed, particularly over short to medium distances (under 30 metres).

Traditional training showed a slight increase in 10 m speed (1.1%) and 20 m speed (1.5%); however, this was not statistically significant compared to the control group, which showed increases of 2.2% in 10 m speed and 0.2% in 20 m speed. Functional training exhibited a small decrease in 10 m speed (0.9%) and a marginal increase in 20 m speed (0.2%), which were also not statistically significant compared to the control group. Importantly, changes in 10 m and 20 m sprint speed did not surpass MDC_{95} values in any group, suggesting that observed variations may not reflect meaningful or true changes in linear sprint performance.

Effect size analysis supports this interpretation. For 10 m sprint speed, the traditional training group (TTG) showed a small negative effect compared to the control group (Hedges' g = –0.19), while the functional training group (FTG) demonstrated a moderate negative effect (g = –0.56), suggesting limited or possibly adverse adaptations in short-distance sprint performance. For 20 m sprint speed, TTG showed a small positive effect (g = 0.23), while FTG showed no effect (g = 0.00), indicating that traditional training may have offered a slight benefit for longer sprint distance, albeit without statistical significance.

When comparing traditional training to functional training, traditional training demonstrated slightly better improvements in both 10 m and 20 m speed; however, these differences were not statistically significant, and the corresponding effect sizes reinforce the absence of a clear advantage for either training method.

This outcome has also been found in the literature. A meta-analysis conducted by Liao et al (141) found no statistically significant difference between unilateral and bilateral resistance training on measures of linear speed. The pooled effect size for speed performance was found to be trivial and non-significant. This indicates that neither training method demonstrated a clear advantage over the other in enhancing linear speed.

One possible explanation for the findings in the current study is that previous literature suggests significant improvements in sprint performance, particularly in the rate of force development (RFD), require heavy resistance training (13). However, the participants in the present study trained at an intensity of approximately 60-70% (≈8RM), which may not have been sufficiently heavy to elicit the desired RFD adaptations. Supporting this approach, Stern et al. (141) found Bilateral and unilateral training resulted in improvements in the 10 m sprint (4.29% and 5.20% respectively). The study utilised heavier loads of 75-85% 1RM and combined plyometric and resistance training in their study, which may account for the observed improvements in sprint speed. However, participants in the Stern et al (141) study were older (17.6 ± 1.2 years) and had a minimum of two years of training experience. They were, therefore, likely more able to train with heavier loads (higher %1RM) (1, 33, 34). Additionally, research has indicated that combining resistance training with plyometric or sprint specific drills is likely the most effective approach for enhancing sprint speed over short distances (260).

Change of Direction Speed

Change-of-direction (CoD) speed is a critical physical attribute in many field-based team sports, including soccer, handball, and rugby. The ability to rapidly change direction while maintaining speed and control is essential for effective performance in these sports, where athletes frequently need to decelerate and accelerate in new directions during gameplay. CoD speed is not only vital for in-game performance but also serves as an important predictor of on-field success and is used to distinguish between elite and sub-elite athletes (21).

When examining change-of-direction (CoD) speed, the analysis revealed a significant overall effect of group on agility improvement, although no significant difference was observed between the once-per-week training group and the control group. Both the traditional training group (TTG) and the functional training group (FTG) demonstrated meaningful improvements, with the FTG showing significantly greater gains in CoD performance compared to both the control and TTG groups. This highlights the superior effectiveness of functional training for enhancing agility.

Notably, improvements in both experimental groups exceeded the minimum detectable change (MDC_{95}) thresholds, indicating likely true performance enhancements. In the TTG, left and right 505 CoD test scores improved by +0.16 m/s and +0.19 m/s respectively, both above the MDC_{95} threshold of 0.07 m/s. The FTG achieved even greater gains, with changes of +0.24 m/s (left) and +0.15 m/s (right), further reinforcing the robustness of these improvements. Conversely, none of the changes in the control group surpassed the MDC_{95}, suggesting any observed variation was likely due to measurement error rather than actual performance change. These findings are supported by the effect size analysis. For the left-side 505 CoD test, TTG showed a moderate positive effect (Hedges' g = 0.97), while FTG demonstrated a large effect (g = 1.56). Similarly, on the right-side test, TTG exhibited a moderate effect (g = 0.55), and FTG again showed a large effect (g = 1.08). These magnitudes further emphasise the strong practical benefits of functional training on change-of-direction ability and provide additional support for the superiority of this approach in developing agility in youth athletes.

Resistance training has been shown to effectively enhance change-of-direction speed. A meta-analysis by Chaabene et al. (21) found a significant positive effect of resistance training on change of direction speed with greater improvements in youth, particularly children and adolescents. These improvements are attributed to both neural and morphological adaptations. Neural changes include better motor unit recruitment, synchronisation, and increased rate coding, leading to more efficient muscle contractions during change of direction tasks. Resistance training enhances force generation, particularly in the lower limbs, which is essential for the deceleration and acceleration phases of these movements (21).

Several studies provide insight into why the functional training might be more effective at improving change of direction speed than traditional training. Functional training typically emphasises multi-planar movements and unilateral exercises, which are directly relevant to the demands of the 505 tests, a measure of rapid deceleration and acceleration in lateral directions. Research by Nimphius et al (195) and Brughelli et al (20) suggests that such training modalities are particularly effective in enhancing neuromuscular coordination and stability during changes of direction, key elements that the 505 test specifically measures. Moreover, the training principle of specificity implies that focusing on unilateral and multiplanar movement patterns in training would more effectively translate into improved performance outcomes related to these key attributes (297). In contrast, traditional training focuses on bilateral, linear bi-lateral movements like squats and deadlifts, which, while excellent for developing overall strength and force production, may not translate as effectively to agility and change of direction tasks. The traditional training's less pronounced improvements in the 505 test likely reflect this.

Further limitations

The results of this study suggest that both traditional and functional resistance training interventions were effective in improving physical performance in youth footballers; however, biological maturity may have influenced the magnitude of these adaptations. Maturity offset calculations indicated that the Functional Training Group (FTG) was, on average, the most biologically mature (+0.25 ± 0.37 years), followed by the Control Group at +0.14 ± 0.51 years. The Traditional Training Group (TTG) had the lowest maturity offset, averaging +0.09 ± 0.41 years.

The improvements in countermovement jump height and change of direction ability observed in the FTG may therefore have been partially influenced by their more advanced maturity status (37, 70). In contrast, TTG exhibited the greatest improvement in muscular strength, suggesting that traditional resistance exercises can be effective even in athletes who are not yet fully mature. The absence of meaningful improvements in the Control Group is consistent with their lack of structured resistance training and suggests that maturity alone, while influential, is not sufficient to drive performance gains. Although the differences in maturity offset between groups fell within the standard error of estimate (±0.54 years) for the Moore2 method (57), the observed trend in group means still reflects a progression in biological development that may have contributed to the differences in training responsiveness. These findings support the interpretation that maturity status, while modest in variation, should be recognised as a potential confounding factor when evaluating the effects of different training modalities (35, 70). Future studies may benefit from grouping participants by biological maturity or statistically controlling for maturity offset in order to more precisely assess the true impact of resistance training interventions in youth athletes.

Study Originality

To the best of the author's knowledge, this is the first study to make direct comparison of two comprehensive resistance training programs: traditional resistance training and functional resistance training. Earlier studies have used more specific protocols. For instance, Speirs et al. (272) compared unilateral versus bilateral squat training and found both methods equally effective in improving lower-body strength and sprint performance, but their study focused on changes in a single exercise rather than an entire program. Similarly, Zhao et al. (295) examined the effects of unilateral and bilateral leg press exercises, reporting that unilateral training was more effective for improving unilateral strength, but again, this was limited to the leg press exercise alone.

The study by Keiner et al. (276) comes closest to the current research in its comparison of traditional and functional training methods. However, the functional exercises used in this study lacked the complexity and applicability needed to reflect a comprehensive, well-rounded training program. The author's emphasis on comparing two comprehensive resistance training programs, rather than focusing on individual exercises, offers a more accurate and meaningful understanding of how traditional training and functional training modalities impact athletic performance. This approach is particularly relevant in practical, real-world settings, where strength and conditioning coaches are responsible for developing entire training programs rather than making isolated adjustments to single exercises. Coaches design programs that include a variety of exercises working in concert to achieve specific performance goals. By comparing full training regimens, this study reflects the complexity of realworld strength and conditioning practices, where coaches create programs that integrate a variety of exercises to meet performance goals.

6.7 CONCLUSION

The Functional Training Group demonstrated a meaningful impact primarily on the 505 change of direction test, where it showed significant improvements compared to the Traditional Training Group. This outcome may be attributed to the nature of the exercises included in the functional training, which involved lateral and unilateral movements. These movements are particularly relevant to the 505 tests, which require athletes to decelerate and accelerate quickly in a lateral direction, a movement pattern that is predominantly unilateral in force application (195). Previous research has shown that resistance training focused on directional movements and plyometrics can significantly enhance specific directional performance metrics, such as change of direction speed (20, 195). The inclusion of uni-lateral and multi-planar exercises in the functional training program likely contributed to the observed improvements in the 505 test.

However, it is important to consider the broader context of strength and conditioning, where the primary goals are to increase overall strength, improve force absorption and production, and reduce injury risk (29, 210, 266). The findings from this study suggest that traditional training demonstrated greater gains in lower body muscular force, which is possibly due to the higher magnitude of loading used in traditional resistance training exercises.

Given the challenges discussed earlier in this thesis, such as the limited training experience of novice athletes, the significant time constraints in training sessions, and the logistical difficulties of managing larger groups, it may be more advantageous at an early stage to prioritise the simpler and more efficient traditional training approach. traditional training exercises, such as squats and deadlifts, not only allow for greater loading but are also simpler to teach and supervise, especially when working with larger groups of athletes. This makes traditional training particularly well-suited for developing foundational strength and force production in a time efficient manner, ensuring that athletes can make meaningful progress even within the constraints of group training sessions.

6.8 PRACTICAL APPLICATIONS

Traditional Training and Functional Training Group approaches can both offer benefits. functional training may be more advantageous for improving change of direction speed, while traditional training proves more effective for increasing force production and overall strength.

While functional training can be valuable in specific contexts, such as improving agility or movement proficiency, it does not offer the same broad impact on essential physical qualities as traditional training does particularly in the early stage of training. Therefore, traditional training should be the primary focus in early training programs, with functional training exercises incorporated later as athletes progress and require more specialised training to enhance performance.

This is not to say that functional training lacks value. As athletes progress in their training and look to enhance specific aspects of their performance, such as change of direction speed, and reduce strength imbalances, functional training can certainly be incorporated. Over time, the inclusion of multi-planar and unilateral exercises can complement the foundation built through traditional training, helping athletes further refine their technique and develop training competency. functional training just does not seem to provide enough of a beneficial effect, particularly in terms of force production and overall strength, to justify prioritising it over traditional training.

CHAPTER 7

Investigating the acute effects of Resistance training and Football training session sequence in youth footballers.

7.1 ABSTRACT

Current guidelines do not offer specific recommendations regarding the sequence of sports specific or resistance training within a training program. Existing research has primarily focused on concurrent training's long-term effects or the comparison of individual exercises, with limited exploration into the immediate effects of training session sequence. This study investigates whether the order of football training (FT) and resistance training (RT) impacts performance within the same training session in youth footballers. Fifteen male academy football players, aged 14 years, were recruited for this study. Participants performed eight training sessions over eight weeks, alternating between two session sequences: football training before resistance training (FT > RT) and resistance training before football training (RT > FT). Neuromuscular fatigue was assessed using countermovement jump (CMJ) and rate of perceived exertion (RPE). Dynamic stress load (DSL), and the number of accelerations were used as markers of football training workload. Data were analysed using a linear mixed model (LMM) to evaluate the impact of session sequence on performance metrics. The results indicated no significant differences between the FT > RT and RT > FT sequences in terms of CMJ height ($F(1, 26.53) = 3.27$, $p = .082$), DSL ($F(1, 27.54) = 0.35$, $p = .561$), accelerations ($F(1, 33.46) = 0.692$, $p = .411$), or rate of perceived exertion (RPE) ($F(1, 41.76) = 0.057$, $p = .812$). This suggests that the order of training sessions does not significantly impact subsequent performance measures. These findings provide practical insights for coaches, indicating that the sequence of football and resistance training sessions may not affect the athletes' performance in subsequent sessions. This flexibility allows coaches to adjust training schedules based on logistical needs without compromising training outcomes in youth footballers.

7.2 INTRODUCTION

In the competitive landscape of youth football, players require multifaceted training regimens to meet the sport's physiological demands. An in-season training week for academy-level players typically includes diverse training modalities, each contributing uniquely to the athlete's development. Key among these is technical training, essential for refining sport-specific skills and tactical understanding. Equally important is resistance training (RT), which aids physical development and reduces injury risk (1, 33). The sequencing of these sessions is crucial as it can significantly impact the effectiveness of the training regimen. Proper sequencing ensures that each training component is performed when the athlete is best prepared to handle the specific demands of the exercise, thereby maximising adaptations and minimising the risk of overtraining or injury. Youth athletes, particularly those in academy-level football, face significant challenges due to time constraints and the pressures of balancing technical training with physical development.

The NSCA (1) and UKSCA (33) do not currently provide recommendations on exercise sequence. While they do not explicitly comment on the sequence of training, they recognise the importance of managing accumulated neuromuscular fatigue to reduce its impact during training sessions (1, 33). This principle of monitoring neuromuscular fatigue can reasonably be extended to the sequencing of resistance and sportsspecific training, where improper order could contribute to unnecessary fatigue and hinder performance.

Concurrent training involves the integration of RT and endurance training within a single program. Research on this training style shows mixed results. Some research suggests that concurrent training can lead to less optimal gains in muscular strength due to conflicting physiological adaptations, also known as the interference effect (298-300). Wilson et al (300) confirmed this hypothesis through a meta-analysis, demonstrating that RT alone produced greater improvements in muscle strength, hypertrophy, and power compared to concurrent training.

Conversely, other studies suggest concurrent training could enhance both strength and endurance. Davis et al (301) found substantial improvements in both strength and endurance in athletes engaged in concurrent training, highlighting its potential benefits for overall athletic performance. Further, Eddens et al (302) emphasised the role of training sequence in mitigating the interference effect. The systematic review revealed that performing strength training first minimised interference, resulting in balanced improvements for both performance outcomes.

Current guidelines from the NSCA and UKSCA do not provide specific recommendations regarding the sequence of resistance and aerobic training for youth. The position papers emphasise the importance of including both types of training in a well-rounded fitness program but refrain from suggesting a particular order. According to the NSCA, the benefits of concurrent training programs that integrate both resistance and aerobic exercises are well-supported, particularly for improving body composition in youth (1, 33). However, there is no consensus on whether performing RT before or after aerobic training is more advantageous. Similarly, the UKSCA and ASCA suggest the need for structured, progressive, and supervised training regimens without specifying the optimal sequencing of these exercises (37, 110). Consequently, the current literature does not conclusively determine if the order of concurrent training has a significant impact on training outcomes for young athletes.

Research into the effects of concurrent training on sprint speed has yielded positive results. For instance, Kotzamanidis et al (166) found significant improvements in running velocity, specifically in the 30m dash, following a combined high-intensity strength and speed training program. This improvement was notably greater compared to that seen with conventional RT alone.

Bluett et al (303) reported significant improvements in leg strength for both aerobic and concurrent training groups, with no significant difference between them. Similarly, Kotzamanidis et al (165) found significant strength gains in both the combined training and resistance-only groups. Santos et al (304) found significant improvements in explosive strength tasks such as medicine ball throws and countermovement jumps after a concurrent strength and endurance training program in adolescent girls. Similarly, Alves et al (305) reported significant gains in explosive strength in prepubescent children following combined strength and aerobic training, particularly when the training was performed in separate sessions.

Improvements have also been found in in squat and countermovement jump performance in soccer players following a combined high-intensity strength and speed training program (166, 304). To the best of the authors knowledge there are no studies examining the acute effects of intrasession sequencing of sport specific training and resistance exercises. Most studies have focused on the long-term effects but have not explored how the order of training within a single session might influence outcomes. To the best of the authors knowledge only three papers have investigated the effects of intra session sequencing i.e. manipulating whether RT is performed before or after sports specific training (230, 306, 307).

Makhlouf et al. (95) examined how the sequence of strength and endurance training affects performance in young male soccer players. Participants were divided into four groups: a control group (CG), strength before endurance (SE), endurance before strength (ES), and alternating strength and endurance on different days (ASE). Over 12 weeks, all experimental groups showed significant improvements across various physical fitness metrics, regardless of the training sequence.

Key performance indicators such as strength, jump height sprint times and change of direction improved significantly in all experimental groups compared to the control. Notable gains were observed in maximal strength exercises like the bench press and squat. The study concluded that combining strength and endurance training in a single session yielded better performance improvements than separating them on alternate days. Additionally, the sequence of exercises did not significantly impact the outcomes, supporting the effectiveness of concurrent training for enhancing overall fitness.

Alves et al. (169) analysed the effects of concurrent strength and aerobic training on explosive strength in prepubescent children. The study involved 128 participants split into three groups: strength before aerobic training (GSA), aerobic before strength training (GAS), and a control group (GC) with no specific training. The findings revealed that both experimental groups (GSA and GAS) showed significant improvements in explosive strength measures, while the control group showed no notable changes. Specifically, the GSA group demonstrated better performance in strength-related tasks such as the 1-kg and 3-kg medicine ball throws, as well as in the standing long jump and sprint times. These results suggest that performing strength training before aerobic exercises (GSA) is more effective for improving explosive strength. Additionally, both the GSA and GAS groups showed improvements in the standing long jump and countermovement jump, although the GSA group performed better in these metrics. Overall, the study concluded that concurrent training, regardless of the sequence, can enhance explosive strength in children, but the sequence of strength before aerobic exercises may yield greater gains in muscular strength and power development.

Enright et al. (170) explored the effects of different concurrent training sequences over a 5-week period in youth soccer players, comparing a Strength before Endurance (S+E) approach with an Endurance before Strength (E+S) approach. Throughout the 5-week intervention, both training sequences led to improvements in various performance measures such as strength, jump performance, and sprint times. However, the E+S group generally showed greater enhancements across these metrics. The study suggests that training endurance before strength may be more effective for overall performance gains, particularly in strength and sprint speed. The authors attribute the superior results observed in the E+S group to potentially more optimal recovery periods between training bouts, as well as prolonged anabolic signalling, which may have enhanced the adaptation process over the 5-week training period. This indicates that when training time is limited, structuring sessions with endurance before strength could maximize performance improvements in youth athletes.

While these studies offer a valuable insight into the long-term effects of concurrent training, The immediate effects of training sequence on performance within individual sessions remain unexplored. Residual fatigue from preceding sessions can impair motor skill performance and the acquisition and retention of new skills (308). It has also been reported that soccer-specific fatigue in youth players significantly decreases neuromuscular control, particularly in the medial thigh muscles, and reduces leg stiffness(309). These changes can impair dynamic stability, increasing the risk of noncontact injuries (309). Additionally, Kennedy and Drake (310) showed that acute fatigue diminishes performance in explosive tasks due to reduced phosphocreatine availability and impaired neuromuscular function. It is therefore important for strength and conditioning practitioners to understand how RT and sports specific sessions can potentially interact with one another, and If there is an acute benefit to a particular sequencing of these sessions.

This study aims to investigate whether the sequence of football training (FT) and RT (RT) impacts performance quality in subsequent sessions. With the hypothesis that the sequence of training will influence the effectiveness of subsequent sessions. Specifically, it is anticipated that performing FT before RT will reduce the effectiveness of the RT session, while performing RT before FT will negatively impact the quality of work in the FT session.

7.3 METHODS

Participants

An under 14s male academy football squad (n=15, height = 162.6 ± 8.7cm, weight 50.7 ± 6.7kg) was recruited for this study. Each participant had regularly engaged in resistance training for over a year and was familiar with the exercises conducted in the resistance training sessions, Participants were given full details of the study procedures and informed of the risks and benefits of the study before any data collection. Each participant completed a physical activity readiness questionnaire (PARQ). Participants provided personal and parental, or guardian written informed consent before participation. All participants were free from injury and deemed eligible for participation by the club's medical staff. Ethical approval was granted by University of Essex.

Procedure

Participants performed 4 sessions of Football training before resistance training and 4 sessions of resistance training before football training over an 8-week period and a total of 8 training sessions. 4 sessions were performed with resistance training taking place before football training and the other 4 sessions had players complete football training before resistance training. Training took place on a Tuesday evening every week, scheduling changed every session, so no two consecutive sessions had the same scheduling. A clear outline of the schedule can be seen below in Table 7.2.

Table 7.1 Description of training sequences for each session

Session 1	**Session 2**	**Session 3**	**Session 4**	**Session 5**	**Session 6**	**Session 7**	**Session 8**
FT > RT	RT > FT	FT > RT	RT > FT	FT > RT	RT > FT	FT > RT	RT > FT

Abbreviations FT - football training, **RT -** resistance training, **> -** denotes before (e.g. FT before RT)

An example of an FT>RT session is as follows: Before each football training session, participants were instructed to wear a STATSports Apex 10 GPS unit (STATSports, Northern Ireland) to record measures of DSL and accelerations during the session. Upon completing the football training, players immediately proceeded to the gym to complete counter-movement jumps. Participants then performed a resistance training session (Table 7.3) following the resistance training values for rate of perceived exertion (RPE) were recorded for each participant. For the RT>FT sessions, this procedure was reversed, with participants first performing the countermovement jump test and resistance training, followed by GPS-monitored football training. An example of the procedure for each type of session can be seen in Figure 7.1. Participant attendance data was recorded for each session and is shown in Table 7.2.

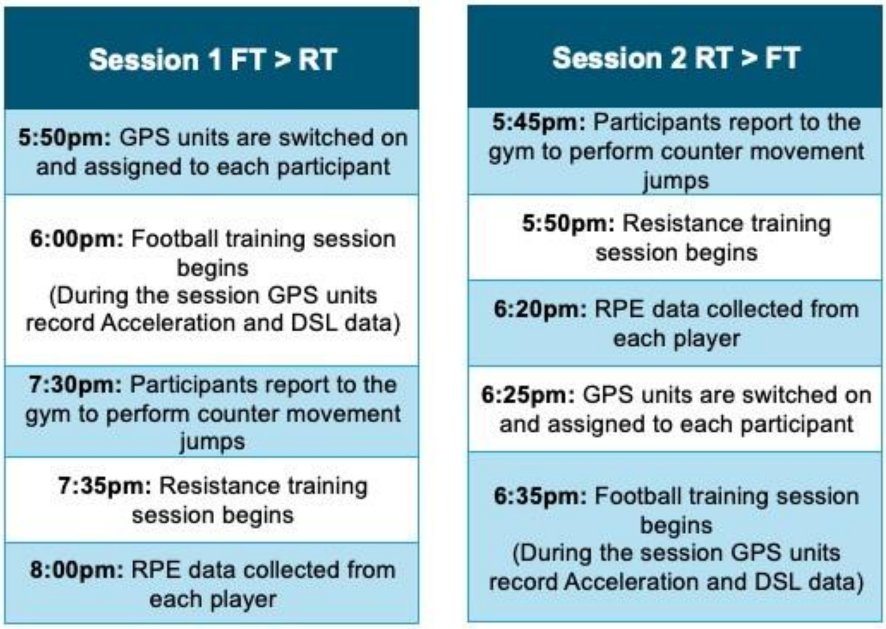

Figure 7.1 A description of training procedure for session 1 and session 2

Table 7.2 Session attendance and percentage data for each participant

Participant	Attendance (%)
1	7 (87.5)
2	7 (87.5)
3	5 (62.5)
4	8 (100)
5	7 (87.5)
6	5 (62.5)

7	6 (75)
8	6 (75)
9	7 (87.5)
10	5 (62.5)
11	7 (87.5)
12	8 (100)
13	8 (100)
14	8 (100)
15	7 (87.5)

Resistance Training Intervention

Resistance training consisted of a single whole-body session, shown in Table 6.3, this session was pre-designed by academy coaching staff and represented a standard session prescribed to academy players as part of their routine training schedule. After each resistance training session participants were asked to record a rating of perceived exertion (RPE) score form 0-10 (Borg 1982). The Borg CR-10 (Borg 1982) has been shown to be a valid and reliable method for assessing perceptions of fatigue and intensity during resistance training and physical exertion (311, 312).

Football training sessions were designed and executed by the technical coaching staff. While precise standardisation of these sessions was not feasible, coaches adhered to a specific syllabus. This syllabus ensured that each training session focused on the same technical skills, which provided a level of consistency across all football training sessions. This approach allowed for some degree of standardisation, despite the inherent variability in coaching methods and actual work performed.

Table 7.3 Description of the Resistance training session

Exercise	Volume	Recovery (s)	Load (range)	RPE (range)
Back squats	4 sets 8 reps	90s	25-40kg	7-9
Pull ups	4 sets 8 reps	90s	B/W	7-8
Romanian Deadlift	4 sets 8 reps	90s	25-40kg	7-9
Bench press	4 sets 8 reps	90s	20-35kg	7-9
Planks	3 set 20s hold	60s	B/W	5-7

Abbreviations B/W – Bodyweight, **reps** – repetitions, **RPE -** rate of perceived exertion

Neuromuscular Performance

The counter-movement jump is a valid and reliable method for measuring neuromuscular performance (313-315).

Counter movement jump testing was carried out before each resistance training session. Participants were instructed to keep hands placed on hips and jump as high as possible with no hip or knee flexion during flight phase. Participants completed five jumps with at least 10s rest between each attempt, each jump was executed with a self-selected depth (314). Mean flight time was recorded using ForceDecks FDlite force platforms (ForceDecks, Vald performance, Australia) and data was analysed using ForceDecks software (ForceDecks, Vald erformance, Australia) values for mean flight time were chosen as it has been shown to be reliable for measuring neuromuscular performance than a peak value (316).

Football training workload

Training workload was measured as Dynamic stress load (DSL) and accelerations were taken during the football specific training sessions using STATSports Apex 10 Hz

GPS unit (STATSports, Northern Ireland). Each player had their own unit assigned to them throughout the observation.

Accelerations

Accelerations are calculated as any movement over 2m/s^2 (317) lower numbers of accelerations would suggest higher level of fatigue when considering the muscular effort required to perform these actions (318). It would not be presumptuous to suggest that fatigue would have a direct impact on the amount and quality of movement speed in subsequent sessions. For the purpose of this study a lower number of accelerations would indicate that performance during the football training session may have been hindered due to fatigue.

Dynamic stress load

DSL is captured by a 100-Hz triaxial accelerometer which aggregates the rates of accelerations in three movement axes (X, Y and Z) to form a composite magnitude vector (expressed as G-force) which is inputted to a curved weighted function to get a value in arbitrary units (318-322), it has been shown to be a valid and reliable measure of fatigue (319). Using this measure was intended to provide an indication of fatigue during the football training session. According to the available literature, fatigue could potentially alter running style and result in a greater number of weighted impacts, therefore increase the value obtained for DSL (318, 319). For this study a higher level of DSL is an indicator that performance during the football training session may have been hindered due to fatigue.

7.4 DATA TREATMENT

The aim of this study was to assess whether the sequence of training, resistance training before football training or football training before resistance training, impacts performance in the subsequent session. Performance was measured using dynamic stress load (DSL) and the number of accelerations as markers of football training workload, while countermovement jump height was used as an indicator of neuromuscular fatigue before resistance training and rate of perceived exertion (RPE) were used as an indicator perceived effort after resistance training

To analyse the effects of the training sequence on multiple dependent variables over time, a Linear Mixed Model (LMM) approach was employed. LMM was chosen for its ability to handle repeated measures and account for both fixed and random effects, allowing for the inclusion of variability across participants and sessions. This method was particularly appropriate given the study's design, where participants were measured multiple times across different training sequences.

There were four dependent variables analysed; Jump Height (cm), Dynamic Stress Load (DSL), Number of Accelerations, and Rate of Perceived Exertion (RPE). Each dependent variable was modelled separately in the LMM. The independent variable was the training sequence, football training before resistance training (FT > RT) and resistance training before football training (RT > FT). Participants were included as a random factor to control for individual differences among participants. The variable session, representing the training session number, was included as a repeated measure to account for missing account for missing values when capturing 8 repeated measurements for each participant.

As an example, when analysing DSL; DSL was entered as the dependent variable, training sequence was entered as a fixed effect, while session was included as a repeated measure with participant treated as a random effect to account for individual differences.

The LMM allowed for the examination of training sequence (fixed factor) and random effects (variability between participants). The covariance parameters for the autoregressive structure provided insights into how the dependent variables changed across sessions, while the variance components attributed to participants highlighted the degree of variability in each measure due to individual differences. The random effect of participant ID was included to account for individual differences in response to the training sessions.

A LMM was used to account for the relationship between measurements for each participant within repeated sessions, An autoregressive (AR1) covariance structure accounting for the potential decrease in correlation as the time between sessions increased. For each dependent variable, the main effect for fixed factor (training sequence) tested for overall differences. The LMM adjusts this estimate for withinsubject correlations and between-subject variability. If the fixed effect of training sequence was found to be significant, it would suggest that the training sequence had a significant impact on the dependent variable. This approach was applied consistently across all dependent variables.

7.5 RESULTS

For the RT > FT sequence, the means were 191.753 (SE = 27.485) for DSL, 753.531 (SE = 40.822) for Accelerations, 6.379 (SE = 0.196) for RPE, and 28.407 cm (SE = 0.976) for Jump height.

For the FT > RT sequence, the means were 153.114 (SE = 25.511) for DSL, 707.365 (SE = 37.133) for Accelerations, 6.419 (SE = 0.185) for RPE, and 29.029 cm (SE = 0.969) for Jump height.

The mean difference for DSL between the RT > FT and FT > RT sequences was 38.639 (SE = 32.069), 95% CI [-26.500, 103.778], and was not statistically significant, P = .236. For Accelerations, the mean difference was 46.166 (SE = 55.509), 95% CI [-66.710, 159.042], and was not statistically significant, P = .411.The mean difference for RPE was -0.041 (SE = 0.170), 95% CI [-0.383, 0.302], and was not statistically significant, P = .812. For Jump height, the mean difference was -0.622 cm (SE = 0.344), 95% CI [-1.328, 0.085], and was not statistically significant, P = .082.

The results of the fixed effects analysis indicate that the training sequence did not have a statistically significant effect on jump height, ($F_{(1, 26.53)}$ = 3.27, *P* = .082), Dynamic stress load, ($F_{(1, 27.54)}$ = 0.35, P = .561), Accelerations, ($F_{(1, 33.46)}$ = 0.692, P = .411). or RPE ($F_{(1, 41.76)}$ = 0.057, P = .812).

The variance attributed to participant was estimated at 0.247 (SE = 0.127) for DSL, indicating some variability across participants, though with a degree of uncertainty. The variance for accelerations was substantially higher at 3898.53 (SE = 4015.24), suggesting considerable variability, but with significant uncertainty. For RPE, the variance was 0.288 (SE = 0.172), indicating some variability with notable uncertainty. Jump height showed substantial variability with a variance of 13.46 (SE = 5.21).

For DSL, a moderate negative correlation between sessions was observed (AR1 rho = -0.281, SE = 0.143), indicating a tendency for values to decrease after an increase in the previous session. Weak negative correlations were also noted for jump height (AR1 rho = -0.188, SE = 0.166) and accelerations (AR1 rho = -0.198, SE = 0.144), suggesting slight decreases following increases in the previous session. In contrast, RPE showed a weak positive correlation (AR1 rho = 0.135, SE = 0.151), indicating a slight tendency for scores to increase if they had increased in the previous session.

7.6 DISCUSSION

The present study investigated the effects of training sequence, specifically football training before resistance training (FT > RT) versus resistance training before football training (RT > FT), on several indicators including dynamic stress load (DSL), number of accelerations, jump height, and rate of perceived exertion (RPE). These metrics were utilised to assess whether the sequence of training sessions could influence neuromuscular performance during the session, rather than serving as direct markers of overall athletic performance. The study hypothesised that the sequence would affect these indicators, with FT before RT potentially leading to greater residual fatigue and, consequently, reduced neuromuscular performance within the monitored session.

However, the results indicated that the training sequence had no significant effect on DSL, accelerations, jump height, or RPE, suggesting that the order of training sessions did not impact these specific aspects of neuromuscular performance within the session.

DSL

Dynamic Stress Load (DSL) combines the acceleration rates across three movement axes (X, Y, and Z) to create a composite magnitude vector, expressed as G-force, which is then processed through a curved weighted function to produce a value in arbitrary units (318-322). And has been shown to be a valid and reliable measure of fatigue in existing literature (319).

According to the available literature, fatigue may alter an athlete's running mechanics, leading to an increase in the number of weighted impacts during movement. This, in turn, could elevate the DSL values recorded (318, 319). Therefore, if completing resistance training before football training (RT > FT) increased the level of neuromuscular fatigue in participants, it would be expected to result in an increase in DSL values during the subsequent football session. Contrary to expectations, the findings from this study showed no statistically significant effect of training sequence on DSL. This suggests that the order of training sessions (whether FT > RT or RT > FT) did not significantly influence the cumulative stress experienced by the participants during football training sessions. Similar findings have also been reported in the literature, Snyder et al (318) evaluated the effectiveness of GPS-derived workload metrics in detecting fatigue during a 90-minute match simulation with collegiate soccer players. The study tracked metrics like high-speed running (HSR), speed intensity (SI), accelerations, decelerations, and Dynamic Stress Load (DSL) in 5-minute intervals to determine their sensitivity to fatigue, they found no significant change for DSL, however the study did not report full data only reporting the nonsignificance in DSL. These findings are in contrast with previous literature, Beato et al (319) conducted a study to assess the sensitivity of novel accelerometer-derived metrics, specifically

Dynamic Stress Load (DSL), DSL•m^{-1}, and the Fatigue Index (FI), for monitoring fatigue during intermittent exercise. The study involved 15 physically active male university students who participated in a standardised submaximal intermittent recovery test (Sub-IRT) followed by a repeated sprint protocol designed to induce fatigue. Using Apex 10 Hz GNSS units, the researchers collected data on various external and internal training load metrics. The study found that DSL significantly increased post repeated sprint protocol, indicating its effectiveness in detecting fatigue. Previous studies have also suggested the use of DSL in monitoring fatigue (323-325). These findings indicate that DSL can be an effective method for detecting neuromuscular fatigue in athletes. Therefore, it is reasonable to consider that in the current study, DSL was an appropriate metric for assessing participants' responses to potentially fatiguing training sessions performed sequentially

Accelerations

Accelerations, defined as any movement over 2m/s², require substantial muscular effort. If participants were experiencing neuromuscular fatigue, particularly after completing a resistance training session before football training (RT > FT), a reduction in the number of accelerations during the football session would likely occur, as neuromuscular fatigue is likely to impair the ability to perform high-speed movements, thus decreasing the number of accelerations (318). The results indicated that the training sequence had no statistically significant effect on the number of accelerations. This suggests that resistance training sessions, when performed before the football training sessions, did not significantly impact the participants' ability to accelerate during football training. Similar to these findings Beato et al (319) reported a decrease in the number of accelerations from 33 ± 3 in Drill 1 to 31 ± 4 in Drill 2, representing a

6.06% decrease. Despite this observable reduction, the study determined that this change was not statistically significant.

The statistical analysis included a Bayesian evaluation, which yielded a Bayes Factor (BF10) of 1.6 for accelerations. In Bayesian terms, a BF10 of 1.6 is considered anecdotal evidence, suggesting that the observed decrease in accelerations might not reliably indicate fatigue.

In contrast to the findings from the present study Snyder et al (318) evaluated accelerations as a metric for monitoring fatigue during a 90-minute soccer match simulation with collegiate players. It found that accelerations decreased significantly over the course of the simulation, with a 31% reduction observed within the first 25 minutes, and a further decline of up to 47% by 75 minutes. These reductions were accompanied by moderate to large effect sizes, indicating the practical significance of these changes (0.50 to 0.80), highlighting that accelerations are a sensitive and reliable indicator of neuromuscular fatigue.

Counter-movement jump

The Counter-Movement Jump (CMJ) is a reliable indicator of neuromuscular performance (313-315). Typically, if a participant is experiencing neuromuscular fatigue, their CMJ height would decrease, as fatigue impairs the neuromuscular system's ability to generate explosive power. Therefore, if participants were fatigued after football training before resistance training (FT > RT), it would be expected that there would be a significant reduction in CMJ height during the subsequent testing.

The study found no statistically significant effect of the training sequence on CMJ height. Despite the expectation that fatigue would reduce CMJ performance, the results suggest that the order of training (whether FT > RT or RT > FT) did not significantly impact the participants' neuromuscular performance as measured by CMJ. A meta-analysis by Claudino et al (316) analysed data from 151 articles investigating various CMJ performance variables. The analysis found that the average CMJ height was more sensitive in detecting changes in neuromuscular status compared to the highest CMJ height. Specifically, the average CMJ height showed a significant effect size for detecting fatigue (ES = -0.56, 95% CI [-0.89, -0.24]). Suggesting that the use of average CMJ height, as monitored in this study, would be an appropriate method for assessing neuro-muscular fatigue.

Rate of Perceived Exertion

Rate of Perceived Exertion (RPE) is a subjective measure of how taxing a session feels to the participant. It was hypothesised that RPE would increase after a sequence where football training was conducted before resistance training (FT > RT), as participants would likely feel more fatigued and perceive the subsequent session as more strenuous.

The results indicated that the training sequence had no statistically significant effect on RPE. This suggests that participants did not perceive the sessions to be more taxing based on the order in which they were performed. The study investigated the criterion-related validity of the Borg CR-10 scale for assessing internal training load (TL) in adolescent athletes by examining its correlation with heart rate (HR) measures. RPE has been shown to be valid for use of monitoring perceived fatigue in resistance training (311) and importantly in youth athletes (326). The findings of a recent metaanalysis revealed that the Borg CR-10 scale demonstrated a strong correlation with heart rate, with a Pearson's r of 0.69 (95% CI: 0.60–0.77) (189). This significant correlation indicates that the CR-10 scale is a reliable tool for monitoring perceived exertion and internal TL in adolescent athletes. The study concluded that the Borg CR10 scale is a valid and practical method for quantifying perceived exertion during training in youth athletes.

Study Originality

To the best of the authors' knowledge, this is the first study to directly investigate the acute effects of training session sequence on performance metrics within a single training session in youth athletes. Previous literature has predominantly focused on the long-term effects of concurrent training on markers of athlete performance, such as strength, endurance, and explosive power, often with varying results. Several studies have explored the effects of different training sequences on performance outcomes over extended periods. Previous research has primarily focused on the long-term effects of different training sequences on performance improvements. For instance, Enright et al (307) examined training sequences over a 5-week period, finding that both strength-first and endurance-first sequences enhanced muscle strength and power, with the endurance-first group showing greater improvements in endurance performance. Similarly, Alves et al (306) investigated the influence of training order over 8 weeks in prepubescent children, reporting that strength-first training improved muscle strength. Makhlouf et al (230) studied the effects of training sequence over 12 weeks in elite youth soccer players, concluding that while long-term improvements occurred across all groups, the sequence did not significantly alter the overall performance outcomes

However, none of these studies directly assessed the immediate, acute effects of training sequence within a single session, which was the focus of the current study. In this study, it was hypothesised that the order of training, specifically football training

(FT) before resistance training (RT), would have a negative effect on the subsequent training session. The rationale behind this hypothesis was that performing FT first would lead to neuromuscular fatigue, which might impair the athletes' ability to benefit from the RT session that followed.

Understanding whether training sequence impacts subsequent sessions is especially important when working with youth athletes. For youth athletes, the primary objective is to develop their ability to train and learn how to train competently, both in FT and RT. Training them in a fatigued state, as might occur when sequencing FT before RT, could hinder their ability to learn new motor skills and safely perform complex RT movements. Accumulating neuromuscular fatigue may negatively affect the acquisition and mastery of these essential skills, which are crucial for long-term athletic development.

7.7 LIMITATIONS

One of the potential limitations of this study was the inability to fully standardise the football training sessions. Despite the technical coaches working from a prescribed syllabus, which aimed to ensure a degree of consistency across sessions, it was not feasible to standardise every aspect of what took place during training. This variability is a notable limitation, as it introduces elements of inconsistency that could affect the performance measures being studied. However, it is important to recognise that this limitation also reflects the real-world setting of academy-level football.

In a practical environment, a strength and conditioning coach typically has little to no influence over the content of technical coaching sessions. These sessions are designed and executed by technical coaches, whose primary focus is on skill development, tactical understanding, and game preparation. The strength and conditioning coach would generally assess the players' workload retrospectively and make necessary adjustments to training loads based on that data. This lack of control over the sport-specific aspects of training underscores a key challenge faced in applied sports settings.

Moreover, it is inherently difficult, if not impossible, to standardise sport-specific training activities such as the distance covered, the speed of movement, the number of touches on the ball, or the frequency and intensity of tackles. These variables are highly dependent on the dynamics of each session, the objectives set by the technical coaches, and the spontaneous nature of football practice. As such, the study’s inability to control these factors introduces variability, but this variability is an accurate representation of the conditions under which academy players and coaches operate.

Moreover, the findings imply that the sessions, whether football or gym-based, may not cause neuromuscular fatigue that adversely affects subsequent performance. This could possibly be attributed to youth being more resistant to fatigue and generally needing far less time to recover from strenuous activity than adults (327-329). Research indicates that younger populations tend to recover more quickly and are more resilient to training-induced fatigue, likely because they have a lower capacity to generate high levels of force and power (328-330).

This could explain why the sequence of training sessions did not result in significant differences in performance measures such as dynamic stress load (DSL), accelerations, jump height, or rate of perceived exertion (RPE). Furthermore, the resistance training sessions conducted in this study may not have been particularly taxing on the participants, largely due to their relative inexperience with resistance training. Although the participants had over a year of regular resistance training experience, this duration may not be sufficient to elicit high levels of physical stress, especially when compared to more experienced athletes. Consequently, the overall training loads may have been lower, reducing the potential for significant fatigue or performance decrement during the sessions. Another consideration related to training load is that participants were instructed to self-select weights, aiming to complete the desired repetitions with effort but without reaching failure. As previously discussed in this thesis, when working with a large group of participants, the coach-to-participant ratio can limit the ability to accurately monitor and confirm the workload. Consequently, despite best intentions, participants may not always push themselves as hard as directed.

Rate of Perceived Exertion (RPE) values during the gym sessions were self-reported by the participants, despite familiarity with the practice of reporting RPE values, it remains a subjective measure that can vary widely between individuals. Factors such as personal perception, motivation, and daily physical condition could influence the loads chosen and the RPE reported. As a result, the subjective nature of these measurements introduces variability and potential limitations in accurately gauging the true intensity of the gym sessions.

Countermovement jump (CMJ) height has been shown to be a valid and practical indicator of lower-body explosive performance and is routinely used in applied sport science settings to monitor neuromuscular status (314, 316, 331-333). It is accessible, time-efficient, and sensitive to acute changes in performance following training or competition (316, 334). Its ease of implementation makes it a valuable tool, particularly where resources or time may be limited. However, a limitation of the use of CMJ height in isolation is the potential for athletes to alter their movement strategies under fatigue, enabling them to maintain CMJ height. For example, athletes may unconsciously increase the depth of their countermovement or modify the timing and coordination of muscle activation to compensate for a decline in rate of force development or power output (13, 335, 336). This compensatory adaptation may allow athletes to maintain overall performance outcomes like jump height, while masking subtle deficits in force generation or neuromuscular control (334, 337-339). Gathercole et al. (334) demonstrated that while jump height and peak power often remained stable after fatiguing exercise, other countermovement jump (CMJ) variables showed greater sensitivity to neuromuscular fatigue. Notably, force at zero velocity, mean power, and flight time all exhibited significant reductions immediately post-fatigue, with mean power decreasing by approximately 4.6%. Time-based variables such as eccentric duration and total contraction time also increased subtly but consistently, suggesting changes in jump execution.

To address this limitation future research should consider the incorporating additional force-time and kinematic variables derived from CMJ assessments. One such variable is the rate of force development (RFD), which quantifies the speed at which force is generated. RFD is highly sensitive to both central and peripheral fatigue and tends to decline significantly following neuromuscular stress, making it a more responsive measure than peak force alone (339). Another metric could be Force at zero velocity refers to the force produced at the precise moment when the athlete transitions from the downward (eccentric) phase to the upward (concentric) phase of a countermovement jump. This point represents a critical aspect of neuromuscular function, capturing the efficiency of force transmission during the stretch-shortening cycle. In the study by Gathercole et al. (334), force at zero velocity was identified as one of the most sensitive indicators of neuromuscular fatigue. Following a fatiguing intermittent running protocol, force at zero velocity significantly declined despite jump height and peak power remaining unchanged. This suggests that fatigue can impair an athlete's ability to generate force during this key transition point, even when gross performance outputs are maintained. The authors recommend incorporating this variable into fatigue monitoring protocols, as it provides insight into neuromechanical efficiency and early signs of fatigue that may otherwise be masked (334). Another metric could be flight time to contraction time ratio (FT:CT), which represents the relationship between the duration an athlete spends in the air (flight time) and the time taken to generate the jump (contraction time). In a study by Cormack et al. (332), FT:CT was shown to be a sensitive indicator of post-match neuromuscular fatigue in elite Australian Rules Football players. The ratio significantly decreased by 16.7% immediately after competition and remained suppressed at 24 hours post-match, despite no significant changes in jump height or peak power. This suggests that FT:CT can reveal underlying fatigue-related impairments that may be masked when relying solely on traditional output metrics. (332).

Collectively, these metrics and others would enable a multi-dimensional understanding of neuromuscular performance, revealing impairments that may be concealed when evaluating jump height in isolation. They offer valuable insights into movement quality, mechanical efficiency, and neuromuscular function under fatigue. Future research should therefore not only continue to affirm the validity of CMJ height as a foundational measure but also prioritize the systematic integration of kinetic and temporal variables to enhance the sensitivity and diagnostic power of fatigue monitoring protocols.

7.8 PRACTICAL APPLICATIONS

Earlier in this thesis, it was highlighted that training schedules in academy football are often subject to change or lack organisation due to various factors, including interference from technical coaches. These disruptions can result in an unplanned sequence of training sessions, such as football training being conducted before a gym session, which might traditionally be viewed as less than ideal for performance outcomes. However, the findings of this study suggest that such concerns may be less impactful than previously assumed.

For practitioners, it is important to understand that the sequence of training sessions may not significantly affect the subsequent session's performance, particularly in the context of youth athletes. The highlighted limitations of this study are, in fact, among its greatest strengths, as they accurately reflect the realities of training youth athletes in real-world settings. In practice, strength and conditioning coaches cannot influence technical training sessions, nor can these sessions be fully standardised due to the inherently unpredictable nature of football. Similarly, while resistance training sessions are planned, their execution is often disrupted by rescheduling, and the challenges of managing large groups, where maintaining consistent training intensity and accuracy is difficult.

By accounting for these real-world variables, the study effectively demonstrates how football and resistance training sessions naturally interact. This approach accurately replicates a typical training environment in a youth football academy, providing valuable insights for strength and conditioning coaches. It shows how these two types of training coexist in practice, offering a realistic view of the challenges and dynamics that coaches face in their daily work.

7.9 CONCLUSION

The results of this study indicated that whether football training or resistance training is performed first, there was no observable negative impact on the players' performance in the subsequent session. This of significant difference suggests that coaches and strength and conditioning practitioners may not be concerned with the order in which these sessions are scheduled.

Therefore, from a practical standpoint, these findings offer reassurance that the occasional reorganisation of training schedules, often necessitated by the realities of coaching, should not be a major concern. The flexibility in session sequencing may be utilised without fear of negatively impacting the athletes' performance, allowing for a more adaptable and responsive approach to training that reflects the dynamic nature of youth sports environments.

CHAPTER 8

General Discussion

8.10 GENERAL DISCUSSION

The information outlined in Chapter 1 of this thesis emphasised the significance of resistance training for youth athletes, highlighting its benefits for both physical performance and injury prevention. Properly designed and supervised resistance training is shown to enhance strength, power, and overall athletic ability, particularly in sports requiring high levels of speed, agility, and coordination. National organisations, such as the UK Strength and Conditioning Association (UKSCA) and the National Strength and Conditioning Association (NSCA), recommended resistance training for youth athletes, with a focus on gradual progression, proper technique, and supervision to ensure both safety and effectiveness.

The purpose of this thesis was to investigate how these resistance training guidelines could be implemented in real-world settings, particularly in youth academy football, where time constraints, competing demands, and logistical challenges often limited the ability to follow optimal training protocols. The research aimed to explore whether current practices provided an adequate training stimulus for athletic development and to identify practical solutions that could address the common obstacles faced by strength and conditioning practitioners in youth sports environments. By evaluating these challenges and offering insights, this thesis sought to enhance the application of resistance training in youth athletes while maintaining adherence to best practices and established guidelines.

8.10.7 Chapter 3

Given the complexity of resistance training, where multiple variables interact and influence each other, it became apparent that manipulating a single variable in isolation would not sufficiently capture the overall scope of the research. This complexity made a systematic review, which typically focuses on addressing more specific and narrowly defined questions, an impractical approach for this context.

By adopting a scoping review, we were able to assess not just one isolated variable, but rather the wide array of variables that influence resistance training in youth team sports. This provided a more comprehensive and nuanced understanding of the current body of evidence, which would not have been possible through a systematic review focused on a singular variable or outcome.

In Chapter 2 of this thesis, the literature review on youth team sports provided valuable insights into the current state of research on resistance training variables. The literature search was conducted to assess the existing body of work, with a specific focus on identifying which variables of resistance training, such as sets, repetitions, intensity/load, training frequency, and recovery times, had already been investigated. The review revealed that, while a broad range of topics related to resistance training had been covered, there was considerable variation in the methodologies employed by the studies. Each study adopted different approaches, with inconsistent protocols and objectives, making it challenging to draw direct comparisons between them. The inconsistency in the methods and aims of the studies limited the ability to form clear conclusions or identify patterns across the research.

Additionally, the review highlighted a distinct lack of evidence specifically addressing the core resistance training variables. Few studies made direct comparisons to explore the effects of these primary variables, and many of the investigations did not thoroughly examine how sets, repetitions, intensity/load, training frequency, and recovery times influence performance outcomes in youth team sports. The review of literature highlighted that several areas of research on resistance training in youth sports remain underexplored. There is a clear need for more detailed and consistent research to better understand how various training variables influence performance.

8.10.8 Chapter 4 and 5

In chapter 4 we investigated the effects of training frequency on athletic performance in youth footballers. Current guidelines suggest resistance training two - three times per week is optimal for strength gains in youth athletes, whilst one session is best suited for maintaining strength gains (1, 37, 155) While some previous literature has supported this recommendation (112, 218, 244, 248, 340), the available evidence in youth remains relatively sparse, with limited studies in directly comparing training frequencies available for comprehensive review (218, 244, 247).

After completing the data collection for the study, one limitation became apparent: there was an issue with participant attendance, particularly in the group meant to complete two resistance training sessions per week. This group only received approximately 8.33% more training than the group training once per week, which made it difficult to draw accurate conclusions. Essentially, the study did not effectively compare one versus two sessions per week as intended.

As a result, it was deemed necessary to conduct a follow-up investigation to address the issue of attendance. In Chapter 5, we undertook a second study to directly compare one versus two sessions of resistance training per week in youth athletes. One key methodological change in this study was the inclusion of a control group. By adding a control group, we strengthened the study, allowing us to determine whether improvements in athletic performance were due to the training intervention rather than natural factors such as growth or maturation. Additionally, the control group enabled us to assess whether one session of resistance training is sufficient for improving strength levels, rather than merely maintaining them. Chapter 4 also revealed a similar issue with regards to attendance from participants, with the twice weekly group only receiving 12.37% more training than the once weekly group.

The research from this thesis suggests that performing two resistance training (RT) sessions per week may offer an additional benefit for strength development in youth footballers compared to once-weekly sessions. In both Chapter 4 and Chapter 5, the groups assigned to train twice per week demonstrated slightly greater improvements in strength than those training once per week, despite low actual training exposure due to attendance issues. Notably, even a single weekly RT session produced statistically significant gains in lower body strength relative to a non-training control group (Chapter 5), indicating that a minimal effective dose of RT can still lead to meaningful adaptations in youth athletes.

These findings are partially in agreement with previous research that has directly compared RT session frequency in youth. For example, Faigenbaum et al (244) reported greater strength gains with two weekly sessions than with one, particularly in lower body measures. Similarly, DeRenne et al. (247) found mixed results, with some strength measures favouring one session per week, while others declined or showed minimal change regardless of session frequency. Cavaco et al. (218) and Alves et al. (248), both of which investigated complex training models in youth footballers, found no significant performance differences between groups training once versus twice weekly, suggesting that for certain physical qualities such as speed and agility, RT session frequency may play a less critical role. To the best of the author's knowledge, these four studies represent the only controlled trials to date that have directly compared RT session frequency in youth athletes, making them a key comparative benchmark for the present research.

In addition to these direct comparisons, several other studies in youth football have implemented twice-weekly RT session protocols and reported positive performance outcomes, even though RT session frequency itself was not the variable under investigation. For instance, Christou et al. (113) demonstrated significant improvements in maximal strength in adolescent soccer players using a twice-weekly RT programme. Similarly, Keiner et al. (123), Ruivo et al. (235), and Sander et al. (2013) each reported enhancements in sprint performance, jumping ability, and change-of-direction speed following RT interventions conducted two times per week in youth footballers. These findings collectively support the idea that a twice-weekly RT session frequency is both feasible and effective for driving athletic development in youth populations, particularly when integrated alongside regular sport-specific training.

Furthermore, a meta-analysis by Lesinski et al. (112), which evaluated the effects of RT on strength, power, and speed in youth athletes, concluded that 2–3 RT sessions per week resulted in the greatest performance gains across all outcome measures. This recommendation is broadly consistent with the directional trend observed in the present research; however, the strength of the effect was less pronounced in our studies due to limited between-group exposure (i.e., ~8–12% more training for the twice-weekly group). Nevertheless, the findings from Lesinski et al. lend further support to the assertion that a 2x/week RT session frequency is an effective target in youth RT programming—especially where logistical constraints allow for it.

Most notably, the present research found that performing just one RT session per week was sufficient to elicit significant improvements in lower body strength, countermovement jump (CMJ) performance, and sprint speed in youth footballers. These gains were observed across both studies, with Chapter 5 showing that the once-weekly RT group achieved statistically greater improvements in these performance measures than a non-training control group. This suggests that even minimal RT exposure can lead to meaningful neuromuscular and performance adaptations. These findings challenge the recommendations of both the UKSCA (27), and the NSCA, (1). Both sets of guidelines propose that one RT session per week is suboptimal, typically sufficient only for maintaining existing strength levels. Similarly, the meta-analysis by Lesinski et al. (112) concluded that 2–3 RT sessions per week were optimal for improving strength, power, and speed in youth athletes, and stated that a frequency of one session per week was considered suboptimal for driving meaningful performance adaptations. In contrast, the present findings provide novel evidence that even a single, well-structured RT session per week can positively influence multiple physical performance outcomes in youth footballers.

Previous studies that have directly compared resistance RT session frequency in youth populations have shown that one session per week elicit performance improvements. For example, Faigenbaum et al. (244) found that one RT session per week led to significant gains in lower body strength (leg press) compared to a control group in untrained children. However, upper body strength improvements (chest press) in the once-weekly group were not significantly greater than the control. Similarly, DeRenne et al. (247) reported that a group training once per week experienced greater improvements in upper body strength, but lower body strength declined. The absence of a control group made it difficult to determine whether the observed changes reflected true adaptation or natural fluctuations.

In studies using hybrid training approaches, Cavaco et al. (218) found that one weekly session of complex training significantly improved shooting efficiency in youth footballers compared to a control group but showed no advantage for sprint performance or agility. Similarly, Alves et al. (248) reported that a single weekly session of contrast training led to significant improvements in sprint speed and squat jump performance compared to a control group, although no changes were observed in agility or countermovement jump. Importantly, both of these studies used complex or contrast training protocols, which combine resistance training with plyometric and sport-specific drills, making it difficult to isolate the specific contribution of RT session frequency alone.

These findings are particularly relevant in light of the real-world constraints faced by strength and conditioning coaches in youth sport environments. Across both studies, consistent attendance at twice-weekly sessions proved difficult to achieve due to the complex scheduling demands typical of academy settings, such as overlapping technical sessions, late fixture changes, and general logistical limitations. Even with carefully planned interventions across a 8-week period, the intended RT frequency was not delivered in either study. This mirrors a common challenge in youth development settings optimal programming may be theoretically ideal, but practically unfeasible.

While the data do not allow us to definitively conclude that two sessions per week are superior to one, particularly given the minimal differences in actual training exposure between groups, the small improvement seen in strength development in the higherfrequency groups supports current guidelines that recommend 2–3 sessions per week (1, 37) However, this thesis also offers a realistic and pragmatic insight, that even when optimal frequency is not achievable, one high-quality RT session per week can still drive progress. This challenges the prevailing view that one session is only sufficient for maintenance (112).

For practitioners, this has important implications. Coaches may continue to plan for an optimal RT session frequency of two to three sessions per week, but they can also be reassured that meaningful improvements in strength, speed, and power can still be achieved with a reduced frequency. This insight is particularly valuable for long-term athlete development, as maintaining a minimal but consistent RT exposure during the formative years can help build the technical proficiency, movement competency, and training resilience required for higher-volume training later in an athlete's career.

8.10.9 Chapter 6

This study aimed to compare the effects of traditional resistance training (TTG) versus functional resistance training (FTG) on performance outcomes including lower body strength, lower body power, sprint speed, and change of direction ability in youth footballers. The rationale stemmed from both the theoretical foundations and increasing popularity of functional training in athletic contexts (273-275), as well as the practical constraints discussed in earlier chapters, particularly the need for efficient and effective training modalities within youth academy environments.

The traditional approach to strength training typically emphasises bilateral lifts such as the squat and deadlift, which are well-established methods for improving maximal force production (276-278). In contrast, functional training draws on principles of dynamic correspondence (282) and seeks to improve movement efficiency and sportspecific performance through unilateral, multi-planar, and often directionally loaded exercises (273, 279, 284).

The findings indicate that traditional resistance training led to greater improvements in lower body strength, with the TTG group demonstrating an13.2% increase in isometric force compared to 6.6% in the FTG group and just 0.8% in the control group. This aligns with existing literature showing that bilateral resistance training allows for greater loading and superior strength adaptations (271, 272). This was likely due to the heavier external loads, observed in the study, where TTG participants regularly lifted between 30–50 kg on the hex bar deadlift and 25–40 kg on the back squat, whereas FTG participants used much lighter external resistance (0–20 kg on the RFE split squat and 10–20 kg on the SL RDL). These exercises enable higher levels of force production, which is crucial for foundational strength development.

Conversely, the FTG group demonstrated a significantly greater improvement in CoD performance, as measured by the 505 test. This finding supports the idea that training incorporating lateral and unilateral movement patterns can enhance neuromuscular coordination and movement specificity relevant to directional speed tasks (195, 288). This outcome aligns with the theoretical underpinnings of functional training and forcevector theory, which propose that aligning the direction of resistance with the direction of intended performance transfer can enhance adaptations (283, 285).

For measures of countermovement jump and sprint speed, no significant difference between training modality was observed. This aligns with previous literature suggesting that moderate-intensity resistance training alone may not provide a sufficient stimulus to significantly enhance explosive tasks like sprinting and jumping. For instance, Seitz et al. (260) reported that improvements in sprint performance are more likely when resistance training is combined with high loads and/or plyometric exercises. Similarly, Liao et al. (297) found that neither unilateral nor bilateral resistance training alone had a significant effect on linear speed, highlighting the importance of specificity and intensity. Studies by Stern et al. (271) and Speirs et al. (272) also indicated that higher training loads (75–85% 1RM) and the inclusion of explosive drills are more effective for improving CMJ and sprint metrics. Given that the present study employed moderate training intensities (~60–70% 1RM) without additional plyometric or sprint-specific components, the lack of improvement in these measures is consistent with these prior findings.

From a practitioner standpoint, the results of this study indicate that both traditional and functional resistance training modalities have merit, but their application should be context-dependent. Traditional resistance training remains a more efficient and effective approach for developing foundational strength in novice youth athletes. Its bilateral exercises are generally easier to coach, safer under load, and more timeefficient factors especially valuable in high athlete-to-coach ratio environments typical of youth academies.

Functional resistance training, while potentially more complex and time-consuming, may offer additional benefits as athletes mature. Specifically, the improvements seen in CoD performance suggest that the inclusion of unilateral and multi-directional exercises can enhance sport-specific movement capacities that are essential in football. Therefore, functional exercises might be best integrated progressively as training age and technical proficiency increase.

This study supports a periodised approach to youth strength and conditioning: beginning with traditional bilateral lifts to develop strength and technique,and gradually incorporating more functional exercises to address sport-specific demands. This balanced strategy ensures that athletes receive both the foundational and specialised stimuli necessary for long-term athletic development.

In conclusion, while functional training is gaining traction within the field, traditional style training remains indispensable particularly in the early stages of athletic development. Strength and conditioning coaches should feel confident using traditional methods as the cornerstone of youth training programmes, integrating functional elements strategically based on athlete readiness and performance goals

8.10.10 Chapter 7

To the author's knowledge, this was the first study to investigate the *acute effects* of intrasession training sequence, resistance training before football (RT > FT) versus football before resistance training (FT > RT), on performance measures such as dynamic stress load (DSL), accelerations, countermovement jump (CMJ), and perceived exertion (RPE) in youth athletes.

While previous studies have examined the long-term effects of training sequence on strength, endurance, or power development (230, 305, 307) none have assessed how the sequencing of resistance training and sports specific training within a single training session impacts performance in youth populations. This study therefore represents a novel contribution to the literature, offering new insights into the shortterm interaction effects of football and resistance training and providing practical implications for youth sport training design

The results showed no significant differences in dynamic stress load (DSL), number of accelerations, countermovement jump (CMJ) height, or rate of perceived exertion (RPE) between the two conditions. This suggests that, at least in the short term, the order in which resistance and sport-specific training are performed does not significantly influence neuromuscular performance in youth players.

The findings of the present study are generally in agreement with previous literature in that training order did not appear to critically affect performance outcomes. For example, Makhlouf et al. (230) found improvements in strength, sprint, and change of direction performance across all concurrent training conditions over a 12-week period, with no significant differences based on training sequence. Similarly, Alves et al. (305) reported significant gains in explosive strength in children following combined strength and aerobic training, but with slightly greater improvements when strength training was performed first. Enright et al. (307) also observed performance gains in youth footballers over five weeks, with marginally superior improvements in the endurancebefore-strength group.

However, a key distinction between the present study and those mentioned above lies in the research design. Whereas previous studies focused on the chronic effects of training order over multiple weeks, the current study uniquely investigated the acute effects of intrasession sequencing within a single training day.

Unlike previous long-term studies, the present investigation focused on the immediate effects of training sequence, offering practical insight for day-to-day session planning. Earlier research has shown that residual fatigue can negatively affect skill acquisition and explosive performance (310). While the present study did not directly assess skill learning or technical execution, the absence of significant differences in fatigue-related measures, such as dynamic stress load, countermovement jump, accelerations, and perceived exertion, across both session sequences suggests that players were not in a state of neuromuscular fatigue during either format. This implies that their capacity to learn, adapt, and respond to new training stimuli would likely have remained intact regardless of whether resistance or football training was performed first.

The findings of this study have important implications for strength and conditioning practitioners, especially those working in academy football environments where scheduling constraints and the need for flexibility often make it difficult to maintain a consistent training structure. As outlined earlier in this thesis, coaches frequently have limited control over the sequencing of resistance training (RT) and football training (FT) sessions due to external factors such as fixture changes or technical staff requirements.

The results of this study, when considered alongside existing literature, suggest that the sequence of RT and FT may not significantly influence indicators of fatigue or acute disruption to performance ability, such as dynamic stress load, countermovement jump height, accelerations, or perceived exertion. This aligns with previous research suggesting that youth athletes exhibit greater resistance to fatigue and recover more rapidly than adult populations (69, 327, 341). These physiological characteristics may help explain why session order did not significantly impact neuromuscular responses or perceived effort in the present study.

Consequently, practitioners can be confident that unplanned changes to the sequencing of football and resistance training sessions are unlikely to negatively affect the quality of either training type. Youth athletes appear capable of maintaining performance capacity regardless of whether RT or FT occurs first, allowing coaches to prioritise logistical feasibility without compromising training outcomes.

8.10.11 Thesis Limitations

Limitation 1: Attendance and adherence

One of the main limitations of this research was participant attendance and adherence to the training protocols in Chapters 3 and 4. Attendance issues resulted in variations in total training volume between groups, particularly in the twice-weekly resistance training groups. This inconsistency made it challenging to draw clear comparisons between the different training frequencies. As noted in Chapter 4, these attendance issues reflect the unpredictable nature of academy-level sports, where external demands and scheduling conflicts are common, making it difficult to fully control.

Limitation 2: Homogenous participant groups

The present thesis focused on 13–14 year-old academy football players, a specific and relatively homogeneous group. While the findings provide valuable insights into training interventions for this population, focusing solely on football may limit the generalisability of the results to athletes in other sports. Different sports have varying physical demands, skill requirements, and training schedules which could all influence the effect of resistance training. the age range and maturation status of the participants also pose limitations in terms of the broader applicability of the findings. This thesis also focused on a specific age group of youth athletes, meaning the physiological and developmental characteristics of the participants were relatively uniform. However, the maturation status of athletes, particularly during adolescence, can significantly influence how they respond to training stimuli. Youth athletes experience varying rates of growth and maturation, which affect strength development, neuromuscular coordination, and recovery. This variability can lead to different responses to resistance training and sport-specific training. For younger or less mature athletes, resistance training may need to focus more on developing movement proficiency and injury prevention, while older or more physically mature athletes could respond more favourably to higher intensities and training volumes.

Limitation 3: Non standardised football training

In Chapter 6, the football training undertaken by participants was not standardised, meaning that the volume, intensity, and workload of the football training sessions were not controlled. While this reflects typical practice in a football academy and enhances the real-world relevance of the study, it is important to acknowledge that the lack of standardisation likely had a significant impact on the GPS observations reported in this chapter.

8.10.12 Future directions

Given the difficulty of guaranteeing attendance, future research should prioritise reporting attendance rates, as demonstrated in Chapters 3 and 4 of this thesis.

Reporting attendance in resistance training studies is uncommon; none of the studies reviewed in Chapter 2 of this thesis included attendance data. Incorporating attendance rates allows for a more accurate interpretation of results, as it ensures that the actual training stimulus delivered is considered when evaluating outcomes. This is especially crucial in resistance training research, where the volume and intensity of the training stimulus directly influence the findings. Therefore, reporting attendance should become a fundamental practice in future studies. Without acknowledging whether the intended training was fully completed, the validity of the results may be significantly compromised.

Accurate and thorough reporting of training programmes is essential for evaluating the effectiveness of resistance training interventions. Most of the research reviewed, as well as the chapters in this thesis, have done this effectively, providing clear details of the prescribed training protocols. However, some studies lack specific information regarding key variables such as sets, repetitions, intensity, and recovery times. This omission can make it difficult to fully assess the impact of the intervention and compare it with other studies.

Similar to the issues surrounding the reporting of attendance, detailed reporting of training variables is crucial for accurately assessing how effective an intervention was. The variables in a resistance training programme, such as volume, intensity, and recovery, are critical to its overall effectiveness and can significantly influence the outcomes. If one variable is manipulated in an intervention, it is essential that details of the other variables are provided to allow for proper interpretation. Without this information, it becomes challenging to draw meaningful conclusions or compare the effectiveness of different interventions across studies.

Additionally, it is not only the prescribed training that should be reported in detail, but also the actual training carried out. In instances where the training completed differs from the initial prescription, efforts should be made to report these discrepancies. For example, in this thesis, the chapters provide a simple note on the range of loads utilised, offering context regarding the training performed. Furthermore, this thesis also reports the number of sessions attended, which adds transparency and allows for a better understanding of the actual training stimulus received by the participants. Future research should aim to adopt this level of transparency in reporting both the prescribed and completed training, ensuring that all variables are clearly outlined. This will enhance the ability to compare research findings and determine the true effectiveness of training interventions.

Future research should also consider how age and maturation status affect the applicability of these findings, as training programmes may need to be tailored to suit the developmental stages of the athletes. Additionally, future studies should investigate whether these findings hold true in other sports. By expanding research to include a broader range of age groups, maturation levels, and athletes from different sports, future studies can provide a more comprehensive understanding of how resistance training and sport-specific training interact across diverse populations. This would aid in refining training recommendations to accommodate the unique needs of athletes at various stages of development and in different sporting environments.

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Appendices

Appendix 1

Proposed Title: Investigating the effects of different inter-set recovery times on resistance training performance in youth footballers.

Introduction:

Guidelines from the National Strength and Conditioning Association (NSCA) and the United Kingdom Strength and Conditioning Association (UKSCA) recommend recovery times between sets of resistance training to range between 60 and 180 seconds, depending on the intensity of the training. The purpose of this study was to investigate two primary objectives: (1) determine which recovery duration within the guidelines range is optimal, and (2) examine whether shorter rest intervals could negatively impact performance. Specifically, the study aimed to measure changes in repetition velocity following different recovery times. It was hypothesised that shorter recovery periods would result in a greater reduction in repetition velocity in subsequent sets, indicating neuromuscular fatigue and potentially negative effects on subsequent training performance.

Participants:

38 participants were recruited from an English league 1 football academy. Participants were male and were recruited from an under 13s team (n= 12), and under 14s team (n= 13) and under 15s team (n=11).

Procedure:

Each participant will be assessed during both bench press and back squat movements. Prior to the intervention, participants will be evaluated to determine their 8-repetition maximum (8RM) for each lift. The intervention procedure will consist of performing both a Barbell back squat and barbell bench press for three sets of eight repetitions at a load of approximately 80%, which corresponds to the 8RM. To avoid fatigue, each lift will be tested on separate days. Rest intervals of 30, 60, 90, and 120 seconds will be implemented over a four-week period. The procedure would be as follows.

Week 1:

Day 1 back squat, 3 sets 8 reps, 80%1RM, 30 s recovery between sets.

Day 2 bench press 3 sets 8 reps, 80%1RM, 30 s recovery between sets.

Week 2:

Day 1 back squat, 3 sets 8 reps, 80%1RM, 60 s recovery between sets.

Day 2 bench press 3 sets 8 reps, 80%1RM, 60 s recovery between sets.

Week 3:

Day 1 back squat, 3 sets 8 reps, 80%1RM, 90 s recovery between sets.

Day 2 bench press 3 sets 8 reps, 80%1RM, 90 s recovery between sets **Week 4:**

Day 1 back squat, 3 sets 8 reps, 80%1RM, 120 s recovery between sets.

Day 2 bench press 3 sets 8 reps, 80%1RM, 120 s recovery between sets

Repetition velocity:

It was the hypothesis that shorter recovery sessions could result in neuromuscular fatigue, which would be observed by measuring a reduction in repetition velocity during each repetition. Velocity was to be measured using a linear position transducer (GymAware, Kinetic Performance Technology, Canberra, Australia)