The effect of maturity status on physical performance following traditional dynamic and eccentric resistance training in adolescent male soccer players

by

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Abstract

Background: Developing strength and motor control is crucial for long-term athletic development and reducing injury risk in maturing youth athletes. Moderate load eccentric duration-accentuated resistance training (ECC) may show additional benefits to physical qualities and overall athleticism, relative to traditional dynamic resistance training (TRAD). There is currently a lack of research utilising eccentric training in youth athletes, particularly when considering maturity status.

Methods: Using a mixed longitudinal and parallel groups design, the effect of TRAD versus ECC on physical performance was investigated in adolescent male athletes, accounting for maturity status. In block 1, twenty-nine (11-15 y) male soccer players completed eight weeks of TRAD (repetition eccentric:concentric tempo, 2:1).Subsequently, participants were grouped according to maturity status (age to/from peak height velocity) and back squat strength, for block 2. Twenty-four participants then further undertook TRAD or ECC (tempo range, 3:1-6:1) for 12 weeks (Block 2). Physical performance was tested repeatedly (wk 0-21) and assessed lower body strength, power, speed, change of direction, flexibility, movement competency, mood status and muscle soreness.

Results: In Block 1, TRAD led to substantial improvements in 3RM back squat strength (mean effect-size (ES) change; ±90%CL: ES 1.5; ±0.5), 505 change of direction test (ES 0.7; ±0.3), right (ES 1.0; ±0.9) and left (ES 0.8; ±0.3) straight leg raise and back squat movement competency (ES -0.6; ±0.2). In Block 2, both training groups showed large improvements in 3RM back squat strength at pre- (mean percent (%) change; TRAD = 45; ±18%; ECC = 38; ±12%), circa- (TRAD = 39; ±10%; ECC = 31; ±9%) and post-PHV (TRAD = 34; ±14%; ECC = 28; ±13%). Similarly, both groups showed moderate improvements in IMTP (isometric mid-thigh pull) at pre- (TRAD = 24; ±25%; ECC =17; ±16%), circa- (TRAD = 21; ±14%; ECC =16; ±11%) and post-PHV (TRAD = 18; ±20%; ECC =15; ±20%). Only pre-PHV TRAD showed small improvements in squat jump peak ground reaction force (SJ GRF; 8.5; ±8.5%). There was a decrement in 20-m sprint performance with either training modality pre-PHV (TRAD = 4.6; ±2%; ECC = 3; ±1.3%) and circa-PHV (TRAD = 2.2; ±1.2%; ECC = 2.1; ±1%). Pre-PHV, ECC showed less impairment in 5-m (-16; ±4.7%), 10-m (-7.7; ±3.8%), and 15-m (-4.7; ±3.8%) sprint performance, relative to TRAD. Circa-PHV, ECC was less detrimental to only 5-m sprint, (ECC–TRAD = -6.9; ±3.1%), compared to TRAD. When comparing training modalities, TRAD showed greater improvements for improving straight leg raise pre-PHV (ECC-TRAD = right, -6.3; ±6.6%; left, -6.6; ±7.6%) while ECC showed post-PHV (left = 6.4; ±7.6%).

Conclusions: The initial adaptations associated with eight weeks of TRAD showed substantial improvements in lower body strength, 505 change of direction test, unilateral flexibility and movement competency. Subsequently, 12 weeks of TRAD further benefitted 3RM back squat strength, IMTP, SJ GRF and unilateral flexibility, while ECC led to substantial improvements in 3RM back squat strength and IMTP. Comparing the two training modalities, TRAD was more beneficial than ECC for strength and unilateral flexibility pre-PHV. On the other hand, ECC was less detrimental than TRAD for some sprint splits and beneficial for lower-limb flexibility post-PHV. Hence, moderate-load eccentrics may be a useful lower-load resistance training variation to traditional dynamic training around peak growth in youth soccer players. Practitioners should consider using ECC or TRAD training modalities with youth athletes based on individual athlete PHV and specific training/season goals.

Declaration of authenticity

Master by Research Declaration "I, Anushka Bhargava, declare that the Master by Research thesis entitled "The effect of maturity status on physical performance following traditional dynamic and eccentric resistance training in adolescent male soccer players" is no more than 60,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

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Date: 9th August, 2019

Dedication

This thesis is dedicated to my family. To my dad, who introduced me to tennis when I was 5 years old and has taught me everything I know. He has always supported me financially and emotionally at every step of my life. To my mom, who has made countless sacrifices to support our family and has always shown me the right path. To my brother, who has always been there for me and pushed me to be my best. I am where I am because of all of you. I love you all very much and miss you.

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Contents

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Abbreviations

ECC	Moderate load eccentric duration-accentuated resistance training
TRAD	Traditional dynamic resistance training
PHV	Peak height velocity
RM	Repetition maximum
IMTP	Isometric mid-thigh pull
SJ	Squat Jump
CMJ	Counter-movement Jump
GRF	Ground reaction force
POMS	Profile of Mood Status
DOMS	Delayed onset muscle soreness
VAS	Visual Analogue Scale
Quads	Quadriceps
Hams	Hamstring
RPE	Rate of perceived exertion
CSA	Cross-sectional area
ES	Effect size
SWC	Smallest worthwhile change
SD	Standard deviation
CL	Confidence limit/compatibility limit
CV	Coefficient of variation

List of Symbols

n	Number
kg	Kilogram
cm	Centimetre
m	metre
~	Approximately
%	Percentage
min	Minute
s	Second
y	Year
wk	Week
N	Newton
°	Degree

Introduction

Background

Peak height velocity (PHV) is the period of time in which adolescents experience the fastest change in stature (i.e., the adolescent growth spurt Mirwald et al., 2002). During this time, changes in the muscle-tendon complex and temporary variation in bone density can lead to a more fragile skeleton (Blimkie et al., 1993; Faulkner et al., 2006; Ford et al., 2010a; Iuliano-Burns et al., 2001). Additionally, the time lag between the growth of the muscle-tendon unit and the bone can cause imbalances in strength and flexibility which can contribute to abnormal movement mechanics and a decline in motor control (Beunen et al., 1988; Brown et al., 2017). In youth athletes who are already exposed to substantial training-related stresses upon the musculoskeletal system, the combination of a fragile skeleton, abnormal movement mechanics and decline in motor control may directly impact physical performance in training and competition, and predispose them to an increased risk of injury (van der Sluis et al., 2014). Therefore, a training program involving youth athletes should be aimed at not only improving performance but also limiting the occurrence of injury.

To mitigate the possible detrimental effects of growth and maturation on physical performance in youth athletes, guidelines on youth exercise training advise regular participation in resistance training to improve musculoskeletal health, overall athleticism and reduce the risk of sports-related injury (Lloyd et al., 2014). For example, Philippaerts et al. (2006) saw a decline in the rate of improvement in running speed and explosive strength during PHV versus pre-PHV, in adolescents soccer players. Appropriate application of various forms of resistance training (i.e., traditional dynamic resistance and plyometric training) can improve muscular strength (Behringer et al., 2010), power production (Faigenbaum et al., 2009; Sander et al., 2013), running velocity (Mikkola et al., 2007), change of direction ability (Thomas et al., 2009) and general motor control (Behringer et al., 2011) in youth athletes. Additionally, consensus guidelines on resistance training for youth suggest that practitioners should account for and periodise training according to maturity status (Lloyd et al., 2014). However, there is a limited body of research investigating the effect of resistance training in youth athletes, while accounting for their maturity status (i.e., age to/from PHV).

Meylan et al. (2014) investigated a periodised eight-week traditional dynamic resistance-training program in youth athletes while accounting for development by partitioning participants into pre/mid/post PHV groups for analysis. The authors found that the eight-week program led to improvements in maximum predicted 1RM strength (3.6-10%), supine squat peak power (11-20%), broad jump distance (6.5-7.4%) and reduce 30 m sprint split times (-2.1 to -4.7%) across the entire maturity spectrum. Importantly, the authors concluded that the magnitude of adaptations was maturity-dependent; dynamic resistance training was more beneficial for force-dependent measures (estimated 1RM, maximum force of ballistic squat and broad jump tests) in mid- and post-PHV youth, while pre-PHV youth showed greater relative improvements in velocity-dependent measures (maximum velocity of ballistic squat, and sprint speed) (Meylan et al., 2014). Thus, there is some evidence supporting maturity-dependent beneficial effects of traditional dynamic resistance training in youth athletes. However, current literature in youth fails to investigate the effect of training emphasising particular muscle contraction types (e.g., eccentric, isometric) during resistance training, while accounting for PHV.

In adult populations, eccentric training using supramaximal loads (>1RM) has been shown to benefit physical performance by producing larger improvements in mechanical function (e.g., strength, power, rate of force development and stiffness), musculotendinous morphology (e.g., tendon and muscle fibre cross-sectional area), neuromuscular adaptations (fast motor unit recruitment and firing rate), and performance measures (e.g., vertical jumping, sprint speed, and change of direction) compared to concentric, isometric and traditional dynamic (eccentric/concentric) training (Suchomel et al., 2018; Suchomel et al., 2019). Additionally, the stretch provided by eccentric training has been shown to increase fascicle length and range of motion leading to an increase in lower-limb flexibility (O'Sullivan et al., 2012). A lack of lower-limb flexibility might lead to decrements in performance and increase the risk of injury in youth soccer players (Cejudo et al., 2019). However, supramaximal eccentric training may be unsuitable for athletes that have a lower level of technical competency in resistance training and a lower strength base, given the relative and absolute loading and movements (large compound exercises) utilised. Youth athletes at or around peak growth and maturation might, therefore, be unsuitable for supramaximal eccentric training, as they are more likely to possess a low strength base and may lack suitable motor control and movement competency at that time. Furthermore, specialised equipment is often needed to enable practical application of supramaximal eccentric training, which might limit the suitability of this training variation. Lastly, delayed onset muscle soreness is commonly associated with supramaximal eccentric training, which causes an increase is passive tension and muscle swelling contributing to a decrease in joint range of motion (Douglas et al., 2017). Therefore, there can be a loss of force production and altered movement mechanics following eccentric training, which may lead to impairments in physical performance (Douglas et al., 2017).

A practical and safer alternative to supramaximal eccentric training might be to use submaximal loading (<1RM) and manipulate the total time-under-tension in the eccentric phase of a movement. Compared to traditional dynamic resistance training, moderate load eccentric cycling training has demonstrated similar improvements in muscle strength, cross-sectional area and fibre size in knee extensor muscle, in adults (Hoppeler, 2016). However, the cyclic nature of moderate load eccentric training using a modified ergometer likely yields a distinct physiological and neuromuscular response to moderate load eccentric resistance training, and is likely less sports-specific. Repetition duration-accentuated eccentric training (10 s eccentric contraction) to muscular failure has also been shown to produce similar improvements in muscle performance (1RM strength and absolute muscle endurance) to traditional resistance training, in adults (Fisher et al., 2016). This training approach uses multi-joint movements and basic resistance training equipment; thus is considered more practical in an applied setting than moderate load eccentric ergometer training. Both of these submaximal eccentric exercise strategies have been identified as valuable and safe training modalities in adult populations, as they demonstrate similar improvements to traditional resistance training in muscle performance with lower muscle activation and absolute joint loads. Moderate load eccentric duration-accentuated resistance training (ECC) that utilise submaximal (<1RM) loading could be beneficial for youth athletes during growth and maturation, due to the lower joint loading and practicalities associated with implementing it versus supramaximal eccentric training; and greater movement-specificity compared to eccentric cycling. However, there is no current literature that analyses the effect of ECC training, relative to traditional dynamic resistance training (TRAD) in youth athletes during PHV, as growth and maturity status may moderate the effect of a resistance training intervention.

Therefore, it is also important to account for maturity status when interpreting the impact of a training intervention in youth athletes.

Literature Review

Biological Maturation

Physiological changes associated with maturation

Biological maturation causes disproportionate changes in various physiological systems (skeletal, neuromuscular, endocrine, etc.) which coincide with the adolescent growth spurt (Malina et al., 2004a). These physiological changes an accelerated increase in stature and proportionally smaller increase in muscular force production (Quatman et al., 2006), altered lower-limb strength ratios (Quatman-Yates et al., 2013), and substantial alterations in movement biomechanics (Ford et al., 2010b; Hewett et al., 2015). The progress of physiological systems towards complete maturation varies between individuals in timing, tempo, and magnitude (Lloyd et al., 2016a). In males, these changes are initiated by the endocrine system, through the widespread signalling action of elevated levels of anabolic hormones including testosterone, growth hormone and insulin-like growth factors (Malina et al., 2004b).

Anatomical changes associated with maturation

During peak height velocity (PHV), adolescents experience a rapid increase in stature and body mass, but a proportionally smaller increase in muscular strength (Parker et al., 1990) attributable, at least in part, to the differing time-course in which these changes initiate. For instance, bone growth precedes muscle and tendon morphological changes (Kerssemakers et al., 2009). This growth differential between bone and the muscle/tendon complex may cause joint discomfort and reduced flexibility that leads to a decrement in performance (Ford et al., 2010a; Iuliano-Burns et al., 2001). Therefore, an increase in flexibility might lead to an improvement in muscular performance. For example Ferreira et al. (2007), found that an increase in flexibility led to an increase in peak angle torque for hamstrings, knee extensors and flexors. The hormonal profile during maturation also cause neuromuscular alterations that lead to a temporary disruption in motor control and whole-body coordination, which is commonly known as “adolescent awkwardness” (Philippaerts et al., 2006; Quatman-Yates et al., 2012).

Physical demands for active adolescents across maturation

An addition consideration is early sports specialisation in youth athletes may also lead to a greater risk of overuse injury. The immature musculoskeletal system is exposed to substantial repetitive biomechanical stress associated with training volume, which may be coupled with insufficient recovery time (DiFiori et al., 2014; Pasulka et al., 2017). Inappropriate programming of training in this way might prevail during the adolescent years due to the desire for a higher standard of competition and performance (Lloyd et al., 2016a). Although the magnitude of stress varies according to the nature and frequency of sports training and competition demands (Costa e Silva et al., 2017; Lloyd et al., 2016a), a key training emphasis in young athletes is skill development, which necessitates elevated training volumes at high intensities (Brink et al., 2010; Gonçalves et al., 2012; Vaeyens et al., 2005). Therefore, the overexposure to a limited range of motor patterns with inadequate rest and recovery has previously been associated with decrements in physical performance and increased risk of overuse injury (Lloyd et al., 2016a). Conjointly, early sports specialisation occurring during biological changes of peak maturation contribute to a higher risk of injury in adolescent athletes (Stracciolini et al., 2013). For instance, some reports indicate tendinopathy as the most common overuse injury in adolescent athletes (Le Gall et al., 2006) which could be attributed to an imbalance in the development of the muscle-tendon unit (i.e., differences in muscle strength and tendon stiffness). However, resistance training which is shown to enhance the bone mineral density and improve skeletal health (i.e., increase tendon stiffness), may help to reduce the risk of sports-related injuries in youth athletes (Myer et al., 2011; Valovich McLeod et al., 2011).

Individual variance associated with maturation

Substantial inter-individual variance exists in the extent, timing and tempo of biological maturation in youth (Beunen et al., 2008). This leads to development disparity in the way adolescents of the same age or maturity status, respond and recover from training (Armstrong et al., 2011; Behringer et al., 2011; Behringer et al., 2010). Therefore, exercise scientists and practitioners working with youth athletes are constantly challenged in determining whether the changes in performance are training-induced or growth-related adaptations (Lloyd et al., 2016b; Rumpf et al., 2012). Identifying the nature and extent of training adaptations at different maturation levels may help in prescribing training programs that meet the needs and abilities of the individual to improve performance and mitigate the risk of injury (Lloyd et al., 2016a). Youth of the same age may vary markedly in their biological maturation status which makes chronological age an unreliable measure of maturation status in youth athletes (Beunen et al., 1988). Additionally, skeletal age measures require costly and specialised equipment. Other non-clinical measures of secondary sex characteristics are considered personally intrusive in kids (Mirwald et al., 2002).

Accounting for maturation

The age of PHV is a non-invasive technique that has been validated as a measure of maturation status in adolescents (Mirwald et al., 2002). The onset of PHV is determined by using the known differential timings of growth for standing height, sitting height and leg length (Mirwald et al., 2002). In addition to PHV, the percentage of predicted adult stature (Khamis et al., 1994) has also been recommended, due to the error associated with estimating PHV (Mirwald et al., 2002). Using a combination of these two methods circumvents some of the drawbacks of each method alone (e.g. requirement of measurements over time for PHV versus an immediate estimate via predicted adult stature) and may provide a more accurate and reliable estimate of maturation (Meylan et al., 2014). This approach to estimate biological age has been considered as the most practical way to account for different biological levels of development (before, during and after-PHV) to prevent from associated injury risks and track potential responsiveness to training (Meylan et al., 2014). Youth across all levels of participation are advised to engage in resistance training programs accounting for maturation status to develop the degree of athleticism necessary to sustain the physical demands of their sport and counteract risk factors associated with biological maturation (Lloyd et al., 2014). A well-designed resistance training program can induce substantial improvements in physical attributes, such as muscular strength, power production, running velocity, change of direction speed, and fundamental motor performance in youth athletes (Faigenbaum et al., 2016).

Resistance training

Current guidelines for long- term athlete development

Several models have been developed as general frameworks incorporating key aspects of physical performance for long-term youth athletic development, taking into account maturation status, training age, developmental age and technical competency in youth (reviewed by Pichardo et al., 2018). These models include guidelines around the timing and degree of training emphasis to improve physical qualities of strength, speed, agility, balance, etc., in order to maximize long-term physical development. Importantly, the integrative summary of youth athletic development models highlighted by Pichardo et al. (2018) provides guidance to coaches and practitioners regarding the degree and form of resistance training (traditional, body weight, plyometric etc.), and identifies the need for periodising the eccentric contraction in adolescent youth, in order to improve the plyometric components of muscular performance (Pichardo et al., 2018). Pichardo et al. (2018), suggests progressing plyometric training from minimal to high eccentric loading as movement competency increases. However, at present, there is a lack of evidence in youth to support the benefits of eccentric resistance training, which could relate to the false perception of the training modality (loads greater than 1RM) and practicalities associated with it.

Adaptations in muscular strength following traditional resistance training, across maturation

Strength adaptations to resistance training in children and adolescents appear to be caused by either neural or morphological changes (Behm et al., 2008). Lloyd et al. (2012) suggest that improvements in muscular strength occur across the biological maturation status. A meta-analysis investigating the effect of pre-PHV (age= 10-12.99 y) resistance training found a small effect (effect size, ES = 0.50) on muscle strength in adolescent male athletes (Moran et al., 2017). This is likely due to the hormonal profile at that time which is unsuitable for promoting large increases in muscle size (Faigenbaum et al., 2009). Thus, neural mechanisms are proposed to be the main factor driving improvements in pre-PHV (age= <13 y) muscular strength (Payne et al., 1997). In contrast, large increases in muscle strength were seen circa-PHV (age= 13-15.99 y) (ES = 1.11) and post-PHV (age= 16-18 y) (ES = 1.01) in adolescent male athletes undertaking resistance training programs for 4-16 weeks (Moran et al., 2017). This may be explained by concurrent increases in circulating anabolic hormones which contribute to gains in bone and muscle mass (Malina et al., 2004a; Malina et al., 2015). Two early meta-analyses investigating the effect of resistance training in youth reported mean effect-size increases in strength of 0.57 and 0.75 in 12-13 y old and <18 y old participants, respectively (Falk et al., 1996; Payne et al., 1997). Meylan et al. (2014) showed small to large (3.6-10%) increases in estimated 1RM strength across pre-PHV (-1.7±0.4 y), circa- (-0.2 ± 0.4 y) and post-PHV (1.0 ± 0.4 y). Therefore, traditional resistance training can increase muscular strength in adolescents beyond normal growth and maturation related development through predominantly neural adaptations (Faigenbaum et al., 2009).

Adaptations in muscular power following traditional resistance training, across maturation

The stretch-shortening cycle is another important component of athletic performance that can be manipulated via mechanical loading associated with sport and resistance training (Cormie et al., 2010). A stretch-shortening cycle is described as a muscle performing a rapid eccentric contraction (lengthening of the muscle) immediately before a concentric contraction (muscle shortening) (Cormie et al., 2010). Therefore, the stretch-shorten cycle can positively influence the performance of jumping and running tasks. Additionally, change of direction tasks demand greater eccentric muscle strength to decelerate and stabilize the body (Chaabene et al., 2018). In studies that have accounted for PHV, there are clear benefits to the performance of tasks requiring a substantial stretch-shortening cycle component as a result of undertaking traditional resistance and plyometric training (Lloyd et al., 2016b; Meylan et al., 2014). For instance, Lloyd et al. (2016b) demonstrated substantial improvements in squat jump (ES 0.45) and 20 m sprint (ES 0.08) following six weeks of traditional resistance training in youth athletes that had reached PHV. Meylan et al. (2014) reported increases in peak power in a supine squat machine squat-jump protocol (11 to 20%), small to moderate improvements in broad jump length (6.5 to 7.4%) and reductions in sprint times (-2.1 to -4.7%) following eight weeks of resistance training in pre-, mid- and post-PHV adolescent male soccer players. Thus, in youth athletes, an effective way to influence the performance of tasks requiring the stretch-shorten cycle is via traditional resistance training.

Limitations of traditional resistance training

Adolescents going through PHV might benefit from eccentric resistance training, relative to traditional dynamic resistance training, due to unique muscle and tendon adaptations (de Hoyo et al., 2015). Traditional resistance training performed by athletes usually uses gravitational loads with high muscle activation during the concentric phase, but contrastingly much lower activation during the eccentric phase of the movement (Norrbrand et al., 2008) due to the inherently higher force production of a muscle during an eccentric contraction (Hill, 1938). Skeletal muscle can produce ~50% more force during a maximal eccentric action, relative to maximal concentric (Jorgensen, 1976; Westing et al., 1988). However, loads prescribed during traditional resistance training are limited by concentric strength, with subsequent underutilisation of muscle maximal force potential during the eccentric phase (Wagle et al., 2017). Therefore, practitioners and researchers seek alternative training methods that overload/accentuate the eccentric phase of the movement (Wagle et al., 2017).

Eccentrics and limitations of supramaximal training

Eccentric training protocols in adult athletic populations manipulating the load during the eccentric phase of movement have demonstrated greater improvements in total strength, concentric and eccentric strength, hypertrophy, jump power and reduced risk of injury, relative to concentric-only or dynamic resistance training (Bridgeman et al., 2015; Mike et al., 2017). For instance, HortobÁgyi et al. (2001) demonstrated a twofold increase in knee extensors strength using additional 40-50 eccentric overload versus traditional in untrained adults for 7-days. Yarrow et al. (2008) reported a 22% improvement in 1RM concentric squat following eccentric overload training over a 5-week period. A meta-analysis by Roig et al. (2008) found that eccentric-only training induced greater increases in total strength and muscle hypertrophy in healthy adult population, relative to concentric-only training. These adaptations were presumed to be due to greater absolute loads generated during an eccentric contraction, however there is a lack of substantial evidence to support the influence of neural mechanisms (Roig et al., 2008). In youth athletes during peak growth and maturation, eccentric training using supramaximal loads might predispose the fragile skeleton to a greater risk of injury. The use of weight releasers, limited range of movements (limited sports specificity), high cost of equipment, and safety issues associated with training large numbers of participants at a given time, makes this method impractical in an applied setting. Additionally, youth athletes might lack a resistance training history, strong base of strength, technical competence and coordination. Hence, eccentric training strategies using submaximal loads <1RM) might be a more appropriate training modality in youth athletes.

Benefits of moderate load eccentric training

Moderate load eccentric resistance training is defined herein as being resistance training that accentuates the tempo characteristic (speed of movement) of the eccentric phase of a movement under submaximal loading (i.e., <1RM). The qualifier moderate is used even though loading might be at a high percentage of concentric 1RM, as relative to the upper limit of eccentric force production the loads are most appropriately described as moderate (i.e., the reference point for the qualifier is the eccentric maximal force as opposed to the concentric maximal force). It should be noted that this moderate-load eccentric resistance training is distinct from moderate-load eccentric ergometer training, defined by Hoppeler (2016), as eccentric ergometer exercise protocols lasting between 5 and 30 min . Interestingly, moderate-load eccentric cycling training studies have shown similar increases in muscle strength, cross-sectional area and fibre size in knee extensor muscles to traditional strength training (LaStayo et al., 2000; Lastayo et al., 1999). Hoppeler (2016) speculated this distinct moderate load eccentric training does not require near maximal contractions to observe similar improvements in strength and volume, which are otherwise necessary in traditional strength training. Consequently, moderate load eccentric training involves substantially lower joint loads than traditional resistance training, making it "joint friendly" (Hoppeler, 2016). Hence, this is considered a valuable training modality in orthopedic, rehabilitation and injury prevention settings (Hoppeler, 2016). Literature investigating moderate load eccentric training has largely been limited to the use of eccentric ergometer protocols in clinical populations and outcomes may not be transferable to youth athletes during maturation. However, given the musculoskeletal problems that can occur in youth athletes during maturation, moderate eccentric loading might be useful adjunct to traditional dynamic resistance training at this time.

Benefits of submaximal load and repetition duration accentuated eccentric training

Changes in muscular strength with eccentric resistance training tend to be specific to the speed of the movement and mode of contraction used (Roig et al., 2008). Previous studies in adult athletic populations using submaximal loads have increased the duration of the eccentric contraction to accentuate the eccentric phase of the movement (Fisher et al., 2016; Mike et al., 2017). For example, a practitioner might ask an athlete to increase the time or reduce the speed of descent to the bottom position in the movement. Mike et al. (2017) reported substantial improvement in maximal strength (8.9-13.2%), vertical jump, peak power and average power following eccentric training at varying durations of eccentric contraction (2, 4, and 6 s) for four weeks in college-aged men. However, there was a substantial reduction in peak squat jump velocity with the longest eccentric duration (6 s). The authors speculated eccentric contractions at longer durations might lead to increased maximal strength and power but negatively impact high velocity movements (Mike et al., 2017). Fisher et al. (2016) investigated the adaptations following ten weeks of eccentric only, repetition duration-accentuated eccentric and traditional multi-joint resistance training to muscle failure in resistance-trained men and women. Similar improvement was reported in muscle endurance and predicted 1RM for chest press, leg press and pull down exercises with eccentric only and repetition duration-accentuated eccentric training, relative to traditional resistance training. The authors suggest that the eccentric loading strategies (load and duration accentuated) might be more beneficial than traditional resistance training in the treatment of musculoskeletal injuries because of possibly lower muscle activation and relative effort for the same absolute loads (Fisher et al., 2016). Repetition duration accentuated eccentric resistance training might also be beneficial in youth athletes going through PHV. Therefore, a combination of moderate loading at longer eccentric contractions using fundamental movements might be a superior practical eccentric loading strategy in youth athletes during growth and maturation.

Using eccentric contractions to increase the length of the muscle

The force applied to a muscle during an eccentric contraction is larger than the momentary force produced by the muscle itself, resulting in the lengthening/stretching of the muscle-tendon complex (Douglas et al., 2017). The lengthening during an eccentric contraction affects the mechanical properties of the muscle by shifting the optimum length of peak tension to longer lengths, thus moving the length-tension curve to the right (Brughelli et al., 2007). This change following eccentric exercise is proposed to occur in two different shifts. The initial shift in the curve is acute and is suggested to be caused by muscle damage (Bowers et al., 2004; Proske et al., 2005; Proske et al., 2001). The second shift that occurs following chronic eccentric training (10 days to 8 wk) is proposed to be due to an increase in sarcomeres in series (sarcomerogenesis) and an increase in passive tension at longer muscle lengths in adults (Lindstedt et al., 2002; Morgan, 1990). Sarcomerogenesis plays an important role in maintaining the relationship between sarcomere length and joint angle. The change in the number of sarcomeres in series is expected to be an adaptable property of the muscle (Brughelli et al., 2007). Sarcomerogenesis leads to a shorter sarcomere length for a given muscle, which is expected to hold the myofilaments off the lengthening limb during future eccentric contractions (Brughelli et al., 2007; Morgan, 1990), increasing the stability of the muscle at longer muscle lengths (Brughelli et al., 2007). Several animal and human studies have shown an increase in serial sarcomere number following eccentric training (Butterfield et al., 2006; Butterfield et al., 2005; Koh et al., 1998; Lynn et al., 1998). Similarly, the possible increase in the length of the muscle following eccentric resistance training in youth athletes going through PHV might lead to increase in flexibility, range of motion and stability about the joint thus, reducing discomfort and risk of injury.

Conclusion

Adolescents experience disproportionate and rapid increases in stature compared to gains in muscle strength during PHV (Parker et al., 1990). Additionally, the bone growth preceding muscle-tendon growth can cause joint discomfort and reduced flexibility (Ford et al., 2010a). Hence, improving muscular strength, flexibility and motor control, while accounting for maturity status is crucial for long-term athletic development (Lloyd et al., 2016a). Although TRAD in youth has led to improvements in physical performance (Meylan et al., 2014), the unique benefits of ECC training shown in adults have not yet been investigated in youth population. Eccentric contractions might provide a loaded stretch to the muscle-tendon complex, in addition to the low-grade stretch induced by growth. Putatively, this may cause an increase in either the growth or stretch properties of the muscle-tendon unit in adolescent athletes during the peak growth phase leading to an increase in joint range of motion. The change in the stretch properties of the muscle-tendon complex could also reduce the time lag between bone and muscle-tendon growth, and the associated functional changes (e.g., reduced temporary motor disruption) in youth athletes during PHV. Thus, it is plausible that an increase in either muscle or tendon growth following eccentric contractions in adolescent athletes during the growth phase would have substantial benefit for athletic performance and risk of injury. Therefore, this study aims to analyse the effect of moderate load eccentric duration-accentuated resistance training (ECC) versus traditional dynamic resistance training (TRAD) on physical performance in adolescent male athletes, while accounting for maturity.

Methodology and Conceptual Framework

This study utilised a mixed longitudinal and parallel-groups study design. All participants first completed a period of TRAD with repeated measurement of physical performance variables block 1. Subsequently, participants were randomly allocated into one of two training groups (block 2) with further repeated measurement of the same physical performance (Figure 1).

Inclusion criteria

Forty club level male soccer players (11-15 y) volunteered for the study. Participants had no prior experience in resistance training. Existing health limitations and/or current injuries were assessed via questionnaire (Appendix 1). Participants with current health or injury limitations were excluded from the study or were required to get medical clearance and parent/guardian approval.

Study design

Participants undertook Block-1 TRAD (8 weeks; Figure 1) in order to accustom them to exercise techniques, effort scales and testing protocols, to obtain robust baseline measures, and enabling sufficient longitudinal anthropometric measurement opportunities to estimate PHV. Additionally, the first block allowed the participants ensure all participants accrued technical and physical capabilities sufficient for the demands of the subsequent TRAD or ECC training protocols. Following this, participants were pair-matched based on 1) maturation status and 2) allometrically-scaled 3RM, with random allocation of one member of each pair to either ECC or TRAD for Block 2 (12 weeks; Figure 1).

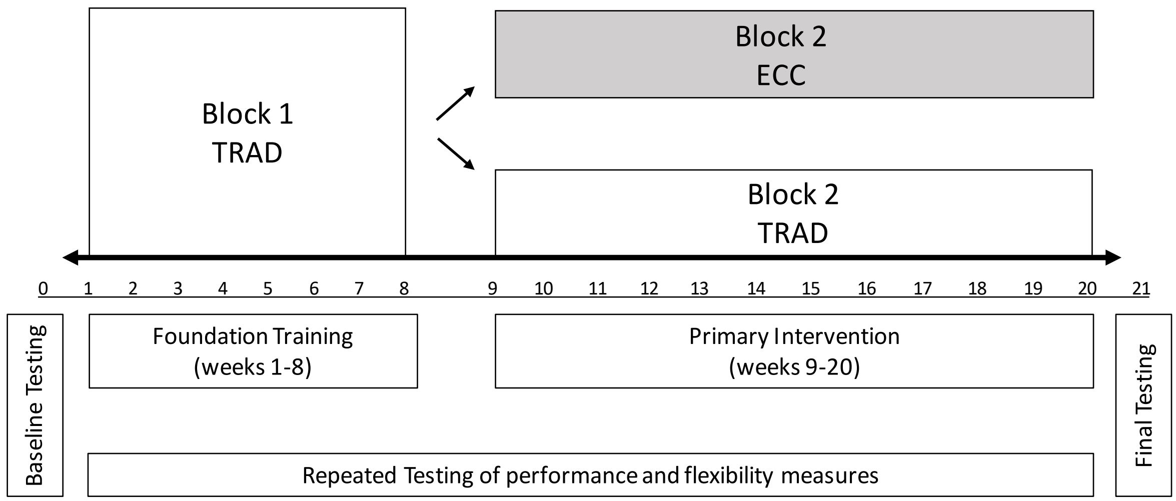

Figure 1. Study design.

Participants

Participant characteristics for each block are shown below (Table 1). As part of their club commitments, all participants had three skill sessions and one match per week. Testing and training sessions related to this study were conducted on the Wednesday of every week (1 session per week) during the bulk of their competitive season, due to their existing training structures; except for one week (week 16 of Block 2) when all participants completed training on a Thursday, due to a pre-existing club commitment. Three participants were excluded from the study due to existing health limitations (n=2) and injury (n=1). One participant did not turn up to sessions due to disinterest. Thirty-six participants undertook Block 1 training. During Block 1, seven participants dropped out due to disinterest (n=3) or citing excessive sports commitment (n=4). Of the 29 participants who subsequently undertook Block 2 training a further five discontinued, due to school/travel commitments (n=3), issues with commuting (n=1), and diagnosis of Osgood Schlatter disease (n=1). The adherence rate for training sessions of the retained participants (n=24) was 81% (Appendix 2). Non-prescribed exercise duration and intensity (Appendix 3) was recorded during Block 2 to estimate individual participant weekly training load.

Table 1. Participant characteristics (mean ± standard deviation) of training Block 1 and 2.

	Block 1 (mean ± SD)	Block 2 Total (mean ± SD)	Block 2 TRAD (mean ± SD)	Block 2 ECC (mean ± SD)
Participants (n)	29	24	12	12
Age (y)	13 ± 1.3	13 ± 1.3	13 ± 1.0	13 ± 1.0
Mass mean (kg)	51 ± 11	52 ± 11	54 ± 11	50 ± 11
Standing height mean (cm)	160 ± 11	162 ± 10	166 ± 8.8	160 ± 12
Sitting height mean (cm)	129 ± 6.4	131 ± 6.3	134 ± 4.0	128 ± 7.3
Time to/from PHV (y)	-0.4 ± 1.3	-0.0 ± 1.3	0 ± 1	-0 ± 1
Predicted adult stature (cm)	181 ± 9.4	182 ± 7.7	184 ± 6.4	180 ± 8.6

Testing Frequency

Across Block 1 and 2, POMS (Profile of mood status) was measured every week. Squat jump, counter-movement jump, and sit and reach were assessed in odd weeks (1-19) while sprint splits, 505 change of direction test (505 COD) and back squat movement competency were assessed in even weeks (0-20). Anthropometric measures for PHV were taken every six weeks and 3-RM back squat was measured at the start, middle, and end of each block (i.e., weeks 1, 5, 9, 15, 21). IMTP (isometric mid-thigh pull) and VAS (visual analogue scale) soreness were measured every week in Block 2 only.

Warm-up Protocol

Participants completed a 10 min warm-up (Appendix 4) comprised of a 5 min jog around an indoor basketball court, followed by dynamic stretches for ~5 min (walking lunges, lateral lunges, and torso rotations × 10 repetitions each).

Predicting Maturity Status

Peak Height Velocity (PHV)

The offset of maturation was determined by age of PHV, which is the most common indicator used in longitudinal studies in adolescents (Beunen et al., 1988). This measure provides an accurate benchmark of maximum growth during adolescence and works as a general landmark for comparisons within and between participants (Mirwald et al., 2002). Standing and sitting heights were measured via fixed stadiometer to the nearest 0.1 cm. Body mass was taken prior to every session with a digital scale to the nearest 0.1 kg. Maturity status was determined by using the years to/from PHV (+1 indicates one year post-PHV, -1 indicates one year pre-PHV). The mean predicted age of PHV for each block was used as a factor within the statistics model to estimate the modifying effect of maturity status.

Predicted Adult Stature

An assessment of maturity status with the percentage of predicted adult stature was also included due to existing error rates associated with the calculation of PHV (± 95%CI, 0.5 years; (Meylan et al., 2015; Mirwald et al., 2002)). This method uses mid parental height (the mean stature of both parents) and participant current stature and weight to predict the adult stature of participants (Khamis et al., 1994). A combination of these methods was used to compare the stage of maturation, according to Meylan et al. (2014). This method is widely accepted as it is shown to present relatively homogeneous and accurate athlete groups based on maturation (Meylan et al., 2014).

Performance Tests

Three-Repetition Maximum Back Squat

Repetition maximum testing is considered a “gold standard” for measuring muscular strength in adult athletic population (Levinger et al., 2009). Repetition maximum strength testing has been validated and is considered safe for adolescents (Faigenbaum et al., 2012). Comfort et al. (2014) predicted 1RM back squat from measured 5RM squat testing in experienced youth soccer players. However, the use of equations to predict 1RM has not been validated in adolescent athletes in the age range of the current investigation, and most prediction equations only go as low as five repetitions (Reynolds et al., 2006). In the present study, participants performed a

3RM back squat. The 3RM testing offers a compromise between measuring near-maximal concentric strength of the lower body with lower absolute loading than 1RM. Due to the level of technical competency required for the 3RM back squat, relative to their starting experience, participants were taken through a familiarization session (week 0) prior to initial testing (week 1). Subsequent testing occurred at the middle and end of each block (Block 1, weeks 5 and 9; Block 2, weeks 15 and 21). Recorded values at week 9 were used as the baseline 3RM for the second block. Participants performed standardised back squat warm-up sets, before undertaking the first set at ~85% of the highest weight lifted in the 3RM familiarization in week 0. Participants were required to perform three squats to a depth where the femur was parallel to the floor. Safety racks and spotters were used to ensure participant safety and adequate depth. After each successful set, the load was increased by ~5% until a failed attempt. Participants were given 2 min rest between each set. The highest load lifted successfully for three repetitions was used for subsequent analyses; an allometrically-scaled 3RM was also derived by dividing the measured 3RM by body mass to the power of two-thirds. The test-retest reliability from model-derived residuals (see Statistical Analysis) for the 3RM back squat was 6.4%; and for scaled 3RM, 6.1%.

Isometric Mid-Thigh Pull (IMTP)

The IMTP has been shown to be a safe and reliable method to determine maximal strength in adolescent athletes (Moeskops et al., 2018; Thomas et al., 2015). IMTP peak force was determined using a custom portable strain gauge (Figure 2) and proprietary software every session during Block 2. The strain gauge was attached at one end to a hook bolted into the floor and at the other end to a handle grip via a chain. For each participant, the grip height was adjusted to the power clean second pull position. Participants were asked to stand with the hook between their feet, knees slightly flexed and shoulders over the bar. Once positioned, they were instructed to apply enough tension to take the slack out of the chain; a 50 N buffer was applied via software to prevent the recording of small pulls during setup. Participants were instructed to undertake a pull progressing over 1-2 seconds to a maximal effort, and to prevent jerking the chain. Two maximal efforts were performed with rest of ~2 min between pulls. Each pull and the associated pull force-trace was visually inspected for appropriateness (i.e., to remove aberrant force spikes due to jerking). Peak force was recorded for each included pull. If peak force deviated by more than ~10% between pulls, a third pull was undertaken and the two closest values retained. The highest obtained peak force was used for subsequent analysis; as with 3RM, an allometrically-scaled IMTP was also determined. Model-derived reliability for both non-scaled and scaled IMTP was 9.8%.

Figure 2. Isometric mid-thigh pull.

Jump Tests

To assess explosive power in soccer players, the study used a combination of jump tasks: (i) a squat jump (SJ), and (ii) counter-movement jump (CMJ). These methods have shown to be reliable and valid measures (CV = 2.1–9.4 cm) to test muscular power in adolescents (Meylan et al., 2012; Ortega et al., 2008). The SJ and the CMJ were performed on a ground-embedded force platform (AMTI, Kistler software (Bioware)). The data was sampled at 1000Hz and the analogue data was low-pass filtered with a 30Hz cut-off. The initiation of ground contact was taken to occur when the force signal exceeded >30N and take-off occurred when the force signal was <30N. Participants held a wooden dowel (bar) across their backs to minimise arm-swing contributions. The squat jump is a concentric-only test. Therefore, participants performed a vertical jump-starting from a half-squat position to reduce the influence of the upper limb at the hip joint, knees at ~90 degrees and trunk straight. The countermovement has an eccentric phase to start, therefore utilizes the stretch-shorten cycle to produce power. Thus, the counter-movement jump is a vertical jump initiated from an upright standing position with extended legs, where the jump was initiated by joint flexion, lowering the body to minimum height, then extension as the body ascends upwards to take off. The participants performed three jumps each. Two minutes rest was given between each test (Secomb et al., 2015). The maximum vertical ground reaction force (peakFv) of each jump trial was normalised to subject body weight. The jump with the highest peak ground reaction force (peak GRF) was used for further analysis. Due to technical issues encountered with the force plate, CMJ data for week 19 and SJ data for week 21 could not be collected. Model-derived reliability for the SJ and CMJ GRF was 12% and 16.3%, respectively.

Sprint Speed

Sprint speed (Thomas et al., 2009) was measured from a split stance position, five centimetres behind a starting line to avoid false testing (i.e., triggering gates with hands or torso before initiating sprint; Lloyd et al., 2011). Participants ran for 20 m through infrared timing gates (Fusion Smart Speed Hub version 1.1.16) set at 5 m splits. Following a standardised warm-up, participants performed timing gate run-throughs at 50% and 75% of maximal effort. They subsequently undertook three sprints at 100% effort with ~60 s rest between each sprint. The splits from the fastest 20 m sprint time were utilised for further analysis. Model-derived reliability for 20 m sprint time was 2.1%.

505 Change of Direction Test

The 505 test was used because change of direction is a physical quality important in soccer (Dragijsky et al., 2017). The 505 test minimizes the influence of individual differences in sprint velocities and accentuates the acceleration and deceleration components along with the change of direction (Thomas et al., 2009; Yanci et al., 2017). Importantly, in the context of the present study, this test was of practical interest because of the eccentric requirement of the change of direction component of the test (in contrast to the largely concentric force requirement associated with the linear 20 m sprint test) (Sheppard et al., 2006). This method of testing change of direction has proven to be a valid and reliable measure in adolescent athletes (CV% = 5.1) (Stojanović et al., 2018). The test was initiated from a split stance position, and a timing gate was (Swift Performance, Speedlight version 2 & App 600.1.2) set 10 m from the start position. Participants ran forward until the 15 m mark where they made a 180° turn with their preferred foot and ran 5 m towards the start mark. Participants performed test run-throughs at 50% and

75% of maximal effort, before performing two trials at 100%. The fastest trial was used for further analysis. Model-derived reliability for the 505 test was 2.9%.

Flexibility

Straight Leg Raise

The straight leg raise test was used to test the unilateral flexibility of the hamstring muscles and is considered a valid test for soccer players (Sporis et al., 2011). The protocol was explained to participants and their parents, and they were asked for permission prior to any bodily contact. Two examiners on a flat, firm-surfaced massage table performed the straight leg raise test with the participant lying in a supine position. The first examiner placed the centre of the goniometer on the greater trochanter and aligned the fixed hand of the goniometer with the superior iliac crest, and the pelvic angle was measured. Examiner two placed one hand under the ipsilateral ankle to fix the ankle in a neutral position and while holding the free end of a tape measure (attached to moving hand of the goniometer) against the lateral malleolus. Examiner two then raised the leg with their other hand immediately below the knee. Examiner one then measured the femur angle; ensuring the pelvic angle did not change as the leg raised. The straight leg raise score for assessing hamstring flexibility was calculated by subtracting the femur angle with the pelvic angle. The test was performed once on each leg (Mierau et al., 1989). Model-derived reliability for the straight leg raise right and left leg was 8.2˚ and 6.4˚ respectively.

Sit and Reach

The sit and reach was used to test the bilateral flexibility of the lower back and corresponding girdle (i.e.,hamstring; Sporis et al., 2011) as it is valid for soccer players. Participants performed the test seated on the floor with knees fully extended and ankles in neutral dorsiflexion against a standard sit and reach box. The participants removed all footwear and were asked to reach forward slowly two times (middle fingers over the top of each other), and each score was recorded (Cornbleet et al., 1996). The highest measure of the two trials was used in subsequent analysis. Model-derived reliability for the sit and reach was 1.9 cm.

Movement competency

Back Squat Assessment

Participants performed back squats (bodyweight), which were video recorded from the anterior, posterior and lateral views. The participants performed ten continuous back squat repetitions with a dowel across their back. The same experienced practitioner analysed and scored each participant's squat movement from three views using the back squat assessment criteria (Myer et al., 2014). The scoring criteria is a 10-point scale, such that a lower score on the scale is indicative of better movement competency. This test has proven to be reliable and sensitive to improvements in neuromuscular performance (Dobbs et al., 2019). Model-derived reliability for the back squat movement assessment was 0.6 units on the 10-point scale.

Profile of Mood Status

The profile of mood status (POMS) for adolescents was used to account for vigour and fatigue of the participants. The questionnaire was completed by the participants every week to monitor mood disturbances that might indicated over training which may impact quality of training on the day (Comotto et al., 2015; Saw et al., 2016). This questionnaire is a shortened version of the original POMS (Lorr et al., 1971) and consists of 24-items (Appendix 5) allowing for a quick and highly reliable measure of six mood states among adolescents (Terry et al., 2003; Terry et al., 1999). The questionnaire was administered by the researcher using a mobile application (Android) specifically developed for the study. To minimize the number of alterations, the application was designed such that participants could not change their initial response. However, if the participant noted that they had made an error in their response, they were asked to retake the entire test. The questionnaire was filled each week prior to the physical training sessions. All participants answered the query “How are you feeling right now?” for the 24 mood descriptors with an accompanying thesaurus to assist in interpreting the descriptors. The descriptors were rated using a five-point response scale starting from 0 (absolutely not) to 4 (extremely) and the participants were instructed to answer for all descriptors. However, only vigour and fatigue were considered relevant measures for this study and used for further analysis. The sum of the reported values was rescaled to range from 0 – 100 and a lower score on the scale represented a better mood status. Model-derived reliability for the POMS was 8.5%.

Visual Analogue Scale (VAS)

Participants utilised a VAS to rate perceived muscle soreness for the quadriceps and hamstrings muscle groups. The scale was 10 cm in length, with "no pain" and "worst possible pain" representing the ends of the scale (Melzack, 1987). Participants were instructed to draw a line upon the scale representing their perceived level of soreness at specified times. Muscle soreness ratings were taken prior to each testing/training session (Wednesdays), with participants being asked to recollect their perceived muscle soreness in the quadriceps and hamstring muscles on the previous Friday evening during training (~2 days after training), match day during the game (~3-4 days after training/on weekend), and pre-testing/training (~7 days since the last training) (Appendix 6). Soreness rating reported for "no match" days were assumed to be on a Sunday. The VAS scale has been considered as an effective tool and has previously been used to quantifying DOMS in youth athletes up to 168 hrs post-training (Hughes et al., 2018). The average reported rating of muscle soreness across the three time points was used in the analysis and a lower score indicated less pain associated with muscle soreness. Model-derived reliability for the VAS quadriceps and hamstring was 14.3% and 15.8% respectively.

Resistance Training Interventions

Following weekly testing and warm-up, participants completed their assigned resistance training protocol (Block 1, TRAD; Block 2, TRAD or ECC). Both training protocols had similar exercises, sets and repetitions prescribed (Appendix 7). The training involved a high level of supervision (1-2 participants per practitioner; close monitoring of tempo and technique). Rate of perceived exertion (RPE) was recorded immediately following every set (Appendix 8), and session RPE (Appendix 9) was recorded within 2 min of completion of each session (Day et al., 2004). In the first training session in Block 1, loads were varied to achieve the target RPE for each set of each exercise. Subsequently, an experienced practitioner estimated the loads to achieve target RPEs for the next session of training, based off the reported RPE for each set and accounting for load changes associated with periodisation of training volume and intensity (i.e., changes in the total number of exercises, sets per exercise, repetitions per set). Loads were then adjusted by practitioners within each session, based off reported RPE for each set. For instance, if the target RPE for three sets of an exercise were (set one) 6, (set two) 8, (set three) 9, and a participant reported for set one an RPE of 8, the load was maintained (or in some instances reduced, to account for accumulating fatigue) for set two, in order to achieve the target RPE of 8; and in anticipation of a target RPE of 9 by set three. If RPE for set two was 8, then the practitioner used their judgement to either maintain or adjust the load or utilise the original target load to achieve the target set three RPE of 9 (Robertson et al., 2005).However, the time under tension varied between the two training protocols. TRAD utilised moderate movement velocity (2 s) during the eccentric phase of each exercise, and a fast (1 s) concentric phase (Appendix 10 & 11). For example, if the participants were performing a squat, they would take two seconds to smoothly descend to the bottom of the squat, and one second to return to the start position. Participants were asked to match the speed/tempo of the movement to a metronome set at 60 beats per min. Each participant had a trained practitioner overseeing each set of every exercise to provide feedback on the tempo, and to adjust technique and loads used.

The ECC training protocol involved manipulating the duration of the eccentric contraction during repetitions, with progression from moderate movement velocity (3 s) to slow eccentrics (6 s) and then back (3 s) over 12 weeks (Appendix 12). Slow training might not carry over to sports/movements that involve fast ECC and SSC (Suchomel et al., 2019). Therefore, practitioners commonly periodise a block of slow eccentric before phasing into a plyometric or explosive training block to optimise the eccentric utilisation improvements from the previous block. Hence, this study aimed to closely replicate real-word practice with this protocol by using a reverse pyramid approach (3s-6s-3s) to ECC movement velocity. The concentric component of each repetition was kept at 1 s. Fundamental bilateral and unilateral lower body exercises were chosen to develop overall lower body strength, along with trunk conditioning exercises. External loads were increased using adolescent specific equipment (lighter barbells & dumbbells) to enable safe execution of lifts. Other equipment like resistance bands, sliders and medicine balls were also used. The exercises were progressed based on external load, tempo and movement complexity.

Statistical Analysis

Changes in the first eight weeks of TRAD were quantified as means and standard deviations (SD) in the first and last weeks. Non-clinical magnitude based decisions were used to report about the potential improvement or impairment in performance. Changes in the following 12 weeks of ECC or TRAD training were quantified with a mixed linear model (Proc Mixed) in the Statistical Analysis System (University Edition, version 9.4, SAS Institute, Cary, NC). To reduce any effects of non-uniformity of effects and error, all performance measures were log-transformed before analysis and outcomes were expressed in percent units after back-transformation (Hopkins et al., 2009). Flexibility and psychometrics were analysed and expressed in raw (original or rescaled) units.

Inspection of the individual trajectories of performance and the other dependent-variable measures (e.g., Figure 5) showed that an individual-slopes model was appropriate to determine and compare the mean 12-wk change in each group; this approach also allowed inclusion of the data of players who rescheduled tests or who missed tests in either Week 9 or 21. The fixed effects in the model to estimate mean changes were therefore the group identity (two levels: eccentric, traditional) and the interaction of group with time (a linear numeric variable coded as -0.5 for Week 9 and +0.5 for Week 21, providing the 12-wk changes as slopes). Each player's mean maturity offset (PHV age) in the 12-week block was also interacted with the interaction of group and time, to determine the modifying effect of maturity on the effect of training; this effect was evaluated for 3 y of maturity (approximately 2 SD; Hopkins et al., 2009), equivalent to the difference in the training effect between players 1.5 y above and below the mean maturity offset. When this modifying effect was clear, the mean predicted changes in the two training groups are presented for participants 1.5 y below and 1.5 y above the predicted age of PHV. A simple linear effect of maturity offset was also included in the model, to estimate the effect of maturity on each player's mean measure without regard to treatment group and to adjust differences between the players to a maturity offset of 0 y (important for deriving an appropriate between-player SD of the measure to standardize the magnitude of effects, as described below).

The random effects specifying the individual-slopes model were the identity of the players (22-24 levels), to estimate each player's mean measure as an intercept at the midpoint of the 12-wk period and at maturity offset of 0 y, and the interaction of identity with time (the individual slopes); these terms were assigned an unstructured covariance matrix, to allow them to be correlated. The other random effects in the model were the interaction of player identity with the interaction of time and maturity offset (to allow for individual differences in the modifying effect of maturity on the effect of training), and the residual error (the standard error of the estimate). In the interest of parsimony, given the small sample size, group differences were not estimated for the random effects and the random effects are not presented or interpreted. However, the square root of the sum of the player-identity and residual variances provided an estimate of the between-player SD and its degrees of freedom for standardizing mean effects, and 0.20 of the SD is presented as the smallest worthwhile substantial change (SWC). The reliability of test measures was estimated via model-derived residuals from repeated measurements during Block 2 and reported in percent or raw units. The quantitative value of the standardized effect (mean/SD) is not presented, but its qualitative magnitude was interpreted and reported using the following scale: <0.2, trivial; 0.2-0.6, small; 0.6-1.2, moderate; 1.2-2.0, large; 2.0-4.0, very large; >4.0, extremely large (Hopkins et al., 2009). Probabilities that the true (very large sample) effect on means was a substantial increase, a substantial decrease, and a trivial difference or change were estimated via the t statistic adjusted for uncertainty in the standardizing SD (Hopkins, 2019a).

Mean changes and differences in mean changes are presented with 90% compatibility limits (ES; ±90%CL). The clinical and non-clinical magnitude-based methods (Hopkins, 2019b; Hopkins et al., 2009) were used to make and report decisions about the potential benefit or harm of eccentric training, traditional training, and the comparison of eccentric with traditional training (since traditional training is the best-practice method with which eccentric training should be compared). Specifically, clinically clear beneficial effects were those for which benefit was at least possible (>25% chance) and risk of harm was acceptably low (<0.5%). Effects, where chance of benefit outweighed risk of harm (an odds ratio of benefit to harm >66), were also deemed clear. Other effects were either clearly non-beneficial (chance of benefit <25%) or unclear (chance of benefit >25% and risk of harm >0.5%). Clear effects were reported with the qualitative probability that the true effect was beneficial, trivial or harmful. The scale for interpreting the probabilities was as follows: 25–75%, possible; 75–95%, likely; 95-99.5%, very likely; >99.5%, most likely. The modifying effects of maturity offset on the training effect were assessed non-clinically: the effect was deemed unclear if the 90% compatibility interval included substantial increases and decreases, and clear effects were evaluated probabilistically as described for clinically clear effects. Inflation of decision error rate arising from a large number of investigated effects was taken into account by highlighting in bold and focusing assessment on clinical effects where the chance of harm was <0.1% and on non-clinical effects that were clearly based on coverage of a 99% compatibility interval.

Results

Block 1

For Block 1 (first eight weeks of TRAD), the magnitude based decisions for the difference in pre- and post-block performance and mood data is presented in Table 2. Eight weeks of TRAD was associated with large improvements in both 3RM (ES 1.4; ±0.5) and scaled 3RM (ES 1.9; ±0.6) strength. TRAD also moderately improved 505 COD (ES -0.7; ±0.30), right (ES 1.0; ±0.9) and left (ES 0.8; ±0.3) straight leg raise and movement competency (-0.6; ±0.2). Lastly, there were small improvements in mood status (ES -0.25; ±0.27) in Block 1.

Table 2: Measures of performance and mood at the start and end of Block 1 of traditional training, and the non-clinical magnitude-based decisions for the post-pre difference.

	Pre Block 1 (mean ± SD)	Post Block 1 (mean ± SD)	Decision[a] (Post – pre)
3RM (kg)	34 ± 15	61 ± 14	**large ↑******
Scaled 3RM ($kg/BM^{2/3}$)	2.4 ± 0.8	4.4 ± 0.6	**large ↑******
Squat jump peak GRF (N)	1060 ± 221	1100 ± 266	trivial[0] ↑
Counter-movement jump peak GRF (N)	1099 ± 272	1030 ± 291	small ↓*
Sprint 5 m (s)	1.19 ± 0.07	1.21 ± 0.06	small ↓*
Sprint 10 m (s)	2.02 ± 0.10	2.03 ± 0.09	trivial[0] ↓
Sprint 15 m (s)	2.77 ± 0.16	2.77 ± 0.15	trivial[000]
Sprint 20 m (s)	3.49 ± 0.21	3.53 ± 0.21	**trivial[0] ↓**
505 COD (s)	2.56 ± 0.11	2.48 ± 0.10	**moderate ↑******
Sit and reach (cm)	24 ± 8.6	23 ± 8.0	**trivial[00]**
Right leg raise (°)	51 ± 14	63 ± 11	**moderate ↑******
Left leg raise (°)	50 ± 13	63 ± 9.1	**moderate ↑******
Squat assessment (0-10)	3.3 ± 2.2	1.9 ± 1.1	**moderate ↑******
POMS (0 - 100)	72. ± 22	66 ± 18	**small ↑***

3RM, three repetition maximum back squat; scaled 3RM, allometrically-scaled 3RM; peak GRF, squat jump peak ground reaction force; COD, 505 change of direction; POMS, vigour and fatigue scores from Profile of Mood States.

[a]Magnitude of the observed effect, with likelihood of a substantial improvement in performance (↑), impairment in performance (↓) and/or trivial clear effect.

Likelihoods of clear substantial effects: * possible; ** likely; *** very likely; **** most likely.

Likelihoods of clear trivial effects: [0] possible; [00] likely; very likely[000].

Bold effects are @99%.

Block 2

PHV = 0 y (at maturity offset)

For Block 2, and at the predicted age of PHV (i.e., circa-PHV = 0), the mean percent change by intervention, the percentage change difference between the interventions, and the clinical inferences for each are presented for performance, mood and soreness data (Table 3). Raw data is presented in appendix 13 and the 3 y modifying effect in appendix 14. Overall, both training modalities were beneficial for improving various measures of strength and flexibility. However, despite 5 m sprint time showing less decrement in the ECC training group than TRAD, both training modalities were harmful to sprint split-time performance.

Maturity status moderated the effect of training; Block 2 ECC was beneficial in improving both 3RM back squat strength (ES 2.8; ±0.1) and scaled 3RM (ES 2.2; ±0.7) circa-PHV. Furthermore, ECC training was moderately beneficial in improving IMTP (0.7; ±0.5), scaled-IMTP (ES 0.9; ±0.6), and both right (ES 0.9; ±0.3) and left (ES 0.9; ±0.3) straight leg raise. The average reported rating for quadriceps muscle soreness was moderately reduced (ES -0.9; ±0.6) with ECC.

Block 2 TRAD was associated with a very large increase in 3RM (ES 3.4; ±1.1) and scaled 3RM (ES 2.6; ±0.8) and moderate benefit to IMTP (ES 0.9; ±0.6), scaled IMTP (ES 1.2; ±0.7) and both right (ES 0.9; ±0.3) and left (ES 0.9; ±0.4) straight leg raise. TRAD also showed a small benefit to squat jump performance and hamstring soreness. On the contrary, TRAD was moderate to largely harmful for 5 m (ES 1.9; ±0.7) and 10 m (ES 0.8; ±0.6) sprint times, respectively, and slightly harmful to 15 m (ES 0.59; ±0.56) and 20 m (ES 0.57; ±0.3) sprint and 505 COD (ES 0.37; ±0.4) times.

Comparing the two training modalities (ECC - TRAD), ECC was less detrimental for 5 m (ES -1.7; ±0.8) sprint performance than TRAD, circa-PHV. Additionally, ECC was less detrimental to 10 m sprint and 505 COD times, relative to TRAD. However, ECC was slightly more harmful for force-related measures (3RM strength, IMTP, SJ and CMJ peak GRF), back squat movement competency and hamstring soreness compared to TRAD at circa-PHV.

Table 3: Predicted changes in performance, mood and soreness measures associated with Block 2 (post-pre) eccentric and traditional training at the age of peak height velocity (circa-PHV = 0), the differences in the changes, and clinical magnitude-based decisions for the changes and differences.

	SWC for benefit	Eccentric		Traditional		Eccentric - traditional	
		Mean; ±90CL	Decision[a]	Mean; ±90CL	Decision	Mean; ±90CL	Decision
3RM (%)	2.0	31; ±8.5	**v. large** ↑****	39; ±10	**v. large** ↑****	-5.5; ±9.2	small ↓*
Scaled 3RM (%)	2.6	33; ±8.3	**v. large** ↑****	39; ±10	**v. large** ↑****	-4.5; ±9.0	small ↓*
IMTP (%)	4.1	16; ±11	moderate ↑***	21; ±14	moderate ↑***	-4.4; ±15	small ↓*
Scaled IMTP (%)	3.4	17; ±11	moderate ↑***	22; ±15	moderate ↑***	-4.6; ±15	small ↓*
SJ peak GRF (%)	4.4	-1.0; ±4.9	trivial^{0}	6.8; ±6.4	**small** ↑*	-5.6; ±7.2	**small** ↓*
CMJ peak GRF (%)	4.6	-6.8; ±6.8	**small** ↓*	2.4; ±8.8	trivial	-9.0; ±10	**small** ↓**
Sprint 5 m (%)	-0.8	0.7; ±2.0	small ↓*	8.1; ±3.0	**large** ↓****	-6.9; ±3.1	**large** ↑****
Sprint 10 m (%)	-0.7	0.9; ±1.6	**small** ↓*	3.1; ±2.0	**moderate** ↓***	-2.1; ±2.4	small ↑**
Sprint 15 m (%)	-0.7	1.0; ±1.5	**small** ↓*	2.2; ±2.0	**small** ↓**	-1.2; ±2.4	small ↑
Sprint 20 m (%)	-0.8	2.1; ±1.0	**small** ↓***	2.2; ±1.2	**small** ↓***	-0.2; ±1.5	trivial^{0}
505 COD (%)	-0.8	-0.3; ±1.3	trivial	1.5; ±1.7	**small** ↓**	-1.8; ±2.1	small ↑**
Sit and reach (cm)	1.6	0.7; ±1.5	trivial^{00}	0.8; ±1.8	trivial^{0}	-0.2; ±2.3	trivial^{0}
Leg raise right (°)	3.0	13.1; ±2.9	**moderate** ↑****	14; ±3.7	**moderate** ↑****	-1.2; ±4.7	trivial^{00} ↓
Leg raise left (°)	3.0	12; ±3.4	**moderate** ↑****	12; ±4.2	**moderate** ↑****	0.1; ±5.4	trivial^{0}
Squat assess-ment (0-10)	-0.2	-0.1; ±0.6	trivial ↑	-0.6; ±0.9	moderate ↑	0.6; ±1.1	small ↓*
POMS (0 - 100)	3.5	2; ±3.1	trivial^{00}	-2; ±4.3	**trivial^{0}** ↓	3; ±5.2	trivial ↑
Quads soreness (0 - 100)	-4.1	-18; ±13	moderate ↑***	-4; ±16	trivial ↑	-14; ±20	moderate ↑
Hams soreness (0 - 100)	-4.2	-5; ±12	small ↑	-12; ±14	small ↑**	7; ±19	small ↓*

SWC, smallest worthwhile change; 90CL, 90% confidence limits; 3RM, three repetition maximum back squat; scaled 3RM, allometrically-scaled 3RM; IMTP, isometric mid-thigh pull; scaled IMTP, allometrically-scaled IMTP; SJ peak GRF, squat jump peak ground reaction force; CMJ peak GRF, counter-movement jump peak GRF; COD, change of direction; POMS, vigour and fatigue scores from Profile of Mood States; Quads, quadriceps muscle; Hams, hamstring muscle.

[a]Magnitude of the observed effect, with likelihood of a beneficial (↑), harmful (↓) and/or trivial clear effect.

Likelihoods of clear substantial effects: * possible; ** likely; *** very likely; **** most likely.

Likelihoods of clear trivial effects: ^{0} possible; ^{00} likely.

Bold effects are @5/0.1%.

PHV = -1.5 y and 1.5 y (1.5 y pre and post maturity offset)

Block 2 post–pre (week 21–9) mean percent change and 90% compatibility limits by intervention at 1.5 y before (pre-PHV -1.5 y) and after (post-PHV +1.5 y) maturity offset are presented for 3RM back squat (Figure 3), 5 m (Figure 4) and 20 m (Figure 5) sprint times, and right and left straight leg raise (Figure 6). Both training modalities substantially benefited 3RM strength pre- (TRAD, ES 3.6; ±1.5; ECC, ES 3.3; ±1.2) and post-PHV (TRAD, ES 3.0; ±1.3; ECC, ES 2.3; ±1.2), with ECC leading to a smaller increase (ES -0.8; ±1.5) post-PHV versus TRAD; pre-PHV, the difference was unclear (Figure 3). Although both interventions were moderately beneficial in improving IMTP pre- (TRAD, ES 1.4; ±1.2; ECC, ES 1.0; ±0.8) and post-PHV (TRAD, ES 1.0; ±0.9; ECC, ES 0.89; ±0.9), ECC was less beneficial than TRAD pre-PHV (ES -0.5; ±1.4). Both training modalities led to mainly small decrements in performance for the SJ and CMJ, irrespective of maturity status. However, pre-PHV TRAD was associated with a slight improvement in SJ GRF (0.5; ±0.4).

3RM Back Squat

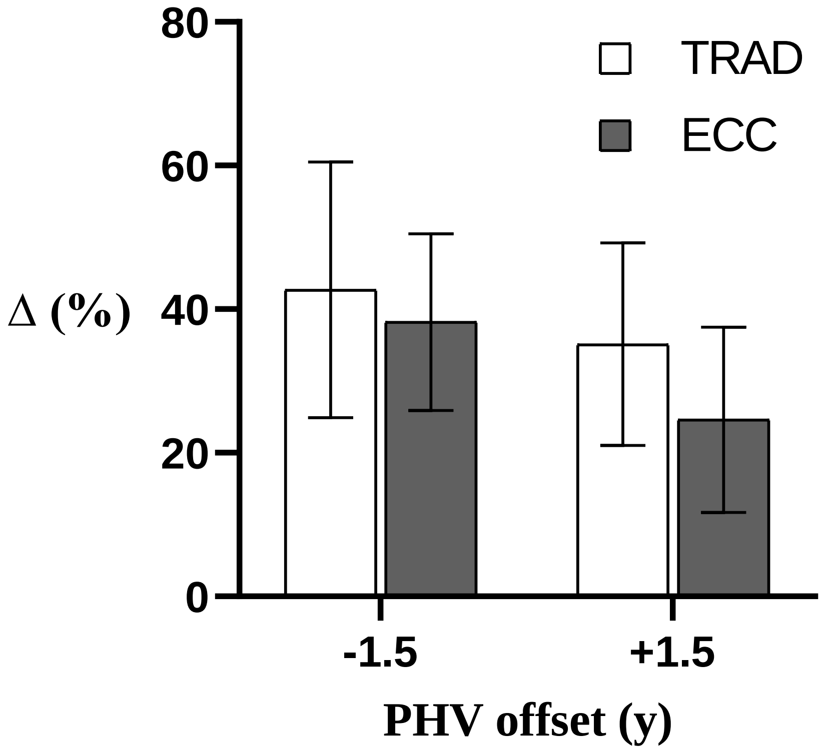

Figure 3. Mean Block 2 post–pre (week 21-9) change (Δ %)) in 3RM back squat at 1.5 years pre and post-peak height velocity (PHV). Error bars are 90% compatibility limits.

Maturity status moderated the effect of training on 5 m (Figure 4) and 20 m (Figure 5) sprint performance. Pre-PHV, the effect of ECC on 5 m sprint time was unclear but there was a decrement in sprint performance associated with TRAD (ES 4.1; ±1.4). Unsurprisingly, ECC was beneficial for 5 m sprint performance pre-PHV (ES -4.1; ±1.5), relative to TRAD. In contrast, post-PHV ECC was associated with a slight decrement in 5 m sprint performance (ES 0.3; ±0.8) whereas the effect of TRAD was unclear; thus, ECC was moderately detrimental to post-PHV 5 m sprint performance (ES 0.6; ±1.1) relative to TRAD. In less mature participants 10 m and 15 m sprint performance clearly favoured ECC training which, relative to TRAD, led to less impairment pre-PHV (10 m, ES -2.2; ±1.2; 15 m, ES -1.3; ±1.1) but not post-PHV (10 m, ES 1.0; ±1.1; 15 m, ES 0.7; ±0.9).

5 m Sprint time

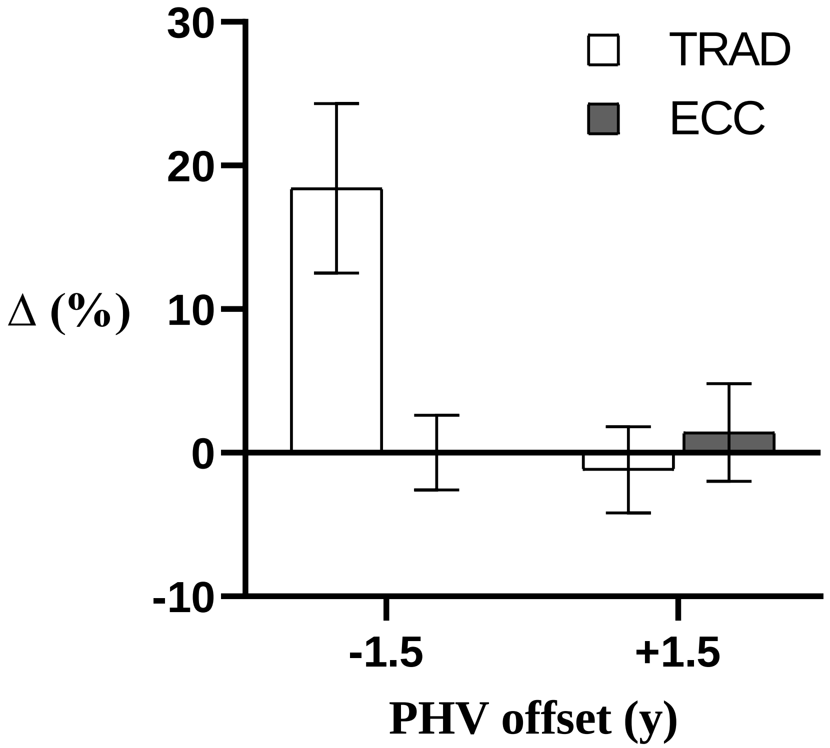

Figure 4. Mean Block 2 post–pre (week 21-9) percent change (Δ (%)) in 5 m sprint at 1.5 years pre and post-peak height velocity (PHV). Error bars are 90% compatibility limits.

Pre-PHV (TRAD, ES 1.2; ±0.6; ECC, ES 0.8; ±0.6) and post-PHV (ECC, ES 0.3; ±0.4) the training modalities led to a decrement in 20 m sprint performance. Post-PHV, ECC led to a small decrement (ES 0.3; ±0.6) in 20 m sprint performance versus TRAD. Otherwise, differences in 20 m sprint performance were trivial or unclear. Additionally, both training modalities were detrimental for 505 COD performance pre-PHV (TRAD, ES 0.6; ±0.7; ECC, ES 0.2; ±0.4) while effects circa- and post-PHV were unclear.

20 m Sprint time

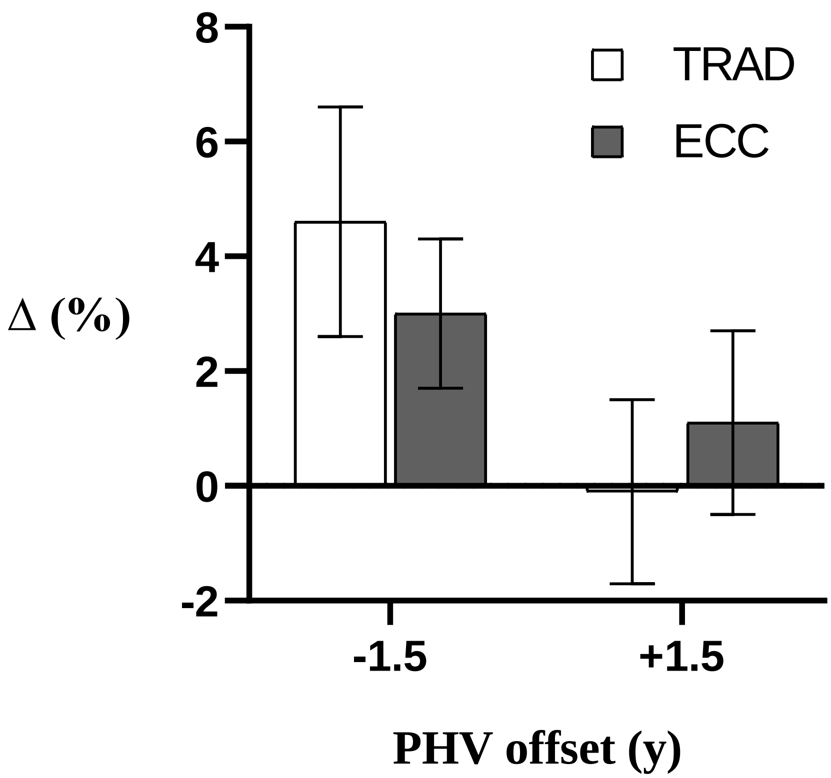

Figure 5. Mean Block 2 post–pre (week 21-9) change (Δ (%)) in 20 m sprint at 1.5 years pre and post-peak height velocity (PHV). Error bars are 90% compatibility limits.

Pre-PHV both training modalities benefited left (TRAD, ES 1.0; ±0.5; ECC, ES 0.5; ±0.4) and right (TRAD, ES 1.0; ±0.4; ECC, ES 0.6; ±0.3) straight leg raise (Figure 6). However, ECC showed less benefit relative to TRAD for left (ES -0.5; ±0.6) and right (ES -0.42; ±0.44) leg flexibility. Similarly, post-PHV both training modalities were beneficial in improving left (TRAD, ES 0.8; ±0.4; ECC, ES 1.3; ±0.5) and right (TRAD, ES 0.1; ±0.35; ECC, ES 1.1; ±0.4) straight leg raise. When comparing the two modalities, ECC showed small benefit to TRAD on left leg straight leg raise (ES 0.5; ±0.6), but for the right leg the difference was unclear. Additionally, the effect of ECC on sit and reach post-PHV led to a slight improvement (ES 0.2; ±0.3).

Right and left straight leg raise

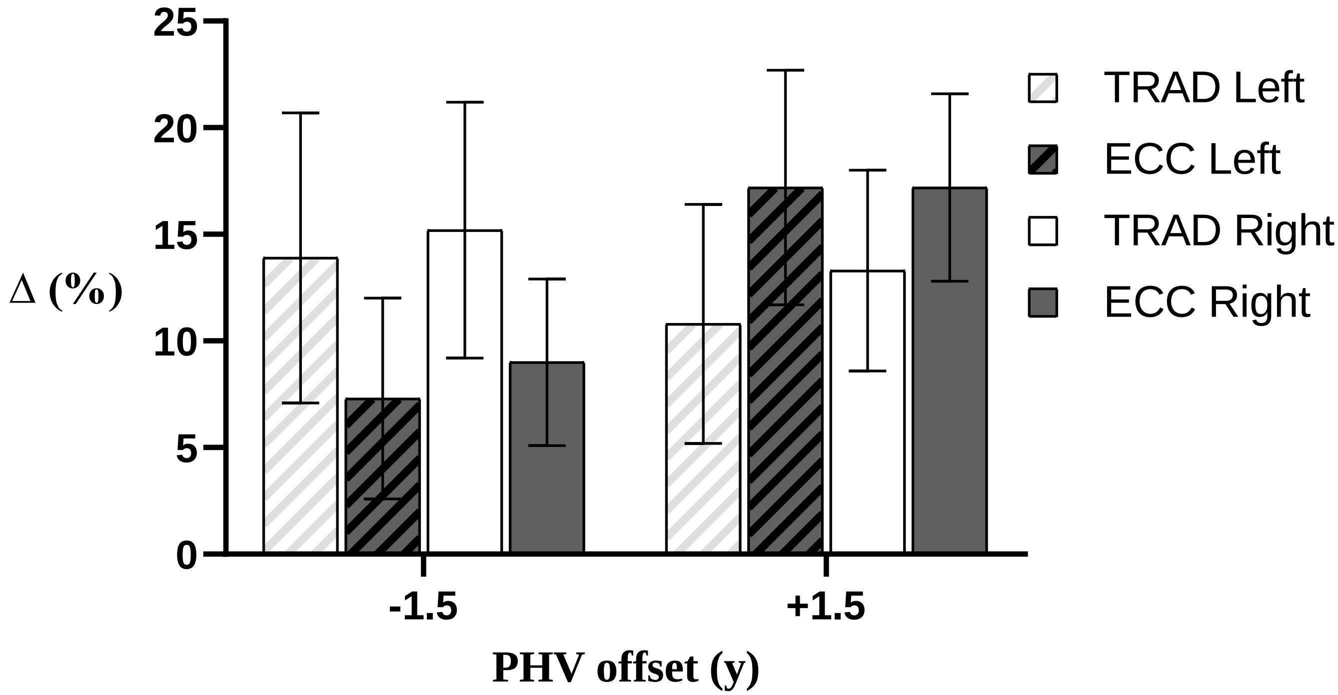

Figure 6. Mean Block 2 post–pre (week 21-9) change (Δ (%)) in right and left straight leg raise at 1.5 years pre and post-peak height velocity (PHV). Error bars are 90% compatibility limits.

ECC training was moderately detrimental for post-PHV back squat movement competency (1.1; ±1.7) relative to TRAD. The effects of either training modality on mood status were often unclear. For the clear effects, pre-PHV mood status showed small deterioration with TRAD (ES -0.38; ±0.4) and the ECC-TRAD difference was correspondingly small (ES 0.4; ±0.5). Post-PHV mood status showed small improvement only with the ECC group (ES 0.2; ±0.3) but the ECC-TRAD differences were trivial (ES 0.04; ±0.4). Quadriceps muscle soreness was moderately reduced with ECC training both pre- (ES -1.0; ±0.9) and post-PHV (ES -0.8; ±10.), yet there was a small increase in hamstring soreness post-PHV (ES 0.4; ±1.5) with ECC relative to TRAD. Pre- and post-PHV effects of the training modalities on measures were otherwise either trivial or unclear.

Discussion

To the author's knowledge, this study is the first empirical research utilising an eccentric resistance training protocol in adolescent male athletes, while determining any moderating effect of maturation on performance measures. This current study examined physical performance changes in response to traditional dynamic resistance training, followed by further traditional dynamic or moderate load eccentric duration-accentuated resistance training in 11-15 year old male soccer players. To quantify the effect of training while accounting for the varying maturation of participants, the modifying effect of maturation (PHV, -1.5 y to +1.5 y) was determined using an individual slopes model, enabling the training effect at PHV0 (circa-PHV) to be reported. With regards to the novel statistical analysis, this method of analysing individual slopes of maturity may be superior to compartmentalising participants into different maturity brackets based on predicted age of PHV (pre-, circa-, or post-PHV), as the latter method risks incorrect partitioning of participants due to the error associated with the equation of PHV (Mirwald et al., 2002).

Key findings

Block 1 traditional training substantially improved 3RM back squat, 505 COD, right and left straight leg raise, back squat movement competency and mood status; effects on 5-20 m sprint performance were, however, trivial. By the end of Block 2, both training groups had made substantial improvements in lower body strength and unilateral hamstring flexibility at all maturity levels. Comparison between groups indicates that TRAD elicited greater improvements in lower-body strength at circa- (ES -0.58; ±1.0) and post-PHV (ES -0.83; ±1.5) and flexibility pre-PHV. Post-PHV, ECC training had more benefit than TRAD to flexibility in youth. However, 5-20 m sprint performance declined in both groups, regardless of maturity. Interestingly, performance of 5 m sprint split circa-PHV and 5-15 m splits pre-PHV were less impaired with ECC, while post-PHV 5-20 m splits were less impaired with TRAD. Altogether, the present data demonstrates that moderate load eccentric duration-accentuated resistance training can improve a range of common performance measures in male youth soccer players but, in comparison to TRAD, ECC was more beneficial to post-PHV lower limb flexibility, less beneficial to lower body strength circa- and post-PHV, and less detrimental to 5 m (circa-PHV) or 5-15 m (pre-PHV) sprint performance. The data supports that, for a range of measures, adaptations to resistance training interventions depend on the maturity status (pre-, circa- and post-PHV) of the participants.

Muscular strength following TRAD

Meylan et al. (2014) found that in male youth, maturity status influenced the changes in various force and velocity-dependent measures following resistance training. Accounting for maturity status by partitioning into pre-, circa- and post-PHV groups, Meylan et al. (2014) observed small to moderate improvements in estimated supine 1RM squat with the largest improvements post-PHV following eight weeks of TRAD (two sessions per week). In the present study, large to very large improvements were seen in 3RM back squat strength, despite only one resistance training session a week. A recent meta-analysis (Moran et al., 2017) of maturity-related variation in adaptations to short-term resistance training (4-16 weeks) showed strength improvements were greatest for circa- (ES 1.11; 0.67 to 1.54) and post-PHV (ES 1.01; 0.56 to 1.46), than for pre-PHV (ES 0.5; −0.06 to 1.07). Moran et al. (2017) speculated heightened concentration of anabolic hormones associated with the onset of PHV and subsequent increase in peak body-mass, which leads to enhanced gains in muscle mass and force production may be the cause for greater improvements in strength in more mature kids. However, the meta-analysis by Behm et al. (2017) noted larger improvements in lower body strength in children than adolescents following resistance training. The findings of present study tend to concur with those of Behm et al. (2017), in that both TRAD and ECC resistance training interventions in this study led to an increase in lower body strength across all stages of maturity, with the greatest improvements in strength pre-PHV (TRAD, ES 3.6; ±1.5; ECC, ES 3.3; ±1.2). However, a major limitation of the meta-analyses by Moran et al. (2017)and Behm et al. (2017) was the broad categorisation of participants (children and adolescents) based on chronological age. This suggests that at least part of the difference between the findings of the present study to those of recent meta-analyses (Behm et al., 2017; Moran et al., 2017) can be attributable to maturity status.

Previous research in youth has found an elevated risk of injury, especially in the lower-limb around the time of PHV (van der Sluis et al., 2014). However, an increase in muscle strength utilising resistance training has shown to improve physical performance and reduce the risk of injury in youth (Myer et al., 2011). Hence, the findings of this study showing a greater increase in strength suggest a better foundational strength can be achieved pre-PHV, which might help in mitigating the increased risk of injury, associated with the onset of PHV. Additionally, it is possible that the neural demands of a resistance training session per week in the context of their habitual background training, combined with appropriate recovery between session might have benefited pre-PHV participants the most for improvements in strength. Notably, these very large improvements in Block 2 are in addition to the large improvements (ES 1.46; ±0.45) observed in response to Block 1 training. Resistance training programs with appropriate supervision and exercise prescription have been shown to improve muscular performance beyond changes associated with normal growth and maturation in youth (Behm et al., 2017). The current study prescribed a practical training program with a very high level of supervision (1-2 participants per practitioner; close monitoring of tempo and technique). Furthermore, loads for each set were based upon achieving a predefined target RPE; thus, the training load was effectively standardised by effort. Hence, it is plausible that the robust control and execution of the intervention in the current study may be a contributing factor to differences in the magnitude of changes in some measures across all stages of maturity (e.g., strength). Although all the participants had no resistance training experience, speculatively the smaller benefit circa- and post-PHV may be due, at least in part, to greater overall physical conditioning experience, and therefore possess a smaller gap to their ceiling of adaptation (Hawley, 2008; Moran et al., 2017).

Muscular strength following ECC

There is a lack of directly comparable studies of eccentric resistance training in adolescents. In adults, Fisher et al. (2016) suggested no significant differences in maximal strength between TRAD, eccentric-only and duration-accentuated eccentric resistance training variations when participants were trained to muscle failure. Furthermore, other studies in adults have shown no significant difference in strength adaptations following eccentric training of various durations at submaximal loads (2, 4 or 6 s) (Mike et al., 2017; Shibata et al., 2018). When looking at the moderating effect of maturity in the current study, TRAD showed greater improvements to ECC in 3RM strength in more mature (circa: ES -0.6; ±1.0 and post-PHV: ES -0.8; ±1.5) and IMTP in less mature participants (pre: ES -0.3; ±1.2 and circa-PHV: ES -0.2; ±0.8). The greater increase in strength with TRAD may be partially explained by the lower absolute load utilised with ECC because the accentuated duration of the eccentric contraction forces those undertaking ECC to use a lower load, the force characteristics of the movement differ (Headley et al., 2011). Additionally, research suggests greater strength gains are observed following ECC training when the protocol for measurement of strength caters to the specific muscle action and speed of movement, (i.e., when it mimics the prescribed training demandsRoig et al., 2008). In the current study, a 3RM back squat was used, which is limited by the maximum concentric force production. Hence, it does not test the true eccentric force production capacity of the participant.

Jump performance

A higher rate of force production capacity is one of the main factors underpinning improvements in sprint and jump performance (Cormie et al., 2007). Behm et al. (2017) concluded that, when considering long-term athlete development, a robust foundation of strength should be emphasised to subsequently optimize power training. In the current cohort, despite substantial improvement in lower body strength, the SJ and CMJ tests that utilise the stretch-shorten cycle have mainly been associated with slight impairments in performance. However, pre- and circa-PHV TRAD was associated with a slight increase in SJ peak GRF. This finding was supported by previous literature in youth that showed small to moderate effects of resistance training on jump measures (Behm et al., 2017). Additionally, Lloyd et al. (2016b) showed significant improvements in jump performance in pre- and post-PHV males following six weeks of traditional dynamic, plyometric, or combined training. The increase in SJ in less mature participants in the TRAD group may be support by “synergistic adaptations” (Lloyd et al., 2016a). This theory refers to specific adaptations following a training modality, which might complement the physiological changes associated with growth and maturation (Faigenbaum et al., 2016; Lloyd et al., 2016b). The small increase in SJ only at pre- and circa-PHV with TRAD may be due to the combination of greater absolute load and faster eccentric contraction velocity (TRAD, 201; ECC, 301-601). Although ECC, TRAD and plyometric training all involve an eccentric contraction with varying velocity (slow, moderate, and fast, respectively), there are no directly comparable studies of the effect of eccentrics in adolescent male athletes on improvements in lower body power. Relating to eccentrics in adults, Mike et al. (2017) found four weeks of eccentric training utilising longer contraction durations (6 s) showed substantial decrements in SJ peak velocity. Hence, the findings of the current study agree with those of Mike et al. (2017). The authors speculated the increased time under tension might be the cause for decrements in peak concentric velocity (Mike et al., 2017). Additionally, most literature in adults supports the use of fast or accentuated load ECC training for improvements in speed and power (Stasinaki et al., 2019; Suchomel et al., 2019).

Sprint performance

Stronger athletes may be better able to perform sprinting activities than weaker counterparts (Comfort et al., 2014). However, despite both resistance-training interventions substantially enhancing back squat strength, findings related to sprint performance were mainly detrimental. In fact, impairments in sprint performance were seen in both training groups, across all maturity stages. Interestingly, relative to TRAD, ECC led to a substantially less impairment in 5 m sprint time pre- and circa-PHV. Additionally, ECC also showed less decrement than TRAD in 10 m and 15 m pre-PHV. However, both training modalities led to a decrement in 20 m sprint performance across all levels of maturity, with ECC being slightly more detrimental post-PHV. On the contrary, Meylan et al. (2014) showed a small to moderate improvement in 10-m and 30-m sprint performance following 8 weeks of TRAD in pre-, circa- and post-PHV boys, in conjunction with improvements in strength of a similar magnitude to those observed in the present study. It should be noted that the maturity brackets adopted by Meylan et al., (2014) differed from those in the current study, and therefore the findings may not be directly comparable. Similarly to the work of Meylan et al. (2014), a hip-dominant exercise requiring horizontal force production (barbell hip thrust) was prescribed based on the supposition that horizontal force application could contribute to improved speed and acceleration (Contreras et al., 2011). However, Meylan et al., (2014) utilised two sessions each week, compared to only one session per week in the current study. Therefore, the differences in the volume and loading of exercises emphasising horizontal vector force production might have contributed to differences in sprint performance outcomes between studies.

Douglas et al. (2018) found that in adults slow, load-accentuated eccentric training produced greater improvements in 40-m sprint time (ES 0.28) and maximum velocity (ES 0.5) versus TRAD. However, it should be noted that as participants in the preceding study were adults and experience athletes, they might have had a better running mechanics to transfer improvements in back squat strength to sprinting in addition to development differences (Cavagna et al., 1971;

Roberts, 2016). Additionally, the authors speculated that the improvement in sprint performance might be due to better storage and utilization of energy due to enhancements in tendon and fascicle length properties associated with eccentric training (Douglas et al., 2018). The lower decrement in sprint performance pre- and circa-PHV in the current study associated with ECC may also be explained by these mechanical changes. However, muscle-tendon stiffness was not directly measured in the current cohort and thus the contribution of these properties remains speculative. Relating to the concept of training specificity, training programs comprising moderate loads lifted at slower movement velocities do not replicate the explosive demands of sports tasks (Behm et al., 2017; Radnor et al., 2017). Hence, absorbing the eccentric forces over a longer duration might nullify the utilisation of the explosive stretch-shorten cycle (Miyaguchi et al., 2008). Prescribing plyometric training has shown to improve sprint performance in youth (Lloyd et al., 2016b). Thus, including a subsequent block of training emphasising power or faster velocity of movement might be necessary to realise improvements in strength and transfer them in sprint and jump performance associated with increased force production.

Lower-limb flexibility

Both Block 1 TRAD, and Block 2 TRAD and ECC training led to moderate to large increase in unilateral lower-limb flexibility, across all levels of maturity. Interestingly, Block 2 TRAD led to a greater increase pre-PHV while ECC showed greater improvements post-PHV. Although there is a lack of data investigating mechanisms related to alterations in flexibility in youth, current literature in adults supports resistance training for improvements in flexibility mediated by changes in fascicle length. In older adults, Reeves et al. (2009) used ultrasound to determine muscle architectural changes in response to traditional dynamic (n9) or eccentric-only (n10) resistance training. The authors found that eccentric training emphasised fascicle lengthening (20% increase) over altering the pennation angle (5% increase), while traditional dynamic training increased pennation angle (35% increase) more than fascicle length (8% increase) (Reeves et al., 2009). In a smaller group of young adult males, Franchi and colleagues also investigated ultrasound-derived architectural adaptations in response to either concentric-only (n6) or high-load (80% eccentric 1RM) eccentric-only (n6) contractions (Franchi et al., 2014). Subsequent work by Franchi et al. (2015), again in young males, found further evidence for contraction specific increases in fascicle length that favoured eccentric training (5%) over concentric (2%), albeit of a smaller magnitude than their earlier study. While the results of these studies clearly favour eccentric training, it is evident that both concentric-only and dynamic training can also increase fascicle length. It is important to note the differences in populations (old and young adults versus youth) and methodology (mechanistic, lab-based vs applied training and testing protocols, different training prescription, etc) between these studies and the present investigation.

The moderate-sized improvements in lower limb flexibility in response to Block 1 TRAD training; and that following Block 2 training, there were further moderate-sized improvements in flexibility across all measured maturities, suggesting substantial capacity to improve hamstring flexibility in this cohort of youth soccer players. Furthermore, the finding that TRAD training was more beneficial to flexibility in pre-PHV youth was also notable. The greater improvements in pre-PHV flexibility with TRAD could be related to strength changes, although more data is needed to establish clear differences in pre-PHV 3RM between groups; and individual hamstring muscles may need to be measured (Xu et al., 2018). However, ECC proved to be slightly more beneficial than TRAD post-PHV for improving left leg flexibility and sit and reach. The difference between legs could be associated with leg preference/dominance during kicking or sports-related tasks. However, it should be noted that these improvements in flexibility were seen in addition to the increases in limb length across the study because of PHV. Therefore, training interventions can enhance lower limb flexibility beyond growth and maturation factors. Additionally, difference in the adaptations to the training interventions at pre-, circa- and post-PHV provides evidence of maturation-dependent effects on lower-limb flexibility and possibly architectural adaptations in youth. The larger improvement in lower-limb flexibility following ECC at circa- and post-PHV might help in reducing the time lag between the growth of the muscle-tendinous units and the bone, and could, therefore, reduce the risk of maturation related injuries.

Movement competency

Movement competency is the ability of an individual to perform a specific human movement. Assessing movement skills helps in identifying the neuromuscular, mobility and strength limitations of an individual (Lubans et al., 2010). Thus, a high level of muscular strength may be a key determinant for improving movement competency (Faigenbaum et al., 2013). Dobbs et al. (2019) found improvements in back squat movement competency at pre- (67%) and post-PHV (91%) following 4 weeks of neuromuscular training (Dobbs et al., 2019). However, it should be noted that the participants recruited in the study of Dobbs et al. (2019) had no prior experience in resistance training, and hence had a greater capacity for improvement in response to training. Findings in the current study show that changes in flexibility and strength following ECC or TRAD did not carry over to improvements in movement competency. Moreover, ECC showed less improvement in back squat movement competency than TRAD post-PHV in Block 2. It should be noted that participants in the current study had already gone through an eight-week block (Block 1) of TRAD training which moderately improved their competency. Therefore, the participants of the current study may have already reached their movement competency ceiling for the particular test by the end of the first block.

Muscle soreness and mood status

Relative to TRAD, the small improvements in mood status (vigour minus fatigue) pre- and post-PHV with ECC may indicate that the current cohort experienced more vigour or less fatigue with ECC. Surprisingly, participants also reported moderately lower quadriceps soreness following ECC across the measured stages of maturity, even though they performed the last set to near-maximal or maximal effort. These findings may partly be attributable to lower absolute load with ECC, and reduced energy cost associated with eccentric contractions (Hoppeler, 2016). Although unaccustomed eccentrics are associated with high levels of muscle soreness in adults, adolescents have been found to experience a lower level of muscle damage and associated soreness (Chen et al., 2014). However, ECC showed slight increases in hamstring muscle soreness post-PHV in the current study. The muscle soreness protocol using VAS, which required participants to recollect their soreness levels, could increase the variability of Friday and game-day responses. However, previous studies on DOMS in youth athletes has proven to be a valuable tool for up to 168 hr post training (Hughes et al., 2018). For a number of measures and comparisons (i.e., IMTP, 505 , sit and reach, soreness and mood status) more data is required to clearly determine if there were substantial differences attributable to the training regimens and maturity. To date, there are no studies that have looked at the effect of any eccentric training in youth. Hence, findings of the present study provide preliminary evidence that this variant of eccentric training conveys different adaptations to traditional dynamic resistance training for a range of performance measures across maturation in youth soccer players.

Limitations

The findings of the current study may be affected by several methodological limitations. Firstly, the underlying cause of the observed changes in Block 1 and 2 cannot be definitively linked to the resistance training interventions alone, as there was lack of a true control group (e.g., players from the same team who completed the same testing protocol but not resistance training). Additionally, different lengths of the training might induce different adaptations (i.e., 12 weeks versus 8 or 16 weeks). Specifically, the reverse pyramid approach of movement velocity (3s-6s-3s) for the eccentrics, might not have been an optimum stimulus to induce greater adaptations (i.e., moving to longer repetition duration such as 7s, 8s to 10s rather than reducing to 3s). Secondly, the error associated with measurement of anthropometry for, and residing within the calculation of PHV itself (±95% CI, 0.5 years; (Mirwald et al., 2002)) introduces variation into the novel modelling of the influence of maturity status on performance measures. Thirdly, performance measures such as leg stiffness, sprint momentum, jump height and unilateral movement competency could not be assessed due to time and technical limitation (a force plate technical error). Finally, in the present study muscle architecture (fascicle length, pennation angle, muscle thickness), which may have provided insight into changes in strength and flexibility measures, was not assessed.

Conclusion

Outcomes should be viewed in light of the context of the study, and with the study limitations in mind. This investigation took place during the competitive season of youth soccer players spanning 11-15 years of age and spread across the immediate years of peak height velocity, and are therefore most applicable to in-season youth soccer athletes at these stages of maturation. Based on the current study conditions, moderate load eccentric duration-accentuated resistance training is a suitable programming option for youth soccer players to develop specific physical qualities, depending on their particular needs and maturity status. For instance, ECC training was more beneficial than TRAD for improving lower limb flexibility post-PHV. This improvement in lower-limb flexibility might reduce the time lag between the growth of the muscle-tendinous units and bone around maturation. The reduction in time lag may also have important implications for mitigating the increased risk of injury associated with the onset of maturation. The lower decrement in sprint splits with ECC versus TRAD at pre- and circa-PHV might shed new light on the performance benefits of ECC.

Practical Application

Moderate-load eccentrics may be a useful lower-load resistance variation to traditional dynamic training around peak growth in youth soccer players. Practitioners might choose to have a block of ECC when kids are at or past their maturity offset to realise the benefits of improved flexibility and lower decrement in sprint performance at the expense of gains in strength. Coaches might then phase into a power/plyometric block to better transfer these improvements to sports specific movements. Additionally, practitioners might also choose to intersperse eccentrics as preconditioning activities before other sessions and keep doing the dynamic work in dedicated sessions to improve concentric qualities. Furthermore, coaches could use an undulating periodisation approach and have more than 1 session of eccentric a week along with traditional and plyometric training.

Future Research

This research on eccentric in adolescent male athletes while accounting for maturation status has raised more questions than answered. Future work in these areas should consider having a bigger sample size and a true control group. Furthermore, the use of ultrasound to assess changes in muscle architectural characteristics in response to training should be considered. Practical performance measures such as leg stiffness, jump height, sprint momentum, unilateral movement competency and balance should be assessed to get a better understanding of strength improvements on lower body power and running velocity. Future work should see if low-load eccentrics could be redistributed throughout other training units to achieve the same beneficial adaptations (e.g., utilised preferentially as a pre-conditioning stimulus as part of progressive warmup). Further research should also analyse the decaying effects of eccentric training in adolescent athletes. Responses to eccentric training might be, at least in part, regulated by genetic factors; future workers could consider the assessment of important gene variants such as

ACTN3 r577X polymorphism which can be assessed by cheek swabs, to help delineate responses to treatment in youth (Broos et al., 2019).

Significance

This thesis adds to the current literature in the areas of long-term athletic development and eccentric training in youth. It contributes applied research in the field of paediatric exercise science and may help in formulating evidence-based guidelines and policies for youth resistance-training prescription. Furthermore, it highlights a substantial gap in the literature (i.e., studies pertaining to eccentric training in youth athletes taking PHV into consideration) and opens up an area of new and ongoing research in youth athlete development and eccentric training.

The data from the current investigation contributes towards understanding the effect of moderate load eccentric and traditional resistance training on a range of performance, flexibility, soreness and mood measures in adolescent male athletes around the time of the peak growth phase. This study also utilises a novel analysis to investigate the moderating effect of maturity status on outcome measures in response to the training interventions.

A key feature of this research is the practical, realistic training program comprising unilateral and bilateral lower extremity movements in multiple planes, which is an effective approach to improve physical characteristics important to athletic performance. Training loads were prescribed to achieve a predefined rating of perceived exertion for every set (thus standardising effort across participants), and training volume and intensity were manipulated to apply progressive overload so that participants reached near-maximal effort on the last set. Therefore, the training program itself may act as a guide for practitioners working with youth athletes in schools, sports academies, the fitness industry, and academic institutions in periodising and progressing their resistance training programs.

Specifically, the study bridges the gap in the literature and contributes to the understanding of, moderate load eccentric exercise prescription and its outcomes in youth athletes. This study might be the first step in putting forward this eccentric training variation as a useful and practical training modality in youth, by demonstrating its effectiveness on performance.

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Appendices

Appendix 1. Health questionnaire for inclusion criteria

CARDIOVASCULAR AND OTHER RISK FACTORS QUESTIONNAIRE
In order to be eligible to participate in the study investigating: "**The effect of maturation status on performance measures and muscle range of motion following eccentric training in adolescent male athletes**" you are required to complete the following questionnaire for your child which is designed to assess the risk to your child during the study and to determine any injury that may exclude them from partaking in the study.

Name of child: ____ Date: ______________________

D.O.B: ________ Age:________ Gender (circle): M / F

If there is an emergency, specify the person who should be contacted and their emergency phone number:

Name: ________________________________ Contact ph.: ________________________________

Please note: In case of a medical emergency, an ambulance may be used to transport your child to the nearest medical treatment service.

Circle the appropriate response to the following questions.

Does your child have, or has your child had

1.	A heart condition?	Yes	No
2.	Cystic Fibrosis?	Yes	No
3.	Diabetes (Type I or Type II)?	Yes	No
4.	High blood pressure?	Yes	No
5.	High cholesterol?	Yes	No
6.	Unexplained coughing during or after exercise?	Yes	No
7.	Breathing problems or shortness of breath (for example, asthma)	Yes	No
8.	Epilepsy or seizures/convulsions?	Yes	No
9.	Does your child take any medications? (please name)	Yes	No

____

10. In the last 12 months has your child had any muscular or joint pain while exercising or injury to muscles or joints? Yes No

If Yes, please explain and indicate where the pain has occurred (e.g. Pain in the back of the right heel)

____
____
____

11. Has your child broken any bones or suffered injury to their bones in the last 12 months?
Yes No

If Yes, please explain where and how the break/injury occurred.

____

____

____

12. Does your child use "puffer" or "ventilator" for asthma? Yes No

13. Does your child self-administer insulin for diabetes Yes No

14. Is your child allergic to food, medications, pollens or other allergens or specific environments?
Yes No

If Yes, please explain what causes have been identified with this/these allergy/ies:

____

____

____

15. Are you aware of any medical reason/condition which might prevent your child from participating in this study? Yes No

If Yes, please explain

____

____

____

I, ____, believe that the answers to these questions are true and correct.

Signature (Parent/Guardian) : ____________________________________ Date: ____________________

Appendix 2. Adherence rate for training.xlsx

Appendix 3. Non-prescribed exercise duration and intensity

Number of hours of Non-prescribed Exercise /Physical Activity in a Week (please fill to the best of your knowledge)

Sport/Activity	Day(s) of Week Sa-Su-Mo-Tu-We-Th-Fr	Time of the Day	Approximate Duration	RPE

Appendix 4. Warm-up

5 min jogging at slow to moderate pace, lateral shuffle, karaoke, inch worm, walking lunge , lateral lunge, romanian-deadlift walk, hurdle walks, torso rotations & arm rotations.

Appendix 5. POMS-A List of questions

Please read each one carefully. Then **circle** the answer which best describes **HOW YOU FEEL RIGHT NOW**. Make sure you answer every question.

Name/Code: Date:

	Not at all	A little	Moderately	Quite a bit	Extremely
1. Panicky	0	1	2	3	4
2. Lively	0	1	2	3	4
3. Confused	0	1	2	3	4
4. Worn out	0	1	2	3	4
5. Depressed	0	1	2	3	4
6. Downhearted	0	1	2	3	4
7. Annoyed	0	1	2	3	4
8. Exhausted	0	1	2	3	4
9. Mixed- up	0	1	2	3	4
10.Sleepy	0	1	2	3	4
11.Bitter	0	1	2	3	4
12.Unhappy	0	1	2	3	4
13.Anxious	0	1	2	3	4
14.Worried	0	1	2	3	4
15.Energetic	0	1	2	3	4
16.Miserable	0	1	2	3	4
17.Muddled	0	1	2	3	4
18.Nervous	0	1	2	3	4
19.Angry	0	1	2	3	4
20.Active	0	1	2	3	4
21.Tired	0	1	2	3	4
22.Bad tempered	0	1	2	3	4
23.Alert	0	1	2	3	4
24.Uncertain	0	1	2	3	4

Appendix 6.

PARTICIPANT CODE: _____________

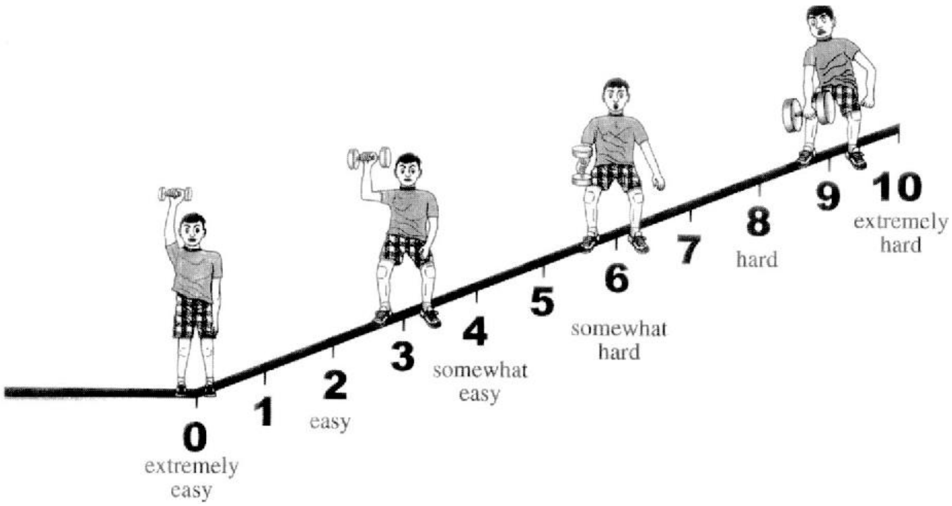
DATE: _____________

Please draw a line for marking the level of pain.

Quadriceps (Front of the thigh) Did you feel any pain, stiffness and/or soreness in your **quadricep** muscle group during the following times:	**Hamstring (Back of the thigh)** Did you feel any pain, stiffness and/or soreness in your **hamstring** muscle group during the following times?
On last Friday evening? NO PAIN |————————| WORST POSSIBLE PAIN	On last Friday evening? NO PAIN |————————| WORST POSSIBLE PAIN
On Match Day? Which day was your match? [ ] NO PAIN |————————| WORST POSSIBLE PAIN	On Match Day? NO PAIN |————————| WORST POSSIBLE PAIN
Right now? NO PAIN |————————| WORST POSSIBLE PAIN	Right now? NO PAIN |———————— WORST POSSIBLE PAIN

Appendix 7: Exercise and intensity prescription for interventions.xlsx

Appendix 8. Exercise RPE sheet



Appendix 9. Session RPE

0	NOTHING AT ALL
0.5	VERY, VERY LIGHT
1	VERY LIGHT
2	FAIRLY LIGHT
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	VERY VERY HARD (MAXIMAL)

Appendix 10: TRAD training data Block 1.xlsx

Appendix 11: TRAD training data Block 2.xlsx

Appendix 12: ECC training data Block 2.xlsx

Appendix 13.

Measures of performance and mood at the start of Block 2 of traditional and eccentric training.

	TRAD (mean ± SD)	**ECC (mean ± SD)**
3RM (kg)	62 ± 15	59 ± 13
Scaled 3RM (kg/BM$^{2/3}$)	4.3 ± 0.7	4.4 ± 0.6
Isometric mid-thigh pull (N)	967 ± 239	900 ± 236
Scaled isometric mid-thigh pull (N/BM$^{2/3}$)	65 ± 10	68 ± 10
Squat jump peak GRF (N)	1127 ± 201	1080 ± 317
Counter-movement jump peak GRF (N)	1025 ± 286	1036 ± 315
Sprint 5 m (s)	1.18 ± 0.07	1.23 ± 0.04
Sprint 10 m (s)	1.99 ± 0.10	2.06 ± 0.08
Sprint 15 m (s)	2.73 ± 0.18	2.8 ± 0.13
Sprint 20 m (s)	3.49 ± 0.26	3.56 ± 0.18
505 COD (s)	2.46 ± 0.09	2.49 ± 0.10
Sit and reach (cm)	25.1 ± 10.7	22.0 ± 5.1
Right leg raise (°)	61.4 ± 9.6	64.7 ± 8.8
Left leg raise (°)	60.8 ± 13.8	64.6 ± 7.5
Squat assessment (0-10)	1.9 ± 1.1	1.9 ± 1.1
POMS (0 - 100)	73 ± 17	62 ± 17
Quads soreness (0 - 100)	17 ± 17	23 ± 28
Hams soreness (0 - 100)	19 ± 17	19 ± 18

Appendix 14.

Modifying effect of 3 y of PHV age on Block 2 of resistance training: changes in performance, mood and soreness associated with eccentric and traditional training, the differences in the changes, and non-clinical magnitude-based decisions for the changes and differences.

	SWC for benefit	Eccentric		Traditional		Eccentric - traditional	
		Mean; ±90CL	Decision[a]	Mean; ±90CL	Decision	Mean; ±90CL	Decision
3RM (%)	2.0	-9.8; ±13	moderate ↓	-5.3; ±17	small ↓	-4.7; ±21	small ↓
Scaled 3RM (%)	2.6	-7.3; ±13	small ↓	-7.7; ±16	moderate ↓	0.4; ±22	trivial ↑
IMTP (%)	4.1	-1.5; ±25	trivial ↓	-4.7; ±28	small ↓	3.4; ±40	trivial ↑
Scaled IMTP (%)	3.4	-1.0; ±21	trivial ↓	-6.5; ±24	small ↓	5.9; ±33	small ↑
SJ peak GRF (%)	4.4	1.9; ±8.8	trivial ↑	-2.9; ±12	trivial ↓	4.9; ±15	small ↑
CMJ peak GRF (%)	4.6	8.7; ±23	small ↑	11; ±28	small ↑	-2.3; ±32	trivial ↓
Sprint 5 m (%)	-0.8	1.3; ±4.7	small ↑	-17; ±5.1	**extremely large ↓******	21; ±9.2	**extremely large ↑******
Sprint 10 m (%)	-0.7	1.9; ±4.3	small ↑	-9.4; ±4.4	**v.large ↓******	13; ±7.1	**v.large ↑*****
Sprint 15 m (%)	-0.7	2.0; ±3.5	small ↑	-5.2; ±4.2	large ↓***	7.6; ±5.9	v.large ↑***
Sprint 20 m (%)	-0.8	-1.9; ±2.0	small ↓**	-4.5; ±2.6	**moderate ↓*****	2.7; ±3.4	moderate ↑**
505 COD (%)	-0.8	-2.2; ±2.7	small ↓**	-2.2; ±3.4	small ↓	-0.0; ±4.1	trivial ↓
Sit and reach (cm)	1.6	2.3; ±3.3	small ↑*	0.5; ±4.1	trivial ↑	1.8; ±5.2	small ↑
Leg raise right (°)	3.0	8.2; ±6.1	**small ↑****	-1.9; ±7.8	trivial ↓	10; ±8.9	moderate ↑**
Leg raise left (°)	3.0	9.9; ±7.6	moderate ↑**	-3.1; ±9.1	small ↓	13; ±11	moderate ↑**
Squat assess-ment (0-10)	-0.2	0.3; ±1.4	small ↑	-0.7; ±2.2	moderate ↓	1.1; ±2.6	moderate ↑
POMS (0 - 100)	3.5	4.0; ±6.6	small ↑*	9.3; ±9.6	small ↑**	-5.3; ±10.7	small ↓
Quads soreness (0 - 100)	-4.1	3.1; ±29	trivial ↑	-11; ±35	small ↓	14; ±45	moderate ↑
Hams soreness (0 - 100)	-4.2	4.9; ±32	small ↑	2.4; ±37	trivial ↑	2.6; ±49	trivial ↑

SWC, smallest worthwhile change; 90CL, 90% confidence limits; 3RM, three repetition maximum back squat; scaled 3RM, allometrically-scaled 3RM; IMTP, isometric mid-thigh pull; scaled IMTP, allometrically-scaled IMTP; SJ peak GRF, squat jump peak ground reaction force; CMJ peak GRF, counter-movement jump peak GRF; COD, change of direction; POMS, vigor and fatigue scores from Profile of Mood States; Quads, quadriceps muscle; Hams, hamstring muscle.

[a]Magnitude of the observed effect, with likelihood of a substantial increase (↑), decrease (↓) and/or trivial clear effect.

Likelihoods of clear substantial effects: * possible; ** likely; *** very likely; **** most likely.

Likelihoods of clear trivial effects: [0] possible; [00] likely.

Bold effects are @99%.