Global Insights into the Role of Strength Training in Soccer, with Particular Reference to Academy Players

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Declaration

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

Abstract

Soccer is a global sport, participated in by both men and women, in professional and academy environments. Researchers have proposed that resistance training (RT) interventions are beneficial for each of these demographics, as generating high levels of muscular strength and power are important for success in soccer. While research has focused on a multitude of training methods aiming to improve strength and power in soccer, an understanding of commonalities and differences between strength and conditioning (S&C) coaches working in various demographics is needed so a training intervention can then be designed with greater ecological validity, while aligning with scientific guidelines for using strength training.

Initially, taking a wide scope of S&C practice, chapter four aimed to investigate whether differences in current soccer S&C practice existed between different global regions. Overall, relatively more coaches in the United Kingdom (UK) believed bodyweight training was the most important RT modality compared to coaches in South America (SA) (45% *vs.* 27%, p = 0.040). Conversely, relatively more first team coaches in the United States of America (USA) than in the UK regarded free-weight RT as the most important training method in their programmes (100% *vs.* 60%, p = 0.033). Further, coaches in Europe conducted fewer formal S&C sessions, placed less importance on free-weight RT and performed less speed and plyometric training compared to coaches in other global regions (all $p < 0.05$). Based on these findings, the S&C practice of coaches in the USA and SA generally align better with scientific guidelines for strength and power development in soccer compared to those in the UK and other European countries, with an emphasis on free-weight RT alongside regular sprint and plyometric training. However, SA academy players were introduced to S&C later (14 ± 2 years-old) than in the UK (12 ± 3 years-old, p = 0.002), which may limit physical development in SA players.

The purpose of chapter five was to investigate the practices of S&C coaches working with male and female soccer players, at first team and academy level. Compared to men's soccer, much less is known about S&C practice in the women's game, and consequently, the S&C approaches taken with women's first team and academy squads may not be appropriate. This investigation highlighted differences in S&C practices between coaches of men's and women's soccer squads on a global scale. Women's academies had fewer weekly in-season S&C sessions than men's academies (1 ± 1 *vs*. 2 ± 1, $p = 0.005$), despite greater injury risk in female players. However, relatively more women's coaches (39%) used the Nordic hamstring exercise (NHE) compared to men's coaches (18%, $p = 0.008$), suggesting the NHE may be used to reduce the higher injury risk in female players. Further, relatively more women's coaches (63%) utilised rating of perceived exertion-based load prescriptions than men's coaches (37%, $p = 0.002$). The subjective methods for training prescription may underload strength training exercises, limiting physical development in female players. Thus, coaches in women's soccer may wish to increase weekly frequency of S&C sessions and use objective methods to prescribe load, thereby optimising performance and minimising injury risk.

Building on the findings in chapter five, the aim of chapter six was to investigate current S&C practice in first team and academy level soccer. Scientific guidelines exist regarding S&C best practice, for both first team and academy level soccer. However, it is not known if these research-informed guidelines are followed in such applied settings. A greater proportion of academy compared to first team coaches assessed acceleration/sprint (92% *vs.* 83%, p=0.026), jump (95% *vs.* 83%, p=0.023) and change of direction performance (77% *vs.* 61%, p=0.031). Therefore, the testing approach taken by academy S&C coaches appears to align with the suggestions from the scientific literature. However, the RT approach employed does not appear to align with scientific guidelines. A greater proportion of academy (54%) *versus* first team (35%) coaches prioritised bodyweight training (p=0.031), despite a similar distribution of movement patterns trained. Overall, 44% S&C coaches reported using training intensities below strength training guidelines (≥80% 1RM). This disparity between strength training guidelines and applied practice of S&C coaches in first team and academy may be due to perceived time restrictions (50% and 49%) and concerns of muscle soreness (70% and 37%).

The purpose of the final experimental study (chapter seven) was to investigate the efficacy of high (HRT) *versus* moderate intensity RT (MRT) (the latter was the approach generally reported in chapters four, five and six) on changes in strength, power, and speed, and to compare delayed onset muscle soreness (DOMS) between HRT and MRT. Intervention groups completed one session per week of parallel back squat for six weeks in-season alongside regular soccer training. Participants performed either 2 × 4 at 90% single repetition maximum (1RM) (HRT) or 3 × 8 at 80% 1RM (MRT). Both training groups experienced similar increases in absolute and relative back-squat strength and vertical jump following the intervention. Further, HRT improved horizontal jump more so than MRT ($p = 0.011$). Importantly, the increases seen following HRT were achieved with 58% less training volume than MRT ($p < 0.001$), and with similar DOMS compared to soccer alone. These findings suggest that HRT may be a more efficient training method to improve physical performance in academy soccer players in-season than the most common training prescription (MRT) currently used by S&C coaches in soccer.

In summary, this thesis observed variation in S&C practice in soccer between global regions (chapter four), between coaches working with male and female soccer players (chapter five), and between coaches working in first team and academy settings (chapter six). The application of scientific research-based RT principles varies widely, with a large proportion of S&C coaches in soccer not following guidance for maximal strength development or maintenance. This may be due to the perceived restrictions of limited time and the potential for DOMS following RT. However, as seen in other sports and shown in chapter seven, when employing scientific research-based strength training principles, a high-intensity, low-volume RT programme is not only feasible in-season but more effective than current practice and helps manage perceived restrictions.

List of abbreviations

%RM; Percentage of repetition maximum

1RM; One repetition maximum

CG; Control group

CMJ; Countermovement jump

COD; Change of direction

CRT; Original resistance training

CSA; Cross-sectional area

CT; Complex training

DJ; Drop jump

EPPP; Elite Player Performance Plan

EUR; European countries excluding the United Kingdom

FIFA; Fédération Internationale de Football Association

HRT; High-intensity resistance training

IMTP; Isometric mid-thigh pull

LTAD; Long-term athlete development

MRT; Moderate-intensity resistance training

NGB; National governing body

NHE; Nordic hamstring exercise

NSCA; National Association for Strength and Conditioning

PHV; Peak-height velocity

PLYO; Plyometric

PWV; Peak-weight velocity

RFD; Rate of force development

RM; Repetition maximum

RT; Resistance training

S&C; Strength and conditioning

SA; South America

SJ; Squat jump

U13; Under 13 squad

U15; Under 15 squad

U16; Under 16 squad

U17; Under 17 squad

U18; Under 18 squad

U21; Under 21 squad

UK; United Kingdom

USA; United States of America

WL; Weightlifting

WLRT; Weightlifting and resistance training

YPD; Youth physical development

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Chapter One – General Introduction

1.2 Introduction

Strength and conditioning (S&C) coaches working in soccer aim to improve their players' muscular power via effective and efficient training programmes. Soccer is a global sport, participated in by both men and women, in professional, academy (youth) and amateur (both senior and youth) environments. Researchers have proposed that resistance training (RT) interventions are beneficial for each of these demographics (Turner and Stewart, 2014, Millar et al., 2020). Further, in youth populations, RT is not only safe (Lloyd et al., 2014a), but can result in significant increases in strength and power, and reduce injury risk (Harries et al., 2012, Lesinski et al., 2016). However, a point of conjecture surrounds best practice and its translation from the literature to the applied setting. This may be partly due to the (perceived) limited time available for soccer academy S&C coaches to implement RT interventions (Read et al., 2018).

Although soccer is the most popular sport worldwide (FIFA, 2006), between country differences in technical and physical demands of matches (Dellal et al., 2011), fixture congestion (Goossens and Spieksma, 2012) and player anthropometrics (Bloomfield et al., 2005) may influence the practice of S&C coaches working in soccer in specific countries/continents. Current observations of practice that have included multiple geographical locations have focused on those working with professional male players, with samples too small for between country/region comparisons (Weldon et al., 2020). Country-specific factors can have a large impact on long-term athlete development (LTAD), such as the chronological age players enter a formal academy pathway (Ford et al., 2012) and the physical development guidelines from national governing bodies (The English Football Association, 2015). Thus, between country differences in S&C practice may exist as a consequence of different LTAD models and/or different match demands/fixture number. If such differences do exist, they should be identified and described, so that researchers can design more ecologically valid training interventions, which are more likely to be adopted by practitioners, thus improving the translation of science into practice.

Beyond global differences, there has been rapid growth in participation in women's soccer in recent years (FIFA, 2018), along with increased physical demands, such as the volume of high-speed running (FIFA, 2020). However, research in this important population is relatively scarce in comparison to male soccer players and requires specific focus (Emmonds et al., 2019a). Despite the physiological differences between male and female soccer players (Roberts et al., 2020), it is not clear if S&C coaches alter training programmes as a consequence. Improving lower-body strength is particularly important in female soccer players. Not only will there be a performance benefit (Millar et al., 2020) but also a decrease non-contact injury risk (Khayambashi et al., 2016). This is important, as there is a high frequency of injury in both professional (Faude et al., 2005) and adolescent (Le Gall et al., 2008) female soccer players. For example, female athletes suffer anterior cruciate ligament injuries four to six times more often than male athletes (Arendt et al., 1999). Despite this knowledge, due to the lack of research in women's soccer, S&C practice with female players may be implemented based on evidence from male populations, which might not be appropriate (Emmonds et al., 2019a). Further, the resources and organisational structure of women's soccer differs to men's in both academy and first team settings (Valenti, 2019). For example, in England, Regional Talent Clubs are the highest standard of women's youth football. Here, under 16 year-old players complete eight hours of total training per week, consisting of pitch-based and S&C sessions (Emmonds et al., 2017). Comparatively, men's academy players of the same age are expected to complete 12 to 16 hours of total training time per week (The English Football Association, 2015). This may result in different training frequencies and methods implemented to develop strength and power. This may have a long-term compounding effect on LTAD and how well a youth player is physically prepared to transition into a senior soccer environment. Thus, comparing current S&C practice between coaches working with women and men soccer players (both at academy and professional level) is necessary to provide valuable insights for both sets of coaches (and researchers) going forward in order to help the continued development of S&C in women's soccer.

Academies within professional soccer clubs work with players of different ages, ranging from very young to early 20s, and their overarching aim is to develop these young, talented soccer players into professional (first team) athletes. For young athletes, development of strength and power may have long-term implications for their sporting careers, as both variables are important for sporting success (Wing et al., 2018) and both are assessed in soccer talent identification protocols (Dodd and Newans, 2018). There are LTAD models within the literature (Lloyd and Oliver, 2012) and from soccer national governing bodies (The English Football Association, 2015), which include physical training guidelines. However, these guidelines are generic and open to interpretation by the practitioner. Though limited detail is not necessarily negative, due to the number of variables to consider when designing a training programme for academy soccer players, a lack of specific guidelines allows for a wide variety of methods to be implemented. For example, the athlete's biological age will influence the focus, volume and intensity of training (McQuilliam et al., 2020). With that in mind, academy S&C coaches will likely use different strength training methods compared to coaches working with the senior squad. Further, an academy S&C coach may be more focused on athletic development, while a senior team S&C coach may be more concerned with performance, which may also influence the approach to physical training. The frequency of strength training sessions in both senior (Cross et al., 2019) and academy players (Brownlee et al., 2018b) is lower than suggested in the soccer-specific guidelines within the literature (Turner and Stewart, 2014, Meylan et al., 2014b). Together, this could suggest not only differences in strength training methods between senior and academy S&C coaches, but also differences between scientific guidelines for optimising strength and power in soccer and actual practice, both of which warrant investigation.

The development of strength and power may have long-term implications for youth soccer players. Soccer requires dynamic, high-intensity actions such as accelerating, sprinting, jumping and changes of direction (Castagna et al., 2003, Murtagh et al., 2019). Maximal strength underpins these athletic muscular performance qualities, by increasing maximal force potential (Schmidtbleicher, 2004). Free-weight RT is an effective method to improve strength in both youth (McQuilliam et al., 2020) and professional athletes (Suchomel et al., 2018). This allows for large compound movements coupled with reduced stability, therefore increasing the recruitment of stabilising musculature around the primary muscles as well as superior reproduction of sporting actions (Lesinski et al., 2016). Youth soccer players can achieve increases in strength, acceleration, sprint, and vertical jump in-season within a short time period when sufficient training intensities are used (≥80% single repetition maximum (1RM)) (Chelly et al., 2009, Styles et al., 2016). The resulting increases in strength and power have been attributed to neural adaptations due to no change in muscle cross-sectional area (Hammami et al., 2018). This is important to consider, as strength relative to body mass has strong correlations with acceleration and vertical jump performance (Styles et al., 2016, Comfort et al., 2014). However, environmental factors, such as time restrictions due to sport-specific technical training and a limited number of appropriately qualified and experienced staff can make translation of scientific literature into applied practice challenging (Bishop, 2008). Therefore, it remains to be seen if high-intensity, low-volume RT, which would require less time and potentially less muscle soreness (Bartolomei et al., 2017), can induce comparable performance gains to low-intensity, high-volume RT in academy soccer players.

While research has focused on a multitude of training methods aiming to improve strength and power in soccer, an understanding of commonalities and differences between S&C coaches working in different global regions, with male and female, and academy and professional players, is needed to help identify areas of research that can be used to inform S&C practice. Training interventions can then be designed and implemented by S&C coaches with greater ecological validity, while aligning with scientific guidelines for using strength training to optimise performance and minimise injury risk in soccer players.

1.3 Aims and Objectives of the Thesis

The overarching aim of this thesis was to investigate the practice of S&C coaches working with female and male soccer players at both academy and professional levels in different global regions, and to explore the impact of high-intensity lower-limb weight training in academy soccer players. Four main objectives were implemented to achieve this aim:

1. To compare current S&C practice in soccer between different global regions, and to highlight any differences in practice, specifically designed to improve strength and power. This topic will be explored in the work described in Chapter Four.
2. To compare current S&C practice in soccer between coaches working with male and female players on a global scale, and to highlight any differences in practice specifically aimed at improving strength and power or reducing injury risk in female players. This topic will be investigated in the work described in Chapter Five.
3. To compare current S&C practice in soccer between coaches working with academy and professional (first team) players on a global scale, and to highlight any differences in practice specifically aimed at improving strength and power in academy players. This topic will be studied in the work described in Chapter Six.
4. To compare the effects of high-intensity, low-volume *versus* moderate-intensity, high-volume lower-limb weight training on strength, power and speed in male academy soccer players. This topic will be explored in the work described in Chapter Seven.

Chapter Two – Strength and conditioning practice in youth soccer: a narrative review of the literature

Adapted from: McQuilliam, S.J., Clark, D.R., Erskine, R.M. and Brownlee, T.E., 2020. Free-weight resistance training in youth athletes: A narrative review. Sports Medicine, 50(9), pp.1567-1580.

2.1 Abstract

Generating high levels of muscular strength and power are important for success in soccer and may have long-term implications for sporting careers in youth soccer players. Importantly, maturation may confound the neuromuscular adaptations to resistance training when attempting to differentiate between training- *vs.* growth-induced strength and power gains, thus potentially leading to erroneous conclusions regarding the efficacy of resistance training in youth athletes. The aim of this review was to critically appraise the literature concerning the efficacy of externally loaded free-weight resistance training on strength and power measures in youth soccer players at different stages of maturation. Strength underpins power production, thus developing strength through traditional resistance training methods can positively influence powerful sporting movements. Additionally, weightlifting has the capacity to improve muscular power via explosive lower-body triple extension, which is important for many sports, including soccer. Despite the complexity of the techniques involved, it can be a safe and effective method to improve athletic qualities in young athletes, potentially more so than plyometric training. Low-load, high-velocity training can have a positive influence on high-speed movements, such as sprinting, but the lack of high-intensity appears to be disadvantageous post peak-height velocity. Irrespective of age, well-coached, progressive strength training, adhering strictly to correct technique, can then be periodised within a long-term athletic development programme. It is important to primarily develop muscular strength, while concurrently refining the technical skill required for weightlifting. Physically mature soccer players should undertake high-intensity resistance training to maximise neuromuscular adaptations, leading to positive changes in strength and power.

2.2 Introduction

In soccer, the ability to generate high levels of muscular power is an important component for success (Young, 2006). Thus, practitioners aim to improve muscular power via effective and efficient training programmes. Previously, a potentially misleading report based on the hospital admission records of injury cases concluded that resistance training (RT) was not safe in youth populations (Commission, 1987). Further investigation determined that many of the recorded injuries were accidents resulting from incorrect exercise technique and/or poor supervision. More recent research has shown that RT in youth athletes can be a safe and beneficial training method (Barker et al., 2014, Lloyd et al., 2014a). Researchers have proposed that RT interventions in youth populations result in significant increases in strength, power and agility and reduced injury risk (Harries et al., 2012, Lesinski et al., 2016). However, a point of conjecture surrounds RT best practice and the translation of this from the literature to the applied setting.

For young soccer players, development of strength and power may have long-term implications for their sporting careers. The confounding factor of maturation on training adaptations in terms of training- vs. growth-induced strength/power gains can complicate the training process. For example, chronologically older male and female youth soccer players have been shown to be stronger in absolute terms but not when strength was normalised to body mass (Morris et al., 2018b, Brownlee et al., 2018a, Emmonds et al., 2017). Environmental factors, such as time restrictions due to sport-specific technical training and a limited number of appropriately qualified and experienced staff available to supervise and implement RT can also make translation of scientific literature into applied practice challenging (Bishop, 2008).

The aim of this review was to critically analyse the scientific literature regarding the use and efficacy of RT regarding neuromuscular adaptations and how they translate into strength and power gains in youth soccer. The objective was to provide recommendations based on the available evidence in the literature on the best practice regarding RT in youth soccer, with particular reference to maturity status.

2.3 Global considerations

Soccer is a global sport with more registered athletes compared to any other sport (FIFA, 2006) but, despite following the same set of rules, differences in technical, tactical and physical match demands exist between countries (Dellal et al., 2011). These differences may influence the training methods implemented by strength and conditioning (S&C) coaches working with male and female players, at professional and academy level. Two recent studies have described the current methods of soccer S&C coaches working with professional soccer players from different countries (Weldon et al., 2020, Loturco et al., 2021). Collectively the practice of S&C coaches from 18 countries reported that training loads were restricted by fixture congestion and time (Weldon et al., 2020). However, the sample size (n = 52) precluded any between country comparison, therefore it was not possible to conclude if training approaches varied by geographical location. Loturco et al. (2021) conducted a similar survey of the S&C practices currently implemented in professional Brazilian soccer teams and there were large differences in the prescription of RT intensity, RT modality and RT exercises used to develop strength and power. Differences in the current approach to S&C appear apparent in professional soccer, however it is not known if this is also the case in youth soccer, and if practice differs between global regions. Further, in a youth development setting, S&C coaches may also have to align their athletes' training with long-term athletic development (LTAD) recommendations outlined by their respective national governing body (NGB). For example, differences exist in the chronological age that young male soccer players enter academies, with those in Portugal starting at 8 ± 2 years old, at 10 ± 2 years old in the United Kingdom (UK), and at 13 ± 1 years old in Brazil (Ford et al., 2012). This may have long-term implications for academy soccer players, as those with greater training ages could benefit from greater strength and power than their less experienced counterparts (Myer et al., 2013). The culmination of these and other factors may well influence S&C coaches' programmes and could result in substantially different training approaches between global regions within professional and academy soccer, in both the men's and women's game. More work is required to understand S&C practice in different global settings in both male and female, academy and professional environments. Such knowledge may enable S&C coaches to broaden their view of current S&C practice in soccer by highlighting examples of good practice and facilitating knowledge transfer between coaches from different global regions. Ultimately, this may further improve the translation of science into practice and enhance the athletic development of soccer players, both male and female, professional and academy.

2.4 Biological sex-based factors

Soccer is a sport played by men and women of all ages, with global participation in the women's game increasing rapidly (FIFA, 2018). This has coincided with an increased professionalism (Culvin, 2021), which has expanded the sport science services female soccer players receive, including S&C support. Strength and conditioning methods not only improve athleticism in female soccer players (Millar et al., 2020) but may also decrease non-contact injury risk (Khayambashi et al., 2016). However, whether male and female athletes require different approaches to develop strength and power has been discussed in the literature, with studies supporting both for (Reynolds et al., 2012) and against this suggestion (Roberts et al., 2020). This is due to the physiological differences between sexes, which may impact the training methods S&C coaches choose to use (Reynolds et al., 2012). Physical performance differences between males and females start to manifest at the onset of puberty, which tends to occur earlier in girls (11-13 years-old) compared to boys (12-15 years-old) (Iuliano-Burns et al., 2001). Until this point, muscle mass is similar but boys experience a larger natural accumulation of muscle mass until approximately 20 years of age, whereas in girls this process halts several years earlier (Tønnessen et al., 2015). This results in greater increases in strength and power in boys than girls, irrespective of RT experience (Ford et al., 2011). Alongside this, coaches of female athletes have been shown to implement lower training frequencies, extra jump training to protect against non-contact injuries and "female-preferred" methods, such as muscular endurance and flexibility (Reynolds et al., 2012). This approach was formed by coaches opinions (65%), highlighting that research into women's soccer is still an under-developed area in comparison to men's soccer (Emmonds et al., 2019a). Consequently, women's and girls' S&C training practices may be based on evidence from male populations, which may be inappropriate considering the sex differences in performance characteristics and injury risk (Emmonds et al., 2019a). Thus, further work is required to investigate S&C practice in coaches working with male and female soccer players, at both professional and academy level.

These differences, both physiologically and those perceived by coaches, may result in different S&C training approaches between men's and women's soccer. Further, far more research on men's senior soccer has been conducted (Weldon et al., 2020, Loturco et al., 2021), than women's (Emmonds et al., 2019a). The importance of physical qualities in women's senior soccer are well detailed, with lower-body strength corelating with both speed and change of direction ability (Emmonds et al., 2019b), which can differentiate between playing standards (Vescovi, 2012). In terms of strength training practices in women's soccer to develop these attributes, there is little information currently available. Elite female soccer players in England complete four to five pitch-based training sessions and one to two strength training sessions per week (Emmonds et al., 2019b), which is comparable to the number of weekly sessions in elite men's teams (Weldon et al., 2020). However, less is known about training prescription during training, and this requires further investigation.

2.5 Long-term athlete development models

Practitioners and researchers have attempted to align various resistance training methods with each stage of maturation in young athletes. As such, several training models have been proposed. Long-term athlete development models may aid in structuring a young soccer player's training. An early, well-known LTAD framework was proposed by Côté (1999), outlining three clear phases: sampling years (ages 6-12 years), specialising years (ages 13-15 years) and investment years (ages 16+ years). However, a potential problem is the classification of athletes based on chronological age (Ford et al., 2011), which is defined as a selected time point from date of birth (Malina, 2011). In youth sport, chronological age is typically utilised to categorise age groups for competitions/academy squads (Cobley et al., 2009). However, individuals of the same chronological age can differ greatly in terms of biological age (Baxter-Jones et al., 2005), which is defined as the stage of an individual's physical growth in relation to skeletal, sexual or somatic attributes (Tanner, 1990). The LTAD model by Bayli and Hamilton (2004) attempted to correct for this by using biological age, through longitudinal monitoring of somatic variables. This allows practitioners to identify time periods of accelerated growth, regarding peak-height velocity (PHV, the fastest rate of skeletal growth) and peak-weight velocity (PWV, which represents the fastest rate of change in body mass due to the maturation-associated accretion of lean mass) for a specific athlete, and programme training accordingly (Bayli and Hamilton, 2004). The timing and speed of biological maturation is highly individual and is, therefore, an important factor to consider when designing a training programme, as it has been proposed to be more appropriate than chronological age (Lloyd and Oliver, 2012).

The LTAD model suggested by Bayli and Hamilton (2004) has been structured utilising supposed "windows of opportunity", during which certain physiological characteristics are theoretically more responsive to training stimuli. However, this theory lacks evidence due to the diversity and range of components that contribute to a variety of sports (Ford et al., 2011). In contrast, the Youth Physical Development (YPD) model suggests that most physical qualities are trainable throughout maturation, with different mechanisms underpinning adaptations (Lloyd and Oliver, 2012). A meta-analysis revealed that youth athletes may benefit from resistance training (RT) to the same extent, independently of age or biological sex (Lesinski et al., 2016), although a later review suggested that absolute increases in strength were greater during or after PHV than those seen pre-PHV (Moran et al., 2017). Due to dissimilar reports, results should be interpreted with caution. These models provide a guideline for effective training prescription, however differences in training history, biological age and sporting requirements will influence the implementation and resulting adaptations.

2.6 Influence of maturation on strength, power and speed

Maturity status has been identified as a contributing factor in soccer to a variety of different physical performance indicators, such as strength, peak-power, sprinting, change of direction speed (COD), as well as both anaerobic and aerobic performance (Philippaerts et al., 2006, Murtagh et al., 2018). It is important to track biological maturation longitudinally, as those who mature early generally have an advantage over their later-maturing peers due to greater strength and power at that point in time. Additionally, there may be a disproportionate number of young athletes with birth dates in the first quarter of the selection year due to an advanced maturity status, known as the relative age effect (Deprez et al., 2013). Although individuals may be physically dominant during adolescence due to early maturation, this may not continue to be the case when fully mature (Cobley et al., 2009). During adolescence, it is possible to be at very different stages of biological maturation with the same chronological age, thus practitioners need to be aware that individuals within the same cohort may require different training stimuli.

The biological changes that occur from childhood through to full maturity directly influence strength and power via multiple mechanisms. Prior to PHV, increases in strength and power via training are suggested to be a result of improved neuromuscular activation (Ford et al., 2011, Philippaerts et al., 2006, Beunen and Malina, 1988, O'Brien et al., 2009). During this stage of maturation (pre-PHV), relatively low concentrations of circulating androgens, such as testosterone and growth hormone, limit the capacity for skeletal muscle morphological adaptations (Vingren et al., 2010). A significant phase of growth starts in girls and boys between 9-12 and 12-14 years old, respectively. In relation to biological maturation, this equates to approximately 1.5 years prior to PHV (Ford et al., 2011). This period of elevated growth rate lasts until 0.5-1 year post-PHV (Philippaerts et al., 2006), during which time another large increase in muscular power occurs (Ford et al., 2011). This increase in strength occurs in both sexes but more so in boys due to more testosterone being secreted by the testes than the ovaries (Ramos et al., 1998). As testosterone is a potent stimulator of muscle protein synthesis (Bhasin et al., 1996) and inhibitor of muscle protein breakdown (Ferrando et al., 1998), it follows that, during this period, boys more than girls experience a significant accretion of muscle mass, which is the main physiological determinant of maximum strength (Bamman et al., 2000). Muscular strength is the ability to apply force on an external object. As the ability to generate concentric force improves, more force can be applied in the same time frame, resulting in greater power production. As such, similar physiological mechanisms may drive maturation-associated increases in both attributes (Haff and Nimphius, 2012). During adolescence, males exhibit a re-distribution of muscle fibre type from predominantly type I to type II fibres (Vogler and Bove, 1985, Glenmark et al., 1992). Type II fibres have a greater cross-sectional area (CSA), allowing for greater force production than type I fibres as well as a faster cross-bridge attachment/detachment cycle, permitting a faster shortening velocity, thus greater power production (Gilliver et al., 2009). Additionally, an increase in limb length during skeletal growth may simultaneously increase the internal moment arm, thus increasing torque production (O'Brien et al., 2009).

Although there are large increases in strength and power during PHV, the greatest gains tend to occur at the onset of PWV. This is typically between six months to a year after PHV, when the rate of lean mass accruement is greatest (Malina et al., 2004). In relation to muscle morphology, three key factors influence power generation: muscle physiological CSA, muscle fascicle length and muscle fascicle pennation angle (Degens et al., 2009), all of which can be assessed non-invasively via ultrasonography. Briefly, muscle physiological CSA represents the CSA of the total number of muscle fibres, perpendicular to their long axes (Close, 1972). Muscle fascicle length is defined by the number of sarcomeres in series, with longer muscle fibres able to contract faster than shorter fibres. Muscle fascicle pennation angle, i.e. the angle at which fascicles insert into the aponeurosis, increases due to fibre hypertrophy, which is caused by an increase in the number of sarcomeres arranged in parallel (Degens et al., 2009). Muscles with larger fibre CSAs and greater pennation angles produce greater forces, while muscles with longer fascicles and smaller pennation angles have a greater shortening velocity (Jaric and Markovic, 2009, Degens et al., 2009). Interestingly, muscle fascicle length and pennation angle appear to be independent parameters of maturation. There appears to be no difference in muscle fascicle length when normalized to body height and muscle fascicle pennation angle seems to be comparable between children, adolescents and adults (Mersmann et al., 2017, O'Brien et al., 2010, Cunha et al., 2019). However, it should be noted that 2D ultrasound imaging of muscle architecture may not accurately quantify differences in a 3D structure, particularly if extrapolation of fascicle measurements is necessary due to limitations with transducer width (Franchi et al., 2019). Further, there are limited data regarding natural development of the aforementioned physical attributes in terms of longitudinal studies and the impact physical training may have.

To contextualise the above points, increases in strength in the absence of gains in body mass have a greater impact on sports, such as soccer, where athletes propel their own body mass, for example during sprinting and jumping. Alternatively, increases in strength with gains in body mass, which are seen during PWV, may have greater influences where both high force movements and momentum become important in sports, such as rugby when tackling and breaking tackles. Realistically, practitioners should expect increases in absolute strength in both boys and girls as a consequence of lean accretion with maturation, while increases in strength normalised to body mass are more likely the product of specific exercise training (Morris et al., 2018b, Emmonds et al., 2017).

2.7 Response to training

There are no minimum age guidelines for youth participation in RT. National governing bodies for S&C support RT for children when the child is both physically and mentally prepared to engage in sport (Barker et al., 2014, Faigenbaum et al., 2009). This is determined based upon their ability to follow instruction, which is central in ensuring safety (Faigenbaum et al., 2009).

As previously mentioned, adaptations differ according to maturity status in youth cohorts (Ford et al., 2011). Load-velocity profiles can estimate maximal force, peak-power and velocity capabilities in the assessed movement. Meylan et al. (2014a) reported different force-velocity-power (kinetic) responses between biological age groups. Following an eight-week RT intervention pre- and circa-PHV cohorts experienced increases in maximal velocity, which in turn improved maximum power on a machine-squat, whereas the post-PHV group expressed increases in power via improved maximal force and velocity. Benefits were more pronounced in the post-PHV group, particularly where high levels of force and power were required, such as 1RM strength test and 10 m acceleration. Furthermore, Rodríguez-Rosell et al. (2017) implemented a low-load, high-velocity RT intervention, applying the same duration and frequency in Spanish male youth soccer players. All groups (U13, U15, and U17) showed significant improvements in strength, jump and sprint assessments, although the degree of improvement diminished with increasing chronological age. The authors concluded that mature athletes requiring greater relative training loads to maximise adaptations, based on higher relative maximal strength or 1RM (Rodríguez-Rosell et al., 2017). To the authors knowledge no studies of this type currently exist in youth female athletes, which is important to recognise, although the recent strength training guidance for youth and adolescent female soccer players described by Wright and Laas (2016) align with the conclusions of Rodríguez-Rosell et al. (2017).

The training status of those included in interventions and subsequent reviews is an important factor as this may influence the efficacy of an intervention. In a systematic review and meta-analysis by Behm et al. (2017), data indicated that untrained youth experience larger increases in both jump and sprint assessments than their trained counterparts due to inferior baseline results and RT being an unfamiliar stimulus. Behm et al. (2017) proposed that trained youth might adapt through neural and morphological adaptations whereas untrained participants will improve primarily via neural pathways. Untrained youth may encounter a greater learning effect due to their relative inexperience. Therefore, untrained subjects may have to initially improve their motor-unit recruitment before morphological changes can be observed (Behringer et al., 2011). However, a subsequent review by Slimani et al. (2018) reported no significant effect of training status on improvements in squat jump (SJ) performance. Slimani et al. (2018) attributed the variances in findings to differences in methodology, as they focused on vertical jump performance exclusively, whereas Behm et al. (2017) included other parameters, such as strength and sprint speed. When considering this potential greater trainability, methods derived from research in untrained youth populations should be implemented in high-level (trained) youth athlete settings with caution.

Despite a plethora of research examining outcome measures i.e. vertical jump and sprint performance, the training history of the participants involved is key. Additionally there appears to be limited research on the underpinning mechanisms behind these physiological adaptations to RT in adolescent athletes (Legerlotz et al., 2016), thus further investigation is required.

2.8 Resistance training methods

The term 'resistance training' is an all-encompassing term used throughout the literature referring to a variety of methods, primarily machines and/or free-weights. These methods have the capacity to augment both muscle physiological CSA and neural activation, which influence muscle strength and power. This section will focus on interventions primarily utilising free-weight RT as well as the commonly used smith-machine. Although the smith-machine it is not a free-weight exercise, it has a prominent place in strength-training research (Schwanbeck et al., 2009). A number of free-weight training methods can induce positive adaptations in strength and power in youth cohorts, including heavy-strength training, weightlifting (WL), peak-power training and a combination of these (Lloyd et al., 2016, Chaouachi et al., 2014, Chelly et al., 2009). However, different modalities appear to be more beneficial depending on physical characteristics targeted and stage of maturity. Free-weight training refers to a load that moves freely in space, e.g. the barbell back squat, and that is not attached to another support structure. Free-weight RT is seen as a more efficient method of improving strength. This allows for large compound movements coupled with reduced stability, therefore increasing the recruitment of stabilising musculature around the primary muscles as well as superior reproduction of sporting actions, such as vertical jumping (Lesinski et al., 2016). The following sections will aim to examine various free-weight RT modalities in youth populations (particularly youth soccer players) and the influence on strength and power.

2.9 Strength training

Maximal strength underpins athletic muscular performance qualities, such as peak-power, by increasing maximal force potential (Schmidtbleicher, 2004). A significant correlation exists between higher relative training intensities (percentage repetition maximum, %RM) and improvements in maximal strength and motor skill performance in youth populations (Behringer et al., 2011). High levels of strength may influence soccer-specific skills and increase jump height and sprint performance in both youth and senior soccer players (Wing et al., 2018, Comfort et al., 2014). Strength training can be defined as high-load RT relative to an individual's maximal strength (≥80% 1RM), utilising two to four sets at low repetition ranges (≤ 6) (Lloyd and Oliver, 2013). Furthermore, a recent meta-analysis highlighted that the most effective intensity to improve strength in youth athletes is 80-89% 1RM (Lesinski et al., 2016). Training at high percentages of maximal strength has an important role in changing tendon properties in adolescent athletes (Mersmann et al., 2017). For example, increasing the stiffness of the muscle-tendon unit should increase the speed at which the force generated by the muscle is transmitted to the bone, reflected in a higher rate of force development and improved sprint and jump performance (Morin et al., 2006). Moreover, reduced tendon strain via an RT-induced increase in tendon CSA may reduce occurrence of tendinopathies (Couppe et al., 2013). High-intensity RT appears to be a fundamental component of a training regime in order to prepare a young athlete for sports participation via increased proxies of performance and reduced risk of injury.

As mentioned previously, improving an athlete's strength may increase both initial acceleration and maximal sprint speed. Improving initial acceleration may be highly beneficial in soccer with approximately 60 accelerations occurring per match (Murtagh et al., 2019). Impulse (the product of force multiplied by time) is a key determinant of acceleration. However, as time is restricted during the ground contact phase, maximising force production within this time window is vital (Hunter et al., 2005). There is a strong correlation between absolute squat strength and sprint performance due to an associated greater rate of force development (RFD) and in turn, ground reaction force (Cronin and Hansen, 2005, Seitz et al., 2014). Thus maximal strength has been identified as an important factor to maximise initial acceleration, where ground contact times >200 milliseconds enable greater force transfer (Cronin and Hansen, 2005). These measures require the recruitment of the lower body musculature in one coordinated movement; consequently, the squat has become the cornerstone of many strength-training programs (Wisloff et al., 2004, Chelly et al., 2009).

When programmed appropriately, adolescents respond positively to high-intensity RT (>80% 1RM). Keiner et al. (2013) compared front and back squat strength in adolescent male soccer players and weightlifters. As expected, weightlifters outperformed soccer players at all age groups. Notably, in the 17-19 years age group, youth weightlifters demonstrated 2.1 ± 0.1 x bodyweight 5RM back squat in comparison to the soccer players who produced a 1.3 ± 0.2 x bodyweight 4RM. Importantly, the weightlifting group completed the test to full-depth and for an extra repetition, whereas the soccer players were limited to parallel depth (thighs parallel to the floor). The full-squat results in a lower load compared to the parallel squat, meaning that differences in strength between the two cohorts may be greater than reported (Pallarés et al., 2019). These studies highlight the efficacy of high-intensity RT in youth populations.

Training programs consist of numerus variables, more than just exercise selection. When designing a RT programme two key components are primarily considered, training volume and training intensity. There are multiple ways to calculate both components. Volume may be quantified via a repetition, volume load and volume index method and intensity as percentage of 1RM or average load for an exercise / overall session to name a few (Haff, 2010). In a sport setting, the demands of competition and the time available may influence these variables, meaning time efficient training methods are of great value. When working with both male and female youth athletes, biological maturity and phases of accelerated growth must also be considered as part of LTAD (Lloyd et al., 2014b).

When the training aim is to build strength in youth athletes, high-intensity RT (>80% 1RM) has been suggested to be the most effective method and benefits can become apparent within a small timeframe (Lesinski et al., 2016). Chelly et al. (2009) implemented an eight-week, twice-weekly squat training program, comprising three sets at intensities between 80 to 90% 1RM in U18 male soccer players with no RT experience. These loads were chosen, as they are suggested to increase RFD, particularly in weaker/untrained participants (Schmidtbleicher, 2004, Haff and Nimphius, 2012). Along with a low RT volume, there were significant increases in peak-power, 40 m sprint, SJ and repeat bounding performance with no increases in thigh CSA, thus the adaptations were suggested to be neurological. Despite improvements in SJ, there were no significant improvements in countermovement jump (CMJ). Speirs et al. (2016) reported similar results after a five-week intervention, utilising 75% to 92% 1RM in U19 British rugby union players with at least one year of RT experience. Although shorter in duration and a similar weekly RT volume to Chelly et al. (2009), there were significant increases in back squat 1RM, 40 m sprint time and agility performance. In combination, there is evidence to suggest high-intensity RT with low training volume can have an impact on acceleration, jump and COD in a short time period (Table 1), especially if the stimulus is unfamiliar.

Alongside training intensity, the volume of training must be considered in the athletic development of youth soccer players. Both Hammami et al. (2018) and Styles et al. (2016) implemented twice-weekly high-intensity RT interventions in adolescent male soccer players over eight and six weeks respectively. Both studies reported significant improvements in strength and 20 m sprint time. The largest improvements in the study by Hammami et al. (2018) occurred in 5 m (11.1%) and 10 m (9.4%) sprint tests, which is in line with previous research

(Comfort et al., 2014). Furthermore, the largest improvements in agility were observed in tests that required a greater number of direction changes. The greater number of accelerations and decelerations associated with multiple direction changes allow for more instances, where greater strength could influence the test outcome. Hammami et al. (2018) also reported significant increases in both SJ and CMJ. This is in contrast to previous research where only increases in SJ were seen (Chelly et al., 2009). Although both interventions incorporated high-intensity loads between 70 to 90% 1RM, the main difference in protocol was training volume. Where Chelly et al. (2009) implemented eight sets per week totalling 18 repetitions, Hammami et al. (2018) completed 42 sets, totalling 186 repetitions. Training volume has been highlighted as an important stimulus for adaptation in athletic populations (Peterson et al., 2004). However, despite a far lower training volume than Hammami et al. (2018), Chelly et al. (2009) also produced significant increases in 1RM half-squat strength, squat jump, as well as 5 m and 40 m sprint performance in the same population. Irrespective of volume, both Chelly et al. (2009) and Hammami et al. (2018) attributed the improvements to neural adaptations, with neither study finding significant changes in thigh CSA, which is in line with a previous review by Ford et al. (2011). A multitude of factors can influence adaptation including previous RT experience, biological age as well as training volume and intensity (Lesinski et al., 2016, Behm et al., 2017, Moran et al., 2017) but it appears that higher training intensities (>80% 1RM) and low volume can lead to similar increases in performance as low intensity, high volume (Table 1).

2.10 Long-term training

The previously mentioned studies were all short in duration (e.g. ≤8 weeks) in chronologically older youth athletes, where biological growth might not be significant enough to affect the RT-induced changes in strength or power. Sander et al. (2013) conducted a 2-year intervention in young male soccer players in Germany to observe the influence of regular RT alongside soccer training on strength and sprint performance. At the start of the intervention, groups consisted of players from U13, U15 and U17 squads matched with control groups performing only soccer training. Key lower-body exercises included both the front and back squat, as well as the deadlift, all at an intensity of 75 to 90% 1RM. The largest effect size was seen in the U13s for both squat tests (back squat ES = 2.0, front squat ES = 1.9). This is supported by Lesinski et al. (2016), where larger effect sizes were seen in younger (≤13 years) than adolescent males (14–18 years) (ES = 1.35 vs. 0.91). Strength training also significantly improved 30 m sprint performance at all 5 m intervals when compared to the control group in both the U13s and U15s squads. The U17s failed to improve 10 m sprint performance, which may have been due to more variability in the percentage change (Sander et al., 2013). Of the control groups, the U13s and U15s improved 15-30 m and 10-30 m sprint interval performance, thus suggesting maturation and/or soccer training influenced these variables. However, the U17s control group did not improve any sprint times. Because this group would not be expected to demonstrate significant maturation-related growth, these results suggest that soccer-specific training does not improve sprint performance, and that the improvements in the U13 and U15 control groups were due to maturation-related growth, not soccer-specific training (Sander et al., 2013). However, maturity status was not assessed and therefore could not be used a co-variate in subsequent analysis to delineate the RT effect from the soccer training effect. Nonetheless, Sander et al. (2013) highlights that long-term RT is effective in improving strength and in turn sprint performance in youth soccer players from 5 m to 30 m. When youth soccer players are systematically exposed to high-intensity RT over a prolonged period of time (e.g. ≥12 months) there can be significant increases in maximum strength as well as sport-specific assessments, such as vertical jumps and sprinting performance (Table 1). The literature suggests that benefits can be seen at all stages of biological maturity, therefore high-intensity RT should be included throughout an athlete’s development.

Table 1: Results of commonly used performance measures from referenced high-intensity strength training studies.

Study	Sport / Sex	Training Type	Age (yr) / Squad	Volume (Sets / reps / intensity)	Total weeks / sessions per week		1RM Strength Back squat (kg)	Squat Jump Height (cm)	CMJ Height (cm)	10m Sprint (s)	20m Sprint (s)
Chelly et al. (2009)	Soccer / Male	RT: Back squat	RT: 17 ± 0.5	3 / 2 - 4	8 / 2	Pre	105 ± 14	31.5 ± 4	33.8 ± 4		
				80 – 90% 1RM		Post	142 ± 15*	34.6 ± 3*	36.3 ± 3		
Hammami et al. (2018)	Soccer / Male	RT: Back squat	RT: 16.2 ± 0.6	4 - 7 / 3 - 8	8 / 2	Pre	99.8 ± 7.5	36 ± 3	37 ± 5	1.92 ± 0.09	3.24 ± 0.03
				70 – 90% 1RM		Post	125.1 ± 4.7*	43 ± 2*	42 ± 4*	1.73 ± 0.01*	3.06 ± 0.02*
Sander et al. (2013)	Soccer / Male	RT: Back + front squat	Under 17s	5 / 4 - 10	2 years / 2	Pre	61.2 ± 10			1.746 ± 0.042	3.020 ± 0.067
				4 -10 RM		Post	120.4 ± 11.4*			1.712 ± 0.045*	2.961 ± 0.058*
			Under 15s			Pre	52 ± 10.7			1.802 ± 0.082	3.120 ± 0.140
						Post	113 ± 15.2*			1.731 ± 0.078*	2.984 ± 0.126*
			Under 13s			Pre	25 ± 9.6			1.917 ± 0.056	3.375 ± 0.101
						Post	90 ± 13.5*			1.813 ± 0.078*	3.194 ± 0.142*
Styles et al. (2016)	Soccer / Male	RT: Back squat + Romanian deadlift	18.3 ± 1.2	3 – 4 / 3 - 5	6 / 2	Pre	125.4 ± 13.78			1.83 ± 0.05	3.09 ± 0.07
				90% 1RM		Post	149.3 ± 16.62*			1.78 ± 0.05*	3.05 ± 0.05*

* Significant difference

Resistance training, RT; Repetition Maximum, RM; Countermovement jump, CMJ;

2.11 Weightlifting

As previously stated, high levels of muscular power are important for soccer performance (Young, 2006). Training to increase maximum strength augments the capacity to develop power (Plisk and Stone, 2003), and a holistic training programme that incorporates maximum strength and WL variations can facilitate this transfer (Hori et al., 2005). In WL movements, the emphasis is typically on movement speed, at moderate to heavy loads. As a result, WL can increase motor-unit recruitment and therefore RFD (Garhammer and Gregor, 1992). The two primary WL lifts are the clean and jerk and the snatch, with derivatives such as the hang-power clean involving high force and velocity outputs (Hori et al., 2005), which are the components of power. Mechanically, WL movements align with the principle of specificity by replicating kinematic and kinetic characteristics of the vertical jump (Canavan et al., 1996). In contrast to traditional RT methods, there is limited research on WL in both soccer and youth populations.

Despite limited research in these areas, results appear to be promising at each stage of biological maturity. Chaouachi et al. (2014) compared WL to traditional RT and plyometric training (PLYO) in 10-12 year-old males for a period of 12 weeks. The RT intervention utilised squats and lunges, whereas the WL program implemented clean and snatch variants. Both groups followed identical set and repetition schemes in an attempt to equalise training volume (i.e. 1-3 sets x 8-12 reps). The results showed no clear differences between RT and WL in terms of increases in 5 m acceleration, 20 m flying sprint or vertical CMJ performance but there was a likely benefit for WL in horizontal CMJ distance. Importantly, there were larger effect sizes for the WL group when compared to the PLYO group for changes in all strength and power variables. Subjects had no previous RT experience and the concentric phase of the squat was not explosive, which should be considered when interpreting these results. In an adolescent cohort with limited RT experience, Channell and Barfield (2008) compared the effect of WL with traditional RT on vertical CMJ performance. Each intervention group shared a number of common exercises, while completing three group-specific core lifts. Similar to Chaouachi et al. (2014), after eight-weeks, both groups saw similar improvements in vertical CMJ performance. Taken together, these results suggest WL may be more effective at improving muscular power and subsequent athletic tasks than PLYO in young populations.

Following a period of WL, Channell and Barfield (2008) suggested improvements in strength and power seen were likely due to neural adaptations, i.e. greater neuromuscular activation of the agonists, synergists and stabilizers, all contributing to improve technique, as well as muscular force and contraction velocity. Arabatzi and Kellis (2012) examined differences in EMG activity between WL and traditional RT to explain why WL may produce better jump performance. They implemented an eight-week high-intensity (80-90% 1RM) intervention in resistance-trained male students, comparing WL variants to traditional RT. They concluded that greater improvements in SJ, CMJ and drop jump (DJ) with WL were due to increased agonist muscle (rectus femoris) activation, reduced antagonist muscle (biceps femoris) co-activation and an increased leg stiffness. The RT group also showed an increased leg stiffness, seen as a decrease in the body's centre of mass during the eccentric phase of a drop jump test. Although there was an increased activation of both agonist and antagonist muscle groups. In powerful actions, such as jumping, increased antagonist muscle co-activation may reduce velocity towards the end of the movement, limiting power production (Baker and Newton, 2005). The results of Arabatzi and Kellis (2012) highlight that ballistic RT in the form of WL, may produce a more beneficial neural activation pattern of agonist and antagonist muscles that is not prevalent with traditional RT. Thus, incorporating WL into a training program appears to be important for improving ballistic actions.

Weightlifting is a training method that has the capacity to improve muscular power by utilising the explosive lower body triple extension, which is essential for sprinting and jump variants in sports, such as soccer (Young, 2006). Despite the complexity of WL and lack of research in youth female athletes, it can be an effective method to improve athletic qualities in young athletes at each stage of biological maturity (Lloyd et al. (2012), Table 2), with minimal injury risk when appropriately supervised (Chaouachi et al., 2014).

Table 2: Results of commonly used performance measures from referenced weightlifting training studies.

Study	Training Type	Age (yr) / Sex	Volume (Sets / reps / intensity)	Total weeks / sessions per week		1RM Strength (kg)	CMJ Height (cm)
Chaouachi et al. (2014)	WL	11.1 ± 1 / Male	1 - 3 / 8 - 12	12 / 2	Effect Size		Large
	RT	11.1 ± 1	Not specified		Effect Size		Small
Channell and Barfield (2008)	RT	15.9 ± 1.2 / Male	3 -5 / 3 - 10	8 / 3	Pre	132.6 ± 30.94	47.2 ± 9.5
			75-95% 1RM		Post	128.3 ± 26.01	48.3 ± 8.9
	WL				Pre	144 ± 41.6	57.5 ± 7.2
					Post	161.6 ± 29.3	60.1 ± 3.9

* Significant difference

Weightlifting, WL; Resistance training, RT; Countermovement jump, CMJ; Repetition maximum, RM

2.12 Peak-power training

Training methods focusing on low-load and high-velocity movements are suggested to be beneficial for sprinting as well as vertical and horizontal jump performance, particularly in pre-PHV soccer players (Negra et al., 2016). Much like WL, training of this nature centres on peak-power production, which can occur at different intensities according to the exercise. Cormie et al. (2007) reported peak-power with external loads occurred at 0%, 54% and 80% of 1RM jump squat, back squat and power-clean, respectively. However, always training at peak-power may limit further improvements, as strength would remain underdeveloped (Haff and Nimphius, 2012). This is important, as greater levels of strength relative to body mass correlate strongly to CMJ height (Nuzzo et al., 2008).

This method has been suggested to improve strength and power via neural mechanisms, making it ideal for pre-PHV athletes, when morphological adaptations are limited. However, post-PHV, increases in peak-power occur predominately via an increase in force generation (Meylan et al., 2014a). Thus, training at peak-power would result in a sub-optimal training load. In a long-term study, Gonzalez-Badillo et al. (2015) implemented a twice-weekly, high-velocity RT intervention in Spanish academy soccer players, where they utilised low-volumes of squats at loads of ~45-59% 1RM combined with jump and sprint training. Interestingly, after six months of RT, both the U16 and U18 groups matched or outperformed the U21 control group in the isoinertial squat strength test, vertical CMJ and 20 m sprint performance tests. Thus, it could be argued that six months RT produced similar or greater gains than five years of soccer training and maturation combined. However, a limiting factor was that there were no measures of maturity and no age-matched control groups, as maturation will have likely influenced these results. Rodríguez-Rosell et al. (2017) employed a similar design but incorporated age matched controls, together with U13, U15 and U17 male soccer players that had no prior RT experience. However, the intervention was much shorter in duration. Over six weeks, a combination of high-velocity full squats (45-60% 1RM), jumps, sprints and COD drills significantly improved isoinertial squat load at 1.00 $m \cdot s^{-1}$ (~56% 1RM), vertical CMJ and 20 m sprint performance in all groups, with the percentage increase reducing with advancing chronological age. Where the U13s and U15s were significantly better than their age-matched control group in all measures post training, the U17s outperformed their control group in the sprint and strength assessments only (Table 3). The results presented here can be explained by the different kinetic responses that increase peak-power at different stages of biological maturity (Meylan et al., 2014a). While pre- and mid-PHV individuals appear to increase peak-power primarily via increasing movement velocity, post-PHV individuals appear to do this principally by increasing force output (Meylan et al., 2014a). While there were increases in strength in the U17 age group the different kinetic responses from reported by Meylan et al. (2014a) suggest that low-load, high-velocity training is sub-optimal with more biologically mature individuals. Additionally, benefits from this method are potentially due to limited/no-previous RT experience, thus, it is less likely to have an effect with increased training age. This suggests that low-load, high-velocity training may still be beneficial for younger as well as more mature soccer players, the incorporation of higher-intensity strength training is likely required to elicit greater improvements in performance.

Table 3: Results of commonly used performance measures from referenced high-velocity, low-load training studies.

Study	Sport	Training Type	Age (yr) / Squad / Sex	Volume (Sets / reps / intensity)	Total weeks / sessions per week		1RM Strength (kg)	CMJ Height (cm)	10m Sprint (s)	20m Sprint (s)
Gonzalez-Badillo et al. (2015)	Soccer	Back squats + Loaded CMJ	U16: 14.9 ± 0.3	2 - 4 / 6 - 8	26 / 2	Pre		35.4 ± 3.9		2.99 ± 0.10
				~45 - 60% 1RM		Post		39.1 ± 4.9*		2.97 ± 0.09
			U18: 17.8 ± 0.4			Pre		38.4 ± 3.0		2.96 ± 0.10
			/ Male			Post		41.3 ± 4.5*		2.92 ± 0.10*
Rodríguez-Rosell et al. (2017)	Soccer	Back Squat	U13: 12.6 ± 0.5	2 - 3 / 8 - 4	6 / 2	Pre	38.6 ± 17.9	26.6 ± 4.3	1.9 ± 0.06	3.38 ± 0.12
				~45 - 60% 1RM		Post	57.2 ± 15.9*	29.8 ± 3.9*	1.84 ± 0.07*	3.29 ± 0.12*
			U15: 14.6 ± 0.5			Pre	64.0 ± 14.5	32.4 ± 5.2	1.78 ± 0.06	3.13 ± 0.11
						Post	81.7 ± 16.6*	35.7 ± 6.1*	1.75 ± 0.06*	3.09 ± 0.11*
			U17: 16.5 ± 0.5			Pre	91.2 ± 12.9	37.8 ± 5.1	1.72 ± 0.06	2.99 ± 0.40
			/ Male			Post	103.5 ± 17.3*	40.0 ± 5.6*	1.68 ± 0.06*	2.95 ± 0.09*

* Significant difference

Countermovement jump, CMJ; Repetition maximum, RM

2.13 Combined methods resistance training

As part of a holistic RT programme, it is unrealistic to implement one method in isolation as seen in certain studies (Chaouachi et al., 2014, Chelly et al., 2009, Gonzalez-Badillo et al., 2015). Aspects of the force-velocity curve are involved in many sporting actions. The synergistic benefits of a combined-method approach on improvements in sprint performance have previously been acknowledged. In a systematic review and meta-analysis, the largest effect sizes on sprint performance were seen when back squat, loaded SJ/CMJ and PLYO were implemented concurrently (ES = -1.20) (Seitz et al., 2014). This was much greater compared to back squat (ES = -0.81) and loaded jump training (ES = -0.29) alone. A similar pattern for training intensity became apparent with a combination of high (>85% 1RM) and very light (<40% 1RM) loads produced the largest effect size (ES = -0.82). While lower effect sizes were seen when high (% RM, ES = -0.52) or low (40-59.9% 1RM, ES = -0.16) loads were used in isolation. Interestingly, medium loads (60-84.9% 1RM, ES = -0.97) in isolation produced the largest ES. With regards to volume, there was a moderate relationship with greater training frequency and sprint performance ($r = 0.50$; $p = 0.001$) and longer rest intervals ($r = -0.47$; $p \leq 0.001$) but no correlations for the number of exercises, sets or repetitions per set. Seitz et al. (2014) suggested that a combination of high-, medium- and very light-loads was the most effective approach to improve sprint performance. Although the participants in the review by Seitz et al. (2014) (13-25 years of age) did not include any pre-PHV but continued into adulthood, it is important to note that Seitz et al. (2014) reported a non-significant correlation for both age and height regarding the effect of RT on sprint performance. This demonstrates that a variety of external loads, and therefore velocities are beneficial at all age groups.

Recently, the combination of both high- and low-load RT within a single training session has gained popularity due to its time efficiency, often referred to as complex training (CT) (Ebben, 2002). A systematic review found CT to be significantly more effective at improving 20 m sprint times and 1RM strength compared to other RT methods but acknowledged that single study outliers may have influenced this (Bauer et al., 2019). Although no significant differences were reported concerning changes in jump, 5 m, 10 m, 30 m and 40 m sprint performance between CT and other methods, the improvements were associated with lower training volumes. Additionally, the authors proposed that the potentially novel exposure to high-intensity RT might have been responsible for improvements following CT, as exposure to high-velocity movements would come from sport-specific training. Therefore, youth soccer players may benefit from training at a range of intensities as part of their LTAD.

Further, in youth soccer players, it is necessary to consider the influence of maturity status on the effectiveness of CT due to the different mechanisms responsible for training adaptations at each stage of maturity (Ford et al., 2011). Both Lloyd et al. (2016) and Radnor et al. (2017) examined the adaptation to traditional RT, PLYO and CT in untrained pre- and post-PHV groups. In both short-term interventions, PLYO was a more effective training method to improve jump and sprint assessments in the pre-PHV groups, while CT was more effective at post-PHV (Lloyd et al., 2016, Radnor et al., 2017). Radnor et al. (2017) continued to specify that CT and RT were more effective for improving variables that required high concentric force production, such as initial acceleration, whereas PLYO was more effective at improving peak running velocity and reactive strength index (Radnor et al., 2017). Further, combining training approaches has greater benefit than a training method in isolation. In post-PHV women soccer players, Lesinski et al. (2021) implemented a twice-weekly, season-long training programme, incorporating high-intensity RT, peak-power training and plyometrics alongside regular soccer training. This resulted in larger improvements in lower-body strength, DJ performance and sprint speed than a low-velocity, high-repetition RT programme that has previously been considered a "female preferred" training approach (Reynolds et al., 2012). Although the RT protocol differed from the suggestions of Lesinski et al. (2016), the results supported the incorporation of high-intensity RT, particularly post-PHV, where greater increases in maximal force, and thus peak-power are possible (Meylan et al., 2014a).

To the author's knowledge, only one long-term study has examined WL as part of a CT program in youth athletes. Pichardo et al. (2019) examined the effect of incorporating WL into a 12-month RT programme on isometric mid-thigh pull (IMTP), vertical CMJ, horizontal CMJ and 30 m sprint performance. The original RT programme (CRT) already comprised traditional RT and plyometric movements (CRT). In the WLRT group, conventional exercises, such as the deadlift and a plyometric movement were replaced with WL exercises for 28 weeks (WLRT), split into initial light-load technique training followed by 14 weeks at higher training intensities. Both groups significantly improved IMTP, vertical CMJ, horizontal CMJ and sprint performance (10–30 m) to a similar extent post-training. However, the timing of these changes varied between groups, with both groups increasing absolute IMTP force mid-way through the training period, but only the CRT group displayed improvements in both 20 m and 30 m sprint tests. From mid-way, training intensity increased in both groups, and from mid- to post-training, there were greater percentage improvements in all jump and sprint measures compared to pre- to mid-training, particularly in the WLRT group. The authors proposed that the increased intensity aided the transfer of improved strength into improved power. The study was not without its limitations, the absence of a control group and the inability to distinguish between the effects of training *vs.* biological maturation due to no measure of maturity. However, with this study, Pichardo et al. (2019) demonstrated the importance of developing strength prior to power, and that longitudinal studies are required to demonstrate the translation of strength into power.

The results from Lloyd et al. (2016), Radnor et al. (2017) and Pichardo et al. (2019) highlight the importance of incorporating both high-force and high-velocity training to improve a range of strength and power measures (Table 4). Improving maximum force production becomes increasingly important post-PHV, due to the maturation-associated muscle growth allowing greater force outputs to improve peak-power (Ford et al., 2011, Meylan et al., 2014a). When incorporated alongside loaded ballistic exercises, research would suggest there are greater improvements in powerful dynamic sporting actions post-training, providing strength has already been developed.

Table 4: Results of commonly used performance measures from referenced complex training studies.

Study	Sport	Training Type	Age (yr) / Sex	Volume (Sets / reps / intensity)	Total weeks / sessions per week		Squat Jump Height (cm)	CMJ Height (cm)	10m Sprint (s)	20m Sprint (s)
Lloyd et al. (2016)	High-school physical education	Pre-PHV RT	12.6 ± 0.3	RT: 3 / 10	6 / 2	Pre	22.3 ± 4.9		2.3 ± 0.2	3.4 ± 0.3
			PHV: -1.4 ± 0.6	75% 1RM		Post	24.8 ± 4.6*		2.2 ± 0.2*	3.4 ± 0.3
		Pre-PHV CT	12.7 ± 0.3			Pre	24.1 ± 4.3		2.2 ± 0.2	3.4 ± 0.3
			PHV: -1.5 ± 0.7	CT: 2-5 / 3 - 10		Post	28.2 ± 4.6*		2.1 ± 0.2*	3.3 ± 0.3*
		Post-PHV RT	16.3 ± 0.3			Pre	32.4 ± 5.0		1.9 ± 0.1	2.8 ± 0.2
			PHV: 1.3 ± 0.3			Post	34.6 ± 5.1*		1.8 ± 0.1*	2.7 ± 0.2
		Post-PHV CT	16.2 ± 0.3			Pre	33.2 ± 5.5		1.9 ± 01	2.8 ± 0.2
			PHV: 1.3 ± 0.6 / Male			Post	37.4 ± 5.4*		1.8 ± 0.1*	2.6 ± 0.2*
Radnor et al. (2017)	High-school physical education	Pre-PHV RT	12.6 ± 0.3 PHV: -1.4 ± 0.6	RT: 3 / 10 75% 1RM	6 / 2	Change %	+16.6 ± 11.7 %*		+3.1 ± 2.3 %*	
		Pre-PHV CT	12.7 ± 0.3 PHV: -1.5 ± 0.7	CT: 2-5 / 3 - 10		Change %	17.7 ± 5.4 %*		+3.34 ± 1.83 %*	
		Post-PHV RT	16.3 ± 0.3 PHV: 1.3 ± 0.3	75% 1RM		Change %	1.4 ± 2.2 %*		0.37 ± 0.43 %	
		Post-PHV CT	16.2 ± 0.3 PHV: 1.3 ± 0.6 / Male			Change %	12.9 ± 3.9 %*		2.68 ± 1.10 %*	
Pichardo et al. (2019)	High-school performance program	WLRT	13.9 ± 0.6 MO: 0.1 ± 0.9	1-5 / 2-12 Not stated	28 / 2	Change %		+17.1 ± 23.4 %*	-24.8 ± 3.4 %*	-24.0 ± 2.9 %*
		RT	14.0 ± 0.5 MO: 0.3 ± 0.6 / Male			Change %		+9.1 ± 19.6 %	-26.1 ± 11.0 %*	-25.3 ± 3.6 %*
Lesinski et al. (2021)	Soccer	CT	15.4 ± 0.6	CT: 1-6 / 3-8 50-95% 1RM	1 Season / 2	Change %		+1.0*	-0.07*	-0.12*
		RT	15.3 ± 0.5 / Female	RT: 1-3 / 20-40 50-60% 1RM		Change %		+4.6*	-0.04*	-0.05

* Significant difference

Resistance training, RT; Complex training, CT; Weightlifting and Resistance training, WLRT; Peak-height velocity, PHV: Countermovement jump, CMJ: Isometric mid-thigh pull, IMTP: Repetition maximum, RM

2.14 Summary and Conclusion

The aim of this review was to critically appraise the scientific literature regarding the use and efficacy of RT in soccer, with specific focus on youth soccer. Resistance training is an important aspect of a young athlete's development and is a safe and effective method when appropriately planned and supervised (Barker et al., 2014). Based on the available evidence in the literature, the objective of this review was to provide recommendations on best practice regarding intensity and volume of RT/WL in youth athletes with specific reference to maturity status, which we have highlighted during the review and summarised below (Figure 1). Irrespective of age or sex, following an initial focus on fundamental movement techniques, such as the squat and hip-hinge, strength development can then be periodised within a LTAD programme. As strength fundamentally underpins power, it is important to first develop this, while concurrently refining the technical skill required for WL. Physically mature soccer players should undertake high-intensity RT to maximise neuromuscular adaptations to RT, leading to changes in physical performance (Figure 1).

It is important to consider that RT is a component of a larger soccer-specific training structure, where time availability for RT/WL may be limited. As soccer is the most participated sport worldwide (FIFA, 2006), it is important to understand current S&C practice in soccer on a global scale and in both men and women players. However, the currently literature is limited to mainly first team men soccer players, in very specific global regions with minimal information regarding other demographics, such as academy or women's football. Expanding this would help understand the current landscape of S&C in soccer as well as identify any potential limitations practitioners face, in order to design both ecologically valid and scientifically supported training interventions.

Chronological age (years)		10	11	12	13	14	15	16	17	18	19	20	21	>21
	in boys	10	11	12	13	14	15	16	17	18	19	20	21	>21
	in girls	8	9	10	11	12	13	14	15	16	17	18	19	>19
Biological age		Pre-PHV				PHV				Post-PHV				
Training focus	Functional movements	FOUNDATIONAL MOVEMENTS												
	Weightlifting		TECHNICAL DEVELOPMENT				INTRODUCTION TO LOAD			HIGH-INTENSITY LOADING				
	Traditional resistance training				INCREASE IN TRAINING INTENSITY									
Recommendations	Exercise perscription	General strength Emphasis on functional movements 1-3 sets x 8-10 reps			Strength development increases in training intensity 2-3 sets x 6-8 reps 70-80% 1RM					High intensity resistance training Traditional and weightlifting movements 3-4 sets x 1-6 reps 70-100% 1RM				
	Weekly frequency	1 session per week			2 sessions per week					2 sessions per week				

Figure 1: Evidenced based recommendations for the developing strength and power within a holistic long-term athletic development plan in youth athletes. Grey refers to a lower focus, green refers to a greater training focus.

PHV: Peak-height velocity; reps, repetitions; RM, repetition maximum

Chapter Three – General Methodology

3.1 Introduction

To gain a better understanding of current strength and conditioning (S&C) practice in soccer an online survey was utilised to maximise the number of potential participants. This data collection tool was employed in chapters four, five and six. Participants' responses were compared in distinctly different ways in each chapter to gain a greater insight into current S&C practice in different global regions (chapter four), between S&C coaches working with men and women soccer players (chapter five), and between S&C coaches working with first team and academy soccer players (chapter six).

3.2 *Survey design and data collection*

The survey was titled, "*Current Practice of Strength and Conditioning Coaches in Soccer*" and was based on previous works of a similar design (Duehring et al., 2009, Jones et al., 2016). This survey aimed to recruit practitioners involved with the provision of S&C services with either first team or academy squads at soccer clubs worldwide. Respondents in this data set worked for soccer clubs in Europe, North America and South America. The study received ethical approval from the Liverpool John Moores University Research Ethics Committee (ethics code: 19/SPS/046).

The online survey platform, 'Jisc Online Surveys' (formerly Bristol Online Surveys; *Joint Information Systems Committee, Bristol, UK*) was used to create the questionnaire and collect answers anonymously. The survey was reviewed for content validity via initial discussions within the research team, and subsequently adjusted following pilot testing with S&C practitioners (n = 3) and external academics (n = 3). Those piloting the study had experience working with first team and/or academy soccer players in either men's or women's professional soccer clubs in the UK. Subsequently, there was a reduction in the number of questions, as well as rewording of others to increase practicality of the research tool, which was approved by the research team (Appendix 1). The survey was then translated into French, Spanish, German, Italian and Portuguese to increase the global accessibility to practitioners in soccer. This was initially performed using Google Translate (*Google*, *California*, *USA*), then corrected by associates of the research group, who were native speakers of these specific languages. The online questionnaire took 17±7 minutes to complete and comprised six sections: (i) academic qualifications and S&C coaching experience; and their preferred methods for (ii) physical testing; (iii) strength and power development; (iv) plyometric training; (v) speed development; and (vi) periodization. Data were collected between 01 December 2019 and 01 July 2020. The survey utilised a variety of answer formats throughout the questionnaire to help standardise answers, such as single choice questions (participant descriptive information) and multiple choice (training modalities). These formats were paired with an open text box for alternative answers if necessary. Other questions were set as open text answers due to the range of answers possible such as the sets, repetitions and intensity prescribed for resistance training. The different question formats can be viewed in appendix 1. The survey was distributed both directly via email (where email addresses were available online or known to the researchers) and indirectly via social media (e.g., Twitter, Linked-In, posted on three occasions over four months). These are methods previously used when collecting data from coaches (Nosek et al., 2020). Participants were encouraged to share the link with their professional networks to increase distribution of the survey (Morgan, 2008). Responses were not limited to one per soccer club due to the potential for multiple squads within a single club. Due to using indirect data collection methods to distribute the survey, it was not possible to calculate response rate. The cover page was accessed 1597 times and 205 individuals started the survey but did not finish, however, it is not possible to identify if the same individual accessed/started the survey multiple times.

3.3 *Participants*

To be eligible to take part in the survey participants had to be directly involved with the delivery of S&C support at their soccer club within men's or women's first team or academy settings at the time of responding to the survey in order to ensure that responses were reflective of current practice. A total of 177 participants completed the survey and all participants' responses were quality controlled prior to being included in the subsequent analysis. If key data were missing, such as whether participants worked with men's or women's, first team or academy squads, these participants were excluded from the study (*n*=7). Thus, a final sample of 170 participants' responses were subsequently analysed. Of the n = 92 participants, who worked with first team squads (either men's or women's), n = 22 were able to indicate whether that were based at a top division (n=10, 46%), second division (n=5, 23%), third division (n=1, 4%) or fourth division (n=6, 27%). The participants who worked within academy settings (n=78), worked with players with ages ranging from under nine to under 23 years-old, and 58% worked with two or more age groups. Of the n = 24 S&C coaches working at a men's academy in England, n = 24 were able to indicate whether that academy was classed as a category 1 (n=10, 42%), category 2 (n=7, 29%) or category 3 (n=7, 29%). Participants comprised S&C/fitness coaches (*n* = 115), sport scientists (*n* = 46) and technical coaches (*n* = 9). The global reach of this survey included responses from the UK (n=70, 41%), Spain (n=7, 4%), Germany (n=6, 4%), Italy (n=3, 2%), Portugal (n=1, 1%), Brazil (n=65, 38%), Uruguay (n=4, 2%), and the USA (n=14, 8%). All participants provided informed consent prior to completing this survey study, which was approved by Liverpool John Moores University's Research Ethics Committee (approval number: 19/SPS/046).

3.4 *Statistical analysis and statistical analysis*

Raw survey data were initially exported into Microsoft Excel (*Excel 2019, Microsoft, Washington, USA*) to reorganise, prior to being imported into SPSS (*version 26, IBM, Armonk,* *USA*) for statistical analysis. For exercise prescription, a sub-selection of data was analysed. Due to the interaction between sets, repetitions and intensity, only answers that provided all three elements were used for statistical analysis. When ranges were provided in a response e.g., session duration 30-60 minutes, the mean of the two points was used for analysis. Due to the wide range and individual variations reported for exercise selection, the raw data were coded into more general groups by movement pattern. This allowed for a quantitative comparison of exercise prescription, e.g., back squat was categorised as a bi-lateral squatting pattern.

To assess between group differences for nominal data, frequency assessment was performed via Pearson's chi-square test of independence, with results reported as percentages of the total group response. To assess between group differences for ratio data (e.g., session duration), a Kruskal-Wallis test was used due to the data not being normally distributed. Statistical significance was set at $p < 0.05$.

Limitations

It is important to acknowledge the limitations of the outlined survey, which is used as part of chapter four, five and six. The design of this survey was not based on a systematic approach, such as the Delphi method but on previously published research that also investigated current S&C practice (Jones et al., 2016, Simenz et al., 2005, Ebben et al., 2004, Duehring et al., 2009). The data gathered using this survey focused on describing the "what" around current S&C practice. However, this approach does not consider the wider context in which the responses were given, also known as the "why". For example, are practitioners programming decisions based their philosophy or the constraints of their environment? This may make interpreting the results of future analysis more challenging. To advance upon the findings presented in chapters four, five and six, potential semi-structured interview questions have been presented, which may be used in future studies to gain a better understanding of the wider context in which decisions around S&C are made. Qualitative research, such as the inclusion of semi-structured interviews (as mentioned above), may provide an opportunity to understand more complex insights into specific areas such as what influences the quantitative responses in survey data. Thus, to build upon the findings within this thesis, semi-structured interviews could be used to gain an understanding of the key factors that influence S&C coaches decisions relating to their practice. Similar to previous work exploring behaviour in elite sports nutritionists (Bentley et al., 2019), this approach allows for focused investigation into key behavioural components as well as open discussions relating to the participants own opinions (Sparkes and Smith, 2013).

It is important to highlight that, during the analysis of the survey data, semi-structured interviews were being planned, and discussions were had with leading academics in the area to develop these. However, due to the sporadic nature and uncertainty surrounding access to academy soccer players for the planned training studies, the research team made a decision to focus on completing that aspect of the project. Thus, it was ultimately not possible to conduct semi-structured interviews as part of the wider research project. However, future studies may be able to utilise these semi-structured interview questions to develop the work from these chapters.

Chapter Four – Global Differences in Current Strength and Conditioning Practice within Soccer

4.1 Prelude

Following the literature review, where we highlighted between country differences in player physical characteristics and the number of competitive fixtures, it is important to establish if these differences are associated with variation in S&C practice. Accordingly, as soccer is an international sport, Chapter Four sought to compare the training methods used by S&C coaches working in soccer in different global regions. Due to region-specific considerations, such as typical match demands, or long-term athlete development models set out by national governing bodies, differences in S&C practice were anticipated. If such differences were to exist, they should be identified and described, so that researchers can design more ecologically valid training interventions, which are more likely to be adopted by practitioners, thus improving the translation of science into practice.

4.2 Abstract

Differences in player anthropometry and match demands exist between top-tier soccer leagues in different countries, which may influence strength and conditioning (S&C) practice within soccer between those countries. Thus, the aim of this study was to investigate whether differences in current soccer S&C practice existed between different global regions. A total of 170 participants, who were involved with the delivery of S&C support at their soccer club (based in South America (SA), USA, UK or other European countries), completed a comprehensive survey examining their S&C methods. Overall, relatively more coaches in the UK believed bodyweight training was the most important resistance training (RT) modality compared to coaches in SA (45% *vs.* 27%, p=0.040). Conversely, relatively more first team coaches in the USA than in the UK regarded free-weight RT as the most important training method in their programmes (100% *vs.* 60%, p=0.033). Coaches in Europe conducted fewer formal S&C sessions, placed less importance on free-weight RT and performed less speed and plyometric training compared to coaches in other global regions (all p<0.05). However, SA academy players were introduced to S&C later (14±2 years-old) than in the UK (12±3 years-old, p=0.002), which may limit physical development. Despite this latter finding, it is reasonable to suggest that S&C practice of coaches in the USA and SA generally align better with scientific guidelines for strength and power development in soccer, with an emphasis on free-weight RT alongside regular sprint and plyometric training compared to those in the UK and other European countries.

4.3 Introduction

Soccer is the most popular sport worldwide and has the most number of registered athletes compared to any other sport (FIFA, 2006). This global impact is reflected in different Fédération Internationale de Football Association (FIFA) confederations and national associations hosting highly successful professional leagues in both the men's and the women's game. Despite following the same set of rules, different technical, tactical and match demands during top league matches have been observed between countries (Dellal et al., 2011), while player anthropometry also differs between several top leagues in different countries (Bloomfield et al., 2005). The number of competitive fixtures also varies between countries, with some teams playing 50 matches a season, and others up to 80 (Julian et al., 2021, Curtis et al., 2018). With more congested fixtures, there may be less opportunity to maintain or improve players' physical capabilities, with more emphasis on recovery (Walker and Hawkins, 2018). Increased match demands, on the other hand, may require players to train more often in order to be more physically robust. These different factors may influence the training methods implemented by strength and conditioning (S&C) coaches for players to meet the different demands of competition and playing styles in different countries/continents, both in terms of performance and injury prevention. However, it is not yet known if these global differences in fixture number and/or match demands translate into differences in S&C practice within professional and academy soccer, in both the men's and women's game.

Although no single study has investigated global differences in S&C practice within soccer, Weldon et al (2020) did describe current methods of S&C practitioners from different countries, working with professional soccer players. However, due to a relatively small sample size (*n* = 52), comparison between global regions was not possible. Weldon et al. (2020) reported that most S&C coaches worldwide have two sessions per week in-season, each lasting 31-45 minutes, with the squat and its variations reported as the most important exercises for

S&C coaches. However, when reporting exercise prescription, Weldon et al. (2020) only reported the most common sets and repetitions used (3-4 sets, 4-6 repetitions), and lacked the important factor of exercise intensity (Fry, 2004). This limited data is compounded by findings that up-to-date fundamental principles of resistance training are not applied in S&C practice in elite Spanish Club soccer (Reverter-Masía et al., 2009).

Current methods used to develop strength and power in youth soccer players have also been questioned recently. Despite increasing training age within an academy S&C programme, no changes in strength relative to body mass have been observed between age groups in either boys (Morris et al., 2018a) or girls (Emmonds et al., 2017). In a youth development setting, coaches may also have to align their athletes' training with long-term athletic development (LTAD) recommendations outlined by their respective National Governing Body (NGB). In England, the Elite Player Performance Plan (The English Football Association, 2015) includes guidelines for each chronological age group, starting from the under 5s. It has previously been reported that young players in England enter elite academy pathways from a much earlier starting age (10 ± 2 years old) than those in parts of France (13 ± 0 years old) and Brazil (13 ± 1 years old) (Ford et al., 2012). This may be due to differences in the organisation and the documents developed by NGBs, such as the French Football Federation's *Charte du Football Professionnel* or the *Foot Professional Academy Support System* in Germany and Belgium (Relvas et al., 2010). Further differences in approach may be seen towards the end of the youth development pathway. In the United Kingdom, there is a traditional academy structure, where the aim is for players to progress through the age groups into the first team squad. However, in the USA, there is the collegiate and draft system, which is vastly different. Collegiate sport in the USA fulfils a pivotal role, acting as a feeder system for athletes into professional sport. Afterwards, Major League Soccer, the top soccer league in North America, utilises the draft system, where college graduates are then signed by professional clubs. The culmination of these and other factors may well influence S&C coaches' programmes and could result in substantially different training approaches between global regions. However, this important question has yet to be investigated.

The comparisons mentioned above between national leagues regarding player anthropometry (Bloomfield et al., 2005) and technical, tactical and physical match outputs (Dellal et al., 2011) have been performed exclusively in first team male soccer players. To the authors' knowledge, no single study has investigated global differences in S&C practice within soccer (including coaches working in both the men's and women's game, and in both professional and academy soccer). Therefore, the aim of this study was to investigate the practices of S&C coaches working in soccer from different countries and continents, using robust statistical analyses in the largest number of respondents to date. It was hypothesized that there would be geographic differences in S&C practice (e.g., time spent in formal S&C sessions and resistance training [RT]), and that these differences would be in line with the typical match demands, fixture number (for professional squads), or LTAD (for academy squads) for that global region.

4.4 Methods

For details of the creation, development, data collection and analysis process please refer to chapter three and appendix 1. Specifically for this chapter, the final sample of 170 participants were grouped into the United Kingdom (UK, n = 70), European countries (France, Spain, Germany, Italy and Portugal) excluding the UK (EUR, n = 17), South America (Brazil and Uruguay; SA, n = 69) and the United States of America (USA, n = 14; (Table 1). In this chapter we completed analysis for all participants together, while also separating into senior and academy. The grouped comparison allowed for a broader overview of current practice in men's versus women's soccer, particularly where limited sample sizes would not allow for statistical analyses if split into smaller sub-groups.

4.5 Results

Demographics

There were differences between global region regarding academic education, with relatively more coaches having a master's degree in the UK (59%), EUR (71%) and USA (71%) compared to SA (23%), where a bachelor's degree was most common (51%) compared to all other locations (χ^2 (9, N = 170) = 52.14, $p < 0.01$, Table 1). This pattern was consistent within first team squads overall and men's squads overall (Table 1). There were no differences between global region regarding number of years' experience in S&C, either overall or within any sub-group (χ^2 (6, N = 170) = 11.56, $p = 0.07$; (Table 1).

Table 1: Participant demographic data.
$p < 0.05$: *

Group	Responses	Years in S&C	Education (%)
United Kingdom	*n* = 70	<5 years = 39% 6-10 years = 43% >10 years = 18%	BSc: 23% MSc: 59% PhD: 19%
Rest of Europe	*n* = 17	<5 years = 41% 6-10 years = 12% >10 years = 47%	BSc: 6% MSc: 71% PhD: 24%
South America	*n* = 69	<5 years = 32% 6-10 years = 30% >10 years = 38%	BSc: 51% * MSc: 16% * PhD: 5% None of the above: 28%
United States of America	*n* = 14	<5 years = 36% 6-10 years = 36% >10 years = 29%	BSc: 14% MSc: 71% PhD: 14%

Resistance Training

The age at which academy soccer players enter a formal S&C programme differed by global region ($H(3) = 15.50$, $p = 0.002$). Those in the UK started at a younger age than those in SA, with no differences between other locations (Fig 1).

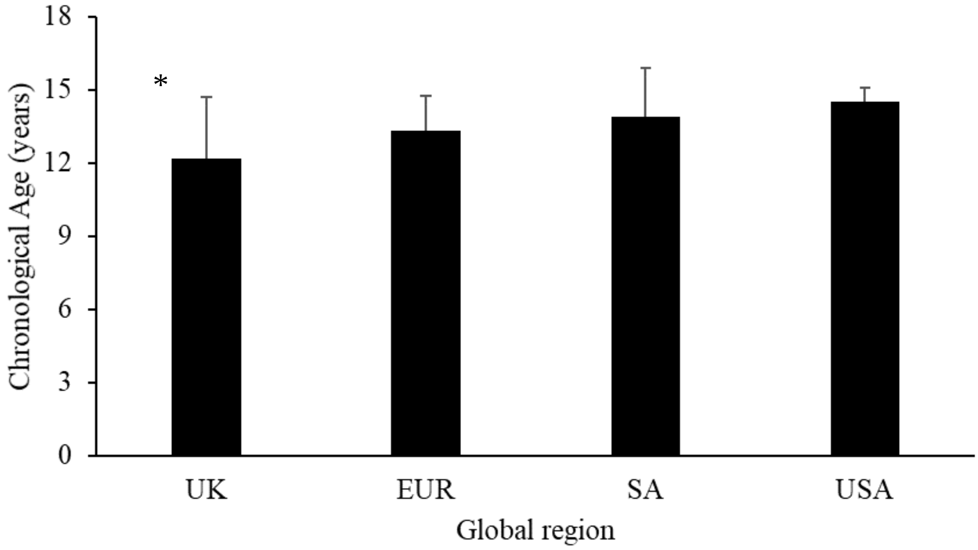

Figure 1: The chronological age that academy soccer players start a formal strength and conditioning programme; * lower than South America (SA) ($p < 0.05$).

The proportion of coaches using free-weight RT did not differ between global region, either overall or in any of the sub-groups (χ^2 (3, N = 170) = 0.96, p = 0.81). Overall, a greater proportion of coaches in the UK used bodyweight training (93%) than in SA (81%) (χ^2 (1, N = 170) = 9.51, p = 0.02) and perceived bodyweight training to be the most important RT method (45% *vs.* 27% respectively; χ^2 (1, N = 149) = 8.24, p = 0.04; Fig 2). A greater proportion of coaches in SA used resistance machines (62%) than in UK (46%) (χ^2 (1, N = 139) = 3.86, p = 0.05). Between first team groups, a larger proportion of coaches in the USA (100%) regarded free-weight RT as the most important method for developing strength and power than coaches in the UK (60%; χ^2 (1, N = 29) = 4.97, p = 0.03; Fig 2). When prescribing RT, there were no differences between global regions for sets ($H(3) = 1.58$, p = 0.66), repetitions ($H(3) = 2.78$, p = 0.43) or estimated percentage of 1RM ($H(2) = 0.69$, p = 0.88, Fig 3).

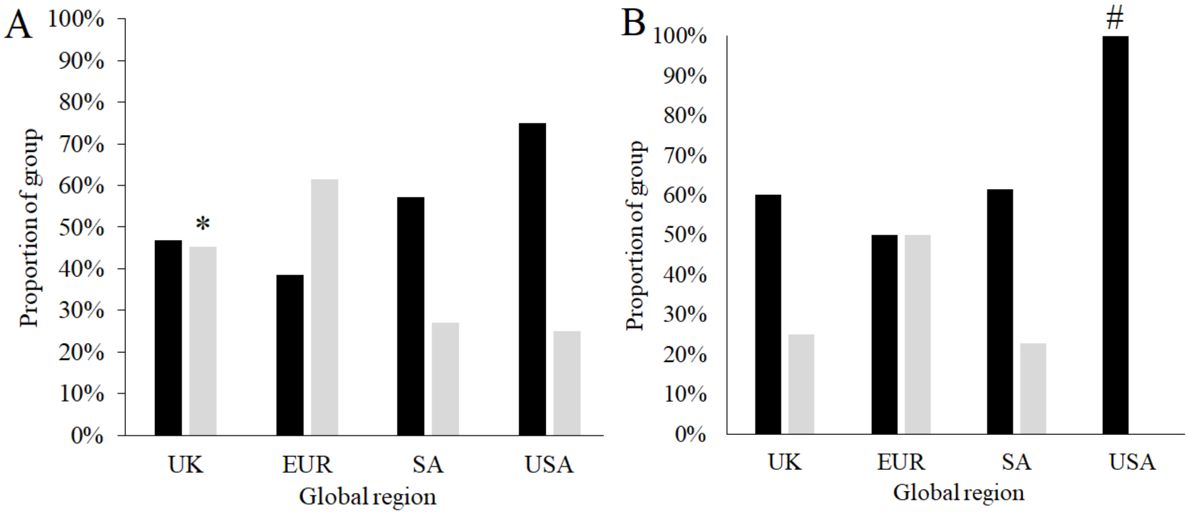

Figure 2: A) The proportions of all participants that believe free-weight (black bars) or bodyweight (grey bars) training are the most important methods to developing strength and/or power with their soccer players. B) The proportions of first team coaches that believe free-weight (black bars) or bodyweight (grey bars) training are the most important methods to developing strength and/or power with their soccer players. * greater than South America (SA); # greater than UK, SA and USA ($p < 0.05$).

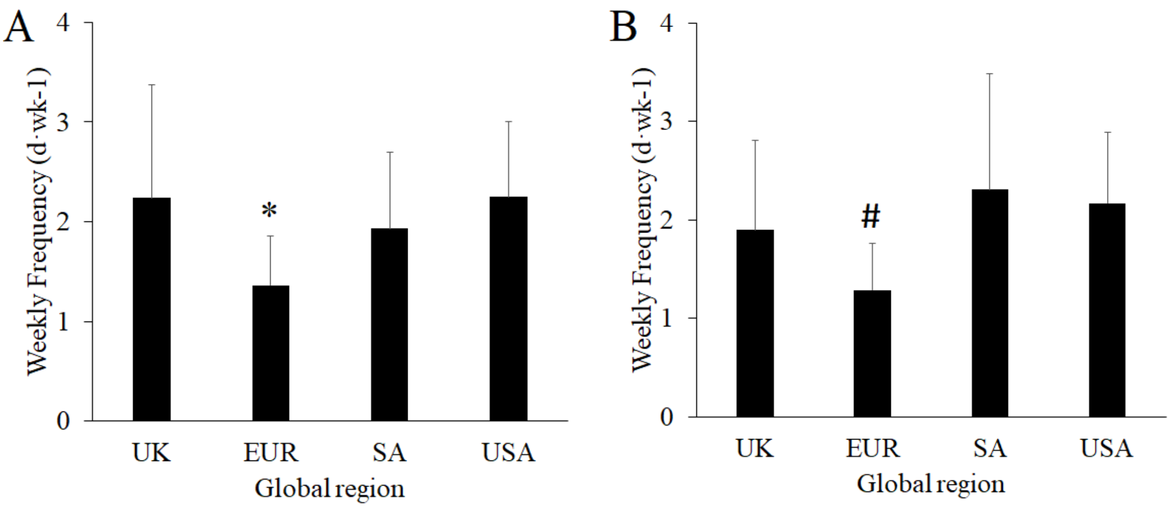

Figure 3: The weekly frequency that coaches utilise plyometric (A) and speed (B) training with their players. # lower than UK, South America (SA) and USA; * lower than SA and USA ($p < 0.05$)

Periodisation

Overall, there was a greater pre-season weekly session frequency reported by coaches in SA (3.0 ± 1.1) compared to coaches in the UK (2.5 ± 0.8) and EUR (2.1 ± 0.9), but not compared with coaches in the USA (2.7 ± 1.0) (H(3) = 18.34, $p < 0.01$). Academy coaches in SA also reported a greater weekly frequency than academy coaches in EUR (2.8 ± 0.9 *vs.* 1.8 ± 0.4) (H(3) = 13.41, $p < 0.01$). During pre-season, overall session duration was longer in SA (56 ± 20 min) than UK (46 ± 13 min) (H(3) = 9.63, $p = 0.02$), with no differences with EUR (49 ± 25 min) or USA (48 ± 11 min). This was consistent with the first team only comparison (H(3) = 9.67, $p = 0.02$), while no differences were seen between global regions for academy coaches (either men's or women's squads). There were no differences between global regions regarding in-season session frequency or duration.

Plyometrics and Speed Training

Overall, plyometrics were implemented more frequently by coaches in the UK (2.2 ± 1.1) and USA (2.3 ± 0.8) during a training week than those in EUR (1.4 ± 0.5; H(3) = 13.12, $p < 0.01$; Fig 4). Overall, speed training was performed more frequently in a training week by coaches in SA (2.4 ± 1.4) than by those in EUR (1.4 ± 0.5; H(3) = 14.96, $p < 0.01$; Fig 4), a result that was replicated in the men's overall comparison. There were no global differences regarding any other variables.

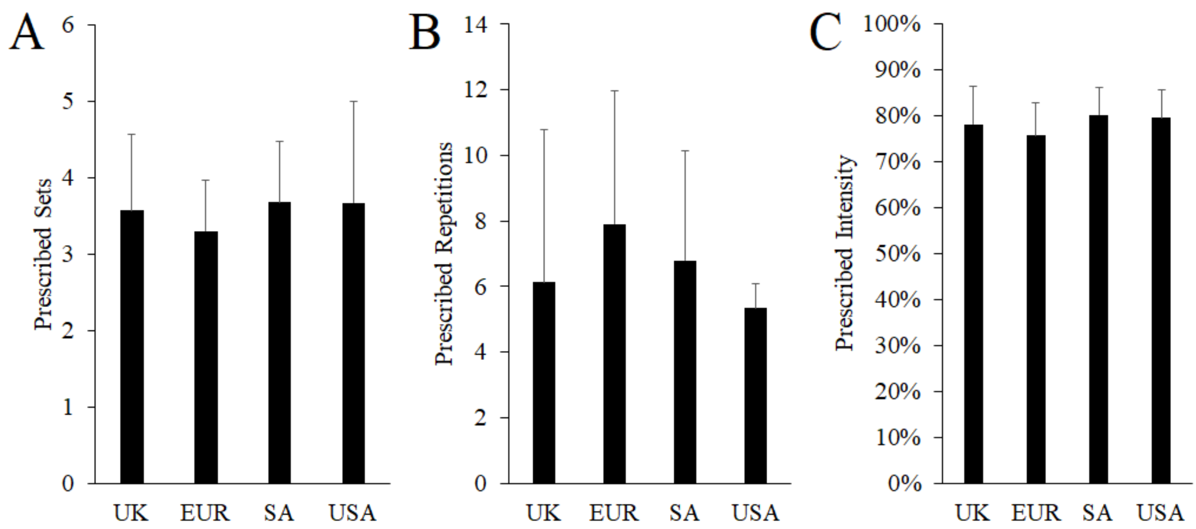

Figure 4: The sets (A), repetitions (B) and intensity relative to 1RM (C) coaches utilise to develop strength in-season with their players.

4.6 Discussion

The aim of this study was to investigate the practices of S&C coaches from different global regions. In line with our hypothesis, there were differences between global regions in the time spent in formal S&C sessions, the frequency of other physical development methods, and the approach taken to develop strength and power. When specifically investigating academy squads, players in SA were introduced to S&C at an older chronological age than their UK counterparts. Overall, relatively more UK coaches perceived bodyweight training to be the most important training modality compared to coaches in SA. However, relatively more first team coaches in the USA than in the UK regarded free-weight RT as the most important training method in their programmes. Coaches in SA performed more (and longer) pre-season S&C sessions than coaches in the UK. Finally, first team coaches in EUR spent less time in formal S&C sessions than coaches in other global regions. Thus, it is reasonable to suggest that S&C practice of coaches in the USA and SA align better with scientific guidelines for strength and power development in soccer, with an emphasis on free-weight RT alongside regular sprint and plyometric training in comparison to those in the UK and EUR.

Developing strength and power is recommended in LTAD models (Lloyd and Oliver, 2012) and is supported by NGBs (Faigenbaum et al., 2009, Lloyd et al., 2014a, McQuilliam et al., 2020). When comparing the chronological age academy players start a formal S&C programme, the current study demonstrated that players in SA start later than those in the UK (Fig 1), which may have implications for their ability to fulfil their physical potential. These differences may be due to the organisational structures and guidance in place. For example, the average age a youth soccer player enters a soccer academy in the UK is 10 years old compared to 13 in France, Brazil and Mexico (Ford et al., 2012). Introducing athletes to S&C training prior to peak-height velocity will maximize training age and the potential to achieve optimal adulthood motor capacity (Myer et al., 2013). The age reported here regarding UK academy boys would suggest they are introduced to RT at 12 years old, approximately two years prior to the age PHV generally occurs in young males, although this varies greatly between individuals (Lloyd and Oliver, 2012). Further, it is important to consider the large variation in within geographic regions, in both the UK and SA groups there was a standard deviation of more than 2 years and range of 9 and 10 years respectively. This may be due to differences in the academy structures governed by nation associations, such as the Elite Player Performance Plan (EPPP) in English men's academy soccer (The English Football Association, 2015). With this, academies are classified into Category 1, 2, 3 and 4 based on the services provided. Category 1 men's academy pathway starts formal S&C at under 12s, whereas Category 4 start at the under 17 age group. The participants presented here from English men's academy soccer were distributed across the top three tiers in this system, predominantly category 1 (42%), with an even distribution between category 2 (29%), and category 3 (29%). This may be one potential reason for the variety of responses seen here. Further, both men's and women's academy responses were analysed within these geographic groups. This likely will have contributed to this large variability, e.g., the S&C guidelines for women's academy tier one as outlined by the Football Association in England within the category criteria are lesser than those for third tier men's academies (The English Football Association, 2015, The English Football Association, 2021a). Moreover, tier two and three in the women's game suggest S&C be incorporated into the pitch sessions (The English Football Association, 2021b). When compared to the EPPP academy structure (for men's academies), the variability between men's and women's academy environments within the same geographic area start to become apparent. Those players introduced to S&C at a later stage of maturation (e.g. after PHV) may be unprepared for more complex training approaches and may not be able to attain the same levels of strength and power compared to those who started earlier (Myer et al., 2013).

Strength and power are important physical components for physical performance, such as jump height/distance and acceleration (Wisloff et al., 2004, Comfort et al., 2014), as well as soccer specific skills, such as winning tackles and headers, (Wing et al., 2018) and higher league finishing positions (Wisloeff et al., 1998). As such, it has been a focus of much research, with a variety of different training methods, such as free-weight RT, bodyweight training and resistance machines providing benefits (Suchomel et al., 2018). The current study showed that, overall, relatively more S&C coaches in the UK regarded bodyweight training as the most important modality when compared to coaches in SA. It is important to consider the greater proportion of academy S&C coaches within the UK sample (61%) compared to SA (26%), which might have influenced this comparison. Bodyweight exercises are an effective training method for novice athletes, such as young academy soccer players, to learn exercise technique and develop a foundation of strength (Suchomel et al., 2018). However, there is a limited opportunity to improve maximal strength, particularly as athletes become more experienced (Suchomel et al., 2018). When comparing first team coaches in the current study, relatively more coaches in the USA than in the UK regarded free-weight RT as the most important training method for their programmes (Fig 3). Research would suggest that free-weight RT is the most effective approach to increase an athlete's strength capacity as well as facilitating an effective transfer to sporting actions, such as acceleration and jump performance (Suchomel et al., 2018, McQuilliam et al., 2020). When comparing the free-weight training approach taken by coaches in the current study, there were no global differences in the sets, repetitions and intensity used to develop strength (Fig 4). However, there was large within group variability regarding these parameters, which may well have precluded any differences from being observed. Despite the importance of building/maintaining strength in-season (Turner and Stewart, 2014), this variation highlights that there were responses reporting repetition ranges and intensities that align more with hypertrophy/strength-endurance (>6 repetitions) and others that follow traditional strength training guidelines (1 to 6 repetitions) (Haff and Triplett, 2015, Kraemer and Ratamess, 2004).The wide range of responses supports the conclusion of Reverter-Masía et al. (2009), i.e. that current S&C practice in soccer does not follow scientifically supported methods for improving strength.

Beyond exercise prescription, numerous factors need to be considered when planning a training programme, such as season phase and time available to train. The pre-season phase is typically characterised by a greater focus on developing physical qualities to sufficiently prepare players for in-season match demands (Ekstrand et al., 2020). The current study showed that, during pre-season, S&C coaches in SA reported undertaking more weekly sessions than coaches in both EUR and the UK, as well as a longer session duration than coaches in the UK. The greater time coaches in SA devoted to training during pre-season may have potential benefits, such as a reduced injury occurrence and severity in-season and, in turn, improved team performance (Ekstrand et al., 2020). While time spent training is an important factor, the training methods used within these sessions will be a key contributing factor (McCall et al., 2020). When transitioning from pre-season to in-season, there is typically a reduction in training volume as focus moves to match performance (Turner and Stewart, 2014). As such, this may limit the opportunity to undertake S&C sessions due to fixture congestion and the need to optimise recovery before the next match (Walker and Hawkins, 2018).

When comparing the number of competitive league fixtures per season, the English, French, Italian, and Spanish top divisions all reported 38 fixtures, with 38 in the Brazilian Serie A and 34 games in Major League Soccer (Goossens and Spieksma, 2012). Without the inclusion of domestic cup competitions, as this greatly depends on an individual team success, there appear to be no differences in domestic league fixtures across a season between the topflight national leagues in EUR, UK, SA and USA. Therefore, the global differences in S&C practice reported here are unlikely due to differences in the number of competitive fixtures. When looking at in-season S&C session frequency in the current study, differences are apparent. While it was not possible to compare the EUR first team group to others due to its small sample size (n = 4), we hypothesize that first team coaches in EUR would continue to report a lower in-season weekly frequency (1.0 ± 0.0) if more responses were collected, resulting in session frequency being lower than other global regions. This is based on coaches in EUR reporting a lower weekly in-season frequency of plyometrics training than UK, SA and USA coaches (Fig 4), and fewer speed training sessions per week in-season, compared to coaches in SA and the USA (Fig 4). Both plyometric and speed training are important components for improving high-speed running performance (Beato et al., 2020, Ramirez-Campillo et al., 2021), and distance covered at high speed during professional men's soccer match play differs between the UK and EUR (Dellal et al., 2011). The demands of these fixtures may influence the training approach, a hypothesis which is supported by the greater frequency of speed training in the UK group compared to EUR. This is an important factor for match success (Faude et al., 2012), with sprint training also being an effective injury prevention method (Malone et al., 2018). It appears that coaches in SA prioritise speed training to develop players more than other global regions, while coaches in the UK spend more time overall on developing strength, power and speed than coaches in EUR, who reported conducting fewer S&C sessions in-season, utilising plyometrics less frequently, and conducting fewer weekly speed sessions.

Limitations

For the findings presented here, there are some limitations that need to be considered. Primarily, the sample size in the USA group (*n* = 14) limited sub-group comparisons, although this number is similar to previous observations of S&C practice in soccer (*n* = 15) (Reverter-Masía et al., 2009), and can still provide a valuable insight regarding geographic comparisons. Secondly, only 28% (*n* = 47) of the 170 respondents reported the sets, repetitions, and intensities they used for strength training in-season. Importantly, most respondents did answer this question (92%), but failed to include the intensity they prescribed. As intensity is a key factor in RT, answers that did not include this information were excluded from analysis. While this limited the number of data points, this is a larger sample than previously seen in soccer (*n* = 15) (Reverter-Masía et al., 2009) and other sports, such as rugby (*n* = 43) (Jones et al., 2016), basketball (*n* = 20) (Simenz et al., 2005), and may reflect the relative number of S&C coaches who prescribe all three factors simultaneously.

Conclusion

Our novel findings suggest that differences in S&C practice in soccer do exist between different geographic locations worldwide, which are likely independent of fixture number or match demands. Coaches in EUR conducted fewer formal S&C sessions, placed less importance on free-weight RT and performed less speed and plyometric training compared to coaches in other global regions. While those working with UK squads devoted more time to physical development than those in EUR, they regarded bodyweight training as the most important RT modality, which is considered sub-optimal for strength and power development. The S&C practice of coaches in the USA and SA, on the other hand, appears to align better with the scientific guidelines for strength and power development in soccer, emphasising the importance of free-weight RT alongside regular sprint and plyometric training. Finally, SA academy players are introduced to formal S&C training at a later chronological age than those in the UK, most likely due to the later age SA players enter academies. Delaying the introduction of S&C in youth players may leave them unprepared for more complex training approaches and preclude them from achieving their full potential regarding neuromuscular adaptations and performance gains in strength, power and speed. S&C coaches may use the data presented here to broaden their view of current S&C practice in soccer. The application of resistance training principles varies widely both within and between these global regions.

Future work to build on the findings from this chapter:

To further investigate the findings presented in this chapter further, semi-structured interviews could be utilised to provide a more in-depth explanation of the key themes that emerged. The following questions have been developed following the guidance of Kallio et al. (2016) when designing a semi-structured interview. This approach is appropriate when investigating people's opinions and perceptions of complex topics. To produce effective interview questions the prior information from the literature review (chapter two) and the findings in this chapter provide the basis to identify the main themes. Questions should be participant focused, one-dimensional and open-ended.

i) *"What factors influence when a player is introduced to a strength and conditioning programme?"*

ii) "*When aiming to develop strength with your players what is your current approach and why?"*

iii) *“What are the main influences/factors you consider when planning the physical training content for the week ahead, e.g., strength and conditioning sessions, speed sessions, etc.”*

iv) *“How does the physical training content change if your team has two competitive fixtures within a single week?”*

Each of these main themes would have spontaneous follow-up questions if required as this would allow for participants to expand on any specific points that came up in the interview. In line with the guidelines provided by Kallio et al. (2016), the proposed questions above would be pilot tested, using a field-testing approach, to increase the quality of data collection, gather important information about their implementation, and be assessed for their effectiveness.

Chapter Five – Mind the Gap! A Survey Comparing Current Strength Training Methods used in Men's versus Women's First Team and Academy Soccer

Adapted from: McQuilliam, S.J., Clark, D.R., Erskine, R.M. and Brownlee, T.E., 2022. Mind the gap! A survey comparing current strength training methods used in men's versus women's first team and academy soccer. Science and Medicine in Football. DOI: https://doi.org/10.1080/24733938.2022.2070267 (published online on 1st May 2022).

5.1 Prelude

Following the observation in Chapter Four that differences in S&C practice were apparent between global regions, it seemed appropriate to investigate any potential differences in practice between S&C coaches working with male and female players due to the increasing popularity of the women's game worldwide. The physiological and biomechanical differences between males and females that manifest during puberty may have an influence on the training approaches taken by S&C coaches. Further, the comparatively limited research in female soccer may result in training practices being based on evidence from male populations. Chapter Five aims to explore this and compare the approach of S&C coaches working with male and female soccer players in professional and academy squads to provide necessary insights for both sets of coaches and researchers going forward.

5.2 Abstract

Much less is known about strength and conditioning (S&C) practice in women's versus men's soccer. The aim of this study was to compare S&C practice between coaches working in men's or women's soccer, at first team or academy level, worldwide. A total of 170 participants, who were involved with S&C support at their soccer club (in Europe, USA and South America, within men's or women's first team or academy settings) completed a comprehensive online survey, designed to evaluate (i) their academic qualifications and S&C coaching experience; and their preferred methods for (ii) physical testing; (iii) strength and power development; (iv) plyometric training; (v) speed development; and (vi) periodization. Women's academies had fewer weekly in-season S&C sessions than men's academies (1.6±0.6 vs. 2.3±0.9, p=0.005). Relatively, fewer women's academy S&C coaches (6%) used Olympic weightlifting movements than men's academy S&C coaches (32%, p=0.030). Relatively, more women's academy coaches (47%) used the Nordic hamstring exercise (NHE) compared to men's academy coaches (15%, p=0.006), but relatively more women's vs. men's first team coaches (61% vs. 38%, p=0.028) and women's vs. men's academy (61% vs. 38% coaches, p=0.049) utilised rating of perceived exertion-based load prescriptions. Notable differences in S&C practice exist between coaches of men's and women's soccer squads, particularly at academy level. For example, fewer weekly S&C sessions in female academy players may have implications for physical development, while the greater use of subjective load prescriptions in both academy and first team women's squads may lead to sub-optimal performance gains.

5.3 Introduction

Soccer is a sport played by men and women of all ages, with global participation in the women's game increasing by 32% between 2010 to 2015, reaching 30 million female players (Griffin et al., 2020) Associated with this and the increased professionalisation (Culvin, 2021) there has been an increase in high-intensity movements during women's match-play, particularly high-speed running (FIFA, 2020). Research into women's soccer has also grown in recent years, however, overall it is still an under-developed area compared to men's soccer (Emmonds et al., 2019a). Consequently, women's training practices may be based on evidence from male populations, which may be inappropriate considering the sex differences in performance characteristics and injury risk (Emmonds et al., 2019a).

Strength and conditioning (S&C) methods not only improve athleticism in female soccer players (Millar et al., 2020) but may also decrease non-contact injury risk (Khayambashi et al., 2016). Female soccer players have a greater frequency of severe injuries compared to male athletes (Mufty et al., 2015). Further, in a single season, 70% of first team (Faude et al., 2005) and 92% of academy aged (Le Gall et al., 2008) female soccer players will experience an injury. This may be due to poor landing mechanics (Sutton and Bullock, 2013), increased laxity and joint instability (Faude et al., 2005) and lower levels of relative strength (Le Gall et al., 2008) compared to male soccer players. Injury risk in young female players may further increase due to growth-related changes associated with puberty, which may reduce movement quality and alter forces during dynamic actions (DiCesare et al., 2019). As such, it has been recommended that all athletes continually engage with an injury prevention programme to mitigate injury risk (Mufty et al., 2015).

The physiological differences between sexes, may impact the training methods S&C coaches choose to use. When observing high-school coaches, Reynolds et al. (2012) reported that 86% coaches working with female athletes believed different approaches were used depending on the athlete's sex, and the authors hypothesised that this was due to coaches perceiving limited benefits of resistance training (RT) on sports performance with female athletes. These differences manifested in lower training frequency, extra jump training to protect against non-contact injuries and "female-preferred" methods, such as muscular endurance (Reynolds et al., 2012). These approaches were not based on scientific evidence but from coaches' own ideas (65%) and the internet (58%). However, this was a small sample (*n* = 14) in a multi-sport environment and may not reflect current S&C practice in academy female soccer players. Further, to the authors' knowledge, no study has investigated whether S&C practice differs between coaches working with male players compared to those who work with female soccer players. This information is important, as it would inform both practice and research in this under-developed area of S&C.

The aim of this study was to investigate the practices of S&C coaches working with male soccer players compared to those working with female soccer players at both first team and academy level, worldwide. Due to limited research in elite female soccer players, we hypothesised that the training methods implemented, particularly exercise prescription, would not differ between coaches working with male players and those working with female players.

5.4 Methods

For details of the creation, development, data collection and analysis process please refer to chapter three and appendix 1. For this chapter, the final sample of 170 participants' responses were grouped into those who worked with men's first team, women's first team, men's academy and women's academy squads (Table 1).

5.5 Results

Demographics

There were no differences in academic qualifications between coaches working with men's *vs.* women's soccer at first team (χ^2 (2, N = 92) = 3.38 p = 0.337) or academy level (χ^2 (3, N = 78) = 0.97, p = 0.809; Table 1). Coaches working with men's first team squads had more years' experience as an S&C coach compared to those working with women's first team squads (χ^2 (2, N = 92) = 10.45, p = 0.005; Table 1). However, there was no difference in the number of years' S&C experience between coaches working with men's and women's academy players (χ^2 (2, N = 78) = 3.01, p = 0.222; Table 1). There were relatively more S&C coaches working with women's first team and women's academy squads than men's first team (84% *vs*. 60% respectively; χ^2 (2, N = 92) = 9.06, p = 0.011; Table 1) and academy squads (89% *vs*. 55% respectively; χ^2 (2, N = 78) = 7.67, p = 0.022; Table 1). There were relatively more sport scientists delivering S&C support to men's first team and men's academy squads than women's first team (35% *vs*. 9% respectively; χ^2 (2, N = 92) = 9.06, p = 0.011; Table 1) and women's academy squads (40% *vs*. 6% respectively; χ^2 (2, N = 78) = 7.67, p = 0.022; Table 1).

Table 1: Participant demographic data.

* Different to equivalent in Women's squad ($p < 0.05$)

Group (n)	Job role	Years in S&C	Academic qualification (%)
Men's first team *n* = 48	S&C/Fitness coaches = 61% * Sport scientists = 35% * Technical coaches = 4%	<5 years = 29% 6-10 years = 19% * >10 years = 52% *	BSc: 25% MSc: 44% PhD: 21% Other: 10%
Women's first team *n* = 44	S&C/Fitness coaches = 84% Sport scientists = 9% Technical coaches = 7%	<5 years = 32% 6-10 years = 45% >10 years = 23%	BSc: 41% MSc: 36% PhD: 12% Other: 11%
Men's academy *n* = 60	S&C/Fitness coaches = 55% * Sport scientists = 40% * Technical coaches = 5%	<5 years = 38% 6-10 years = 40% >10 years = 22%	BSc: 30% MSc: 53% PhD: 14% Other: 3%
Women's academy *n* = 18	S&C/Fitness coaches = 88% Sport scientists = 6% Technical coaches = 6%	<5 years = 61% 6-10 years = 28% >10 years = 11%	BSc: 33% MSc: 56% PhD: 6% Other: 5%

Resistance training methods

There was no difference between the age males or females start a formal S&C programme on a global scale (males: 13±2 years; females: 13±2 years; $t_{106} = 0.123$, $p = 0.903$).

There were no differences between the proportion of coaches working with men's or women's first team squads using free-weight training (98% *vs*. 95% respectively; χ^2 (1, N = 92) = 0.51,

p = 0.599), bodyweight training (88% *vs*. 84% respectively; χ^2 (1, N = 92) = 0.22, p = 0.639) or plyometrics (96% *vs*. 100% respectively; χ^2 (1, N = 92) = 1.87, p = 0.495), when aiming to develop strength and power. There were no differences between the proportion of coaches working with men's or women's academy squads using bodyweight training (93% *vs*. 94% respectively, (χ^2 (1, N = 75) = 0.05, p = 1.000) or plyometrics (90% *vs*. 94% respectively; χ^2 (1, N = 75) = 0.31; p = 0.581). However, a significantly lower proportion women's academy coaches reported using free-weights (83%) compared to men's academy coaches (97%; χ^2 (1, N = 75) = 3.81; p = 0.049).

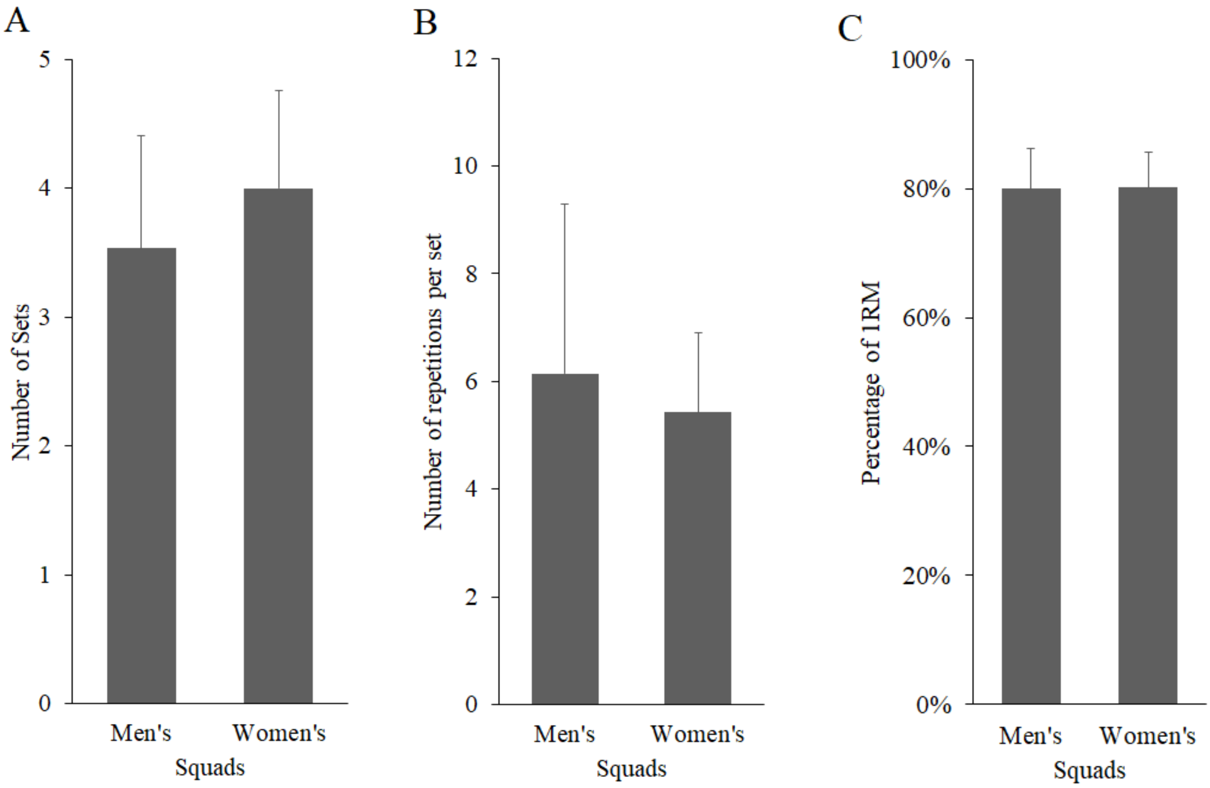

Figure 1: The sets (A), repetitions (B) and training intensity (C) first team coaches prescribe to for strength training in-season.

There were no differences between women's first team and men's first team S&C coaches when programming sets (t_{28} = -1.56, p = 0.129; Fig. 1), repetitions (t_{27} = 0.786, p = 0.438; Fig. 1), or intensity relative to the single repetition maximum (1RM; t_{27} = -0.12, p = 0.904; Fig. 1).

There were no differences in the proportion of coaches working with male or female players, who used a percentage 1RM (first team = 40% *vs*. 41% respectively, χ^2 (1, N = 91) = 0.002, p = 0.963; Academy = 40% *vs*. 39% respectively, χ^2 (1, N = 78) = 0.007, p = 0.933). There were no differences in the proportion of coaches working with male or female players, who used velocity-based metrics (first team = 40% *vs*. 25% respectively; χ^2 (1, N = 91) = 2.447, p = 0.118; Academy = 23% *vs*. 6%; respectively, χ^2 (1, N = 78) = 2.817, p = 0.093). A greater proportion of women's coaches (both first team and academy) utilised RPE-based load prescription than those working with male players (first team = 61% *vs*. 38% respectively; χ^2 (1, N = 91) = 4.84, p = 0.028; Academy = 61% *vs*. 38% respectively, χ^2 (1, N = 78) = 2.922, p = 0.049).

Exercise selection

There were no differences in the proportion of men's or women's S&C coaches prescribing bilateral squat patterns (first team = 78% *vs*. 85% respectively; χ^2 (1, N = 80) = 0.74, p = 0.390; academy = 81% *vs*. 100% respectively; χ^2 (1, N = 76) = 3.71, p = 0.054; Fig. 2), bilateral hinge (first team = 78% *vs*. 80% respectively; χ^2 (1, N = 80) = 0.08, p = 0.785; academy = 85% *vs*. 83% respectively; χ^2 (1, N = 76) = 0.06, p = 0.812; Fig. 2), unilateral exercises (first team = 67% *vs*. 70% respectively; χ^2 (1, N = 80) = 0.06, p = 0.809; academy = 53% *vs*. 77% respectively; χ^2 (1, N = 76) = 3.10, p = 0.078; Fig. 2), and plyometrics (first team = 40% *vs*. 20% respectively; χ^2 (1, N = 80) = 1.87, p = 0.495; academy = 34% *vs*. 41% respectively; χ^2 (1, N = 76) = 0.31, p = 0.581; Fig. 2). There was no difference in the proportion of men's or women's S&C coaches prescribing weightlifting derivatives, such as the clean and jerk, snatch and their variations with first team players (25% *vs*. 35% respectively; χ^2 (1, N = 80) = 0.95, *p* = 0.329; Fig. 2), however, there was a difference with academy S&C coaches (32% *vs*. 6% respectively; χ^2 (1, N = 76) = 4.72, *p* = 0.030; Fig. 2). A greater proportion of women's academy coaches reported specifically using the Nordic hamstring exercise (NHE) than men's academy coaches (47% *vs*. 15% respectively; χ^2 (1, N =76) = 7.69, *p* = 0.006; Fig. 2) but this was not evident in first team coaches (women's = 35% *vs*. men's = 25%, respectively; χ^2 (1, N =80) = 0.95, *p* = 0.329).

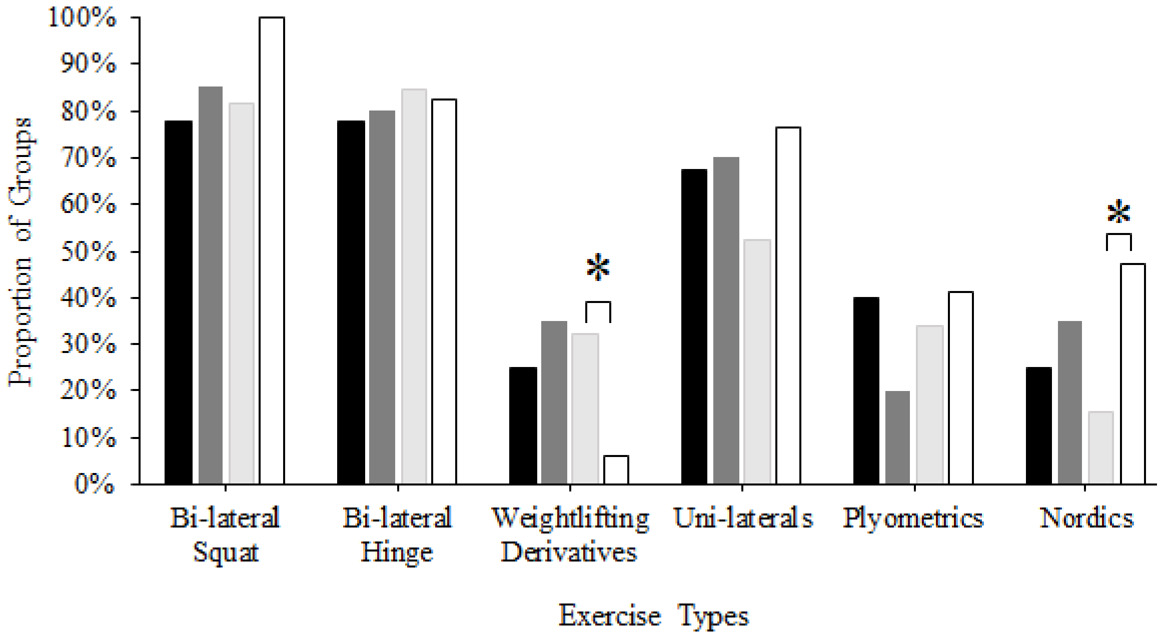

Figure 2: The proportions of men's first team (black bars), women's first team (dark grey bars), men's academy (light grey) and women's academy (white bars) coaches, who incorporated these movement patterns/exercise types into their practice to develop strength and/or power with their soccer players. * difference between men's and women's academy coaches (p < 0.05).

Periodisation

There were no differences between men's and women's coaches regarding the number of weekly S&C sessions during pre-season at first team (t_{87} = -0.99, p = 0.324) or academy (t_{74} = 0.44, p = 0.660; Table 2) level. Mean session duration was greater in women's first team (58±15 minutes) squads than in men's (48±18 minutes; t_{86} = -2.565, p = 0.010; Table 2). However, there were no differences in session duration at academy level (women's = 47±19 minutes *vs* men's = 50±16 minutes respectively; t_{73} = -0.07, p = 0.943; Table 2).

Overall, there was no difference between first team men's and women's coaches regarding the number of weekly S&C sessions in-season (t_{787} = -0.36, p = 0.717; Table 2). However, men's academy coaches prescribed more sessions than women's academy coaches in-season (t_{75} = 2.91, p = 0.005; Table 2). Mean session duration was greater in women's first team squads (53±16 minutes) than in men's (44±18 minutes; t_{84} = -2.69, p = 0.009) but not at academy level (48±16 minutes *vs.* 48±16 minutes respectively; t_{72} = 0.39, p = 0.698; Table 2).

Table 2: Time spent in specific strength and conditioning sessions during pre-season and in-season.

* Different to the equivalent men's team ($p < 0.05$)

Group	Season phase	Weekly frequency	Duration (minutes)
Men's first team	Pre-season	2.83 ± 1.14	48 ± 19
Women's first team		3.18 ± 0.98 *	58 ± 16
Men's academy		2.42 ± 0.80	48 ± 19
Women's academy		2.13 ± 0.74	47 ± 16
Men's first team	In-season	2.18 ± 0.81	44 ± 19
Women's first team		2.26 ± 1.07	54 ± 16 *
Men's academy		2.26 ± 0.90	47 ± 17
Women's academy		1.56 ± 0.63 *	16 ± 17

Restrictions to practice

There were no differences in the proportion of men's and women's S&C coaches, who felt their S&C practice was restricted by potential muscle soreness following RT (first team = χ^2 (1, N = 92) = 1.78, $p = 0.182$; academy = χ^2 (1, N = 78) = 1.32, $p = 0.251$), time (first team = χ^2 (1, N = 92) = 0.05, $p = 0.828$; academy = χ^2 (1, N = 78) = 0.44, $p = 0.508$, Fig. 3) or facilities/equipment (first team = χ^2 (1, N = 92) = 0.25, $p = 0.618$; academy = χ^2 (1, N = 78) = 0.07, $p = 0.796$; Fig. 3).

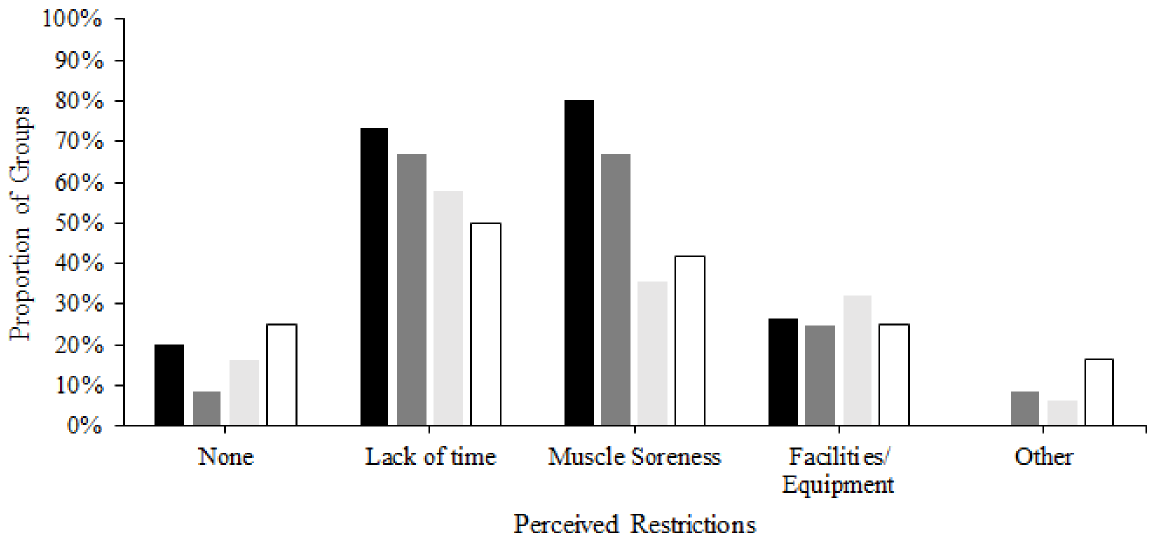

Figure 3: The proportions of men's first team (black bars), women's first team (dark grey bars), men's academy (light grey) and women's academy (white bars) coaches who perceive their S&C practice to be restricted by facilities/equipment, potential muscle soreness following training, lack of time, other or no restrictions at all. Other consisted of; technical coach/player "preferences", "training load" and "fixture congestion".

5.6 Discussion

The aim of this study was to compare current S&C practices of coaches working with male or female soccer players (at either first team or academy level) worldwide. The main findings were: i) women's academies had fewer weekly in-season S&C sessions compared to men's academies; ii) relatively more men's academy coaches implemented weightlifting within their training programmes compared to women's academy coaches; iii) a greater proportion of women's academy coaches reported using the Nordic hamstring exercise (NHE) compared to men's academy coaches; iv) at both first team and academy level, a greater proportion of coaches working with women's squads utilised RPE-based load prescriptions; and v) the sets, repetitions and intensity relative to 1RM that S&C coaches implement were similar between men's and women's first team settings.

Demographics

As S&C coaches develop, it is fundamental to gain a combination of coaching experience and formal education. These components can help differentiate between beginner, competent and more experienced coaches (LaPlaca and Schempp, 2020). According to these criteria, those working with men's first team squads are more experienced than with women's due to more years of experience (Table 1), though with a similar formal education (evidenced via academic qualifications). The latter is similar to previous findings (Weldon et al., 2020), but the differences in experience between groups is a novel finding. As a result, less experienced S&C coaches may be less effective in their programme delivery and more likely to cause potential injury (Carson et al., 2021). At a youth level, S&C coaches of youth female athletes have been reported as being less experienced and qualified than those coaching males (Reynolds et al., 2012), which may play a role in the high injury rate previously reported (Le Gall et al., 2008). However, this was not seen in this study, with similar years of experience and education between coaches of male and female academy soccer players globally, demonstrating greater external validity.

Chronological age staring S&C

As part of an holistic youth athlete development model, both boys and girls are introduced to S&C programmes prior to peak-height velocity (PHV) to maximise long-term benefits (McQuilliam et al., 2020). As PHV coincides with the onset of puberty and tends to occur earlier in girls (11-13 years-old) compared to boys (12-15 years-old) (Iuliano-Burns et al., 2001), it was interesting that academy coaches did not start a formal S&C programme with their youth players (either male or female) until they were ~13 years old. This could potentially be due to differences in the development structures in place. For example, in England, Regional Talent Clubs are the highest standard of women's youth football. Here, under 16 players have been reported to complete eight hours of total training per week, inclusive of pitch-based and at least one S&C session (Emmonds et al., 2017, The English Football Association, 2021a). Comparatively, men's academy players of the same age are expected to complete 12 to 16 hours of total training time per week (The English Football Association, 2015). The S&C guidelines for women's academy tier one in England are lesser than those for the third tier within men's academies. Moreover, for tier three in the women's game, it is suggested that S&C be incorporated into the pitch sessions (The English Football Association, 2021b). This may result in different training frequencies, intensities and volumes of exercises implemented to develop strength and power. However, a limitation of the survey tool used in this study is that it is not possible to conclude why boys and girls are introduced to formal S&C programmes at this age. While programming starts at the same chronological age, this results in youth female soccer players starting S&C programmes at a later stage of maturation than their male counterparts. Introducing S&C training early in a youth athlete's development can have long-term benefits by improving gains in strength and power and helping to prevent injury (Myer et al., 2013). However, it should be noted that strength relative to body mass shows minimal changes with increasing age groups despite the inclusion of S&C sessions in both men's (Morris et al., 2018b) and women's (Emmonds et al., 2017) academies, questioning the effectiveness of methods used by coaches in these environments to develop strength.

Resistance training

Whether male and female athletes require different approaches to develop strength and power has been discussed in the literature, with studies either supporting (Roberts et al., 2020), or refuting this suggestion (Reynolds et al., 2012). The data provided here would suggest there is little difference in the S&C training methods used by coaches for male and female soccer players of similar age. When developing strength, both men's and women's coaches utilised similar sets, repetitions and relative intensity (Fig. 1), as well as movement patterns (Fig. 2).

However, relatively fewer women's academy coaches reported using free-weights (83%) compared to men's (97%). Further differences were seen in the use of Olympic weightlifting and its derivatives, with relatively more men's academy coaches implementing them within their training programmes compared to women's academy coaches (Fig. 2). This is an interesting finding and, it should be explored further as female athletes show comparable improvements in strength and hypertrophy following the same externally loaded RT protocols (Roberts et al., 2020). Despite differences in total muscle mass (Janssen et al., 2000) and phenotype (Roberts et al., 2018) there are no differences in single fibre contraction velocity or force output relative to cross-sectional area between men and women (Trappe et al., 2003). This may help explain why the relative increases in hypertrophy and lower-body strength are similar between sexes, while men exhibit greater increases in absolute terms (Roberts et al., 2020). Following RT, there also appears to be similar muscle protein synthesis and damage responses (West et al., 2012), with suggestions that the menstrual cycle does not influence this (Miller et al., 2006). However, women do experience a lesser inflammatory response (Stupka et al., 2000) and delayed-onset muscle soreness for a shorter period of time following RT (Dannecker et al., 2012). As such, these differences may be a result S&C coaches perceiving a limited benefit of RT in female athletes (Reynolds et al., 2012) as well as an effect of less experience (Table 1). This is worth examining further using alternative research tools that incorporate open-ended questions, such as semi-structured interviews, to get a better understanding of these findings.

Exercise selection and training prescription may not have differed between S&C coaches working with men's and women's players but there were differences in the methods used to assign training load. Relatively more first team and academy women's S&C coaches used subjective measures to assign RT intensity, particularly RPE (61% and 61%, respectively), than men's coaches (38% and 38%, respectively). There are benefits with using subjective measures, such as low cost, efficiency, and not requiring a maximum strength test for prescription (Greig et al., 2020). However, it is possible that self-selected loads could be sub-optimal, as exercises have been suggested to be significantly under-loaded (Dias et al., 2018). Further, it is important to consider the RT experience of the individual when subjectively prescribing loads, as those with less experience are more likely to under-load RT exercises (Dias et al., 2018). The balance between ease of application and athletic benefits should be considered, as training time may limit opportunities for physical development and methods need to be effective. Conversely, there were no differences in the use of objective methods of training load prescription, such as velocity measures and percentages of 1RM. The use of velocity-based methods has gained popularity due to instant feedback, clear targets, and accounting for daily fluctuations in maximum strength and peak-power (Weakley et al., 2020). However, it appears this approach is not widely used in soccer, with only 27% of participants using it to prescribe training intensity, according to our data.

Whether using objective or subjective loading prescriptions, reducing injury risk is a key objective of S&C programming. With greater injury frequency in female soccer players (Mufty et al., 2015), this may explain why more women's academy (47%) than men's (15%) coaches included the NHE in their top five RT exercises. The NHE is purported to be an effective exercise for reducing hamstring injuries in soccer (Van Dyk et al., 2019). However, only two studies within the Van Dyk et al. (2019) review examined its effectiveness in female soccer players, and both showed it had no effect on injury rates (del Ama Espinosa et al., 2015, Soligard et al., 2008). This highlights the need for more female-specific research in this area, as the assumption that what works for male athletes will work for female athletes may lead to erroneous conclusions. Further, the rates of hamstring injuries in female soccer players are lower than their male counterparts (Cross et al., 2013). Nevertheless, the apparent importance placed on the NHE in female soccer suggests it may be an attempt to mitigate the higher risk of soft-tissue injuries in female vs. male players such as ACL injuries, and requires further investigation (Mufty et al., 2015).

Periodisation

Irrespective of injury risk, there appears to be more time directed towards physical development in women's first team squads than in men's. Although weekly session frequency was no different, women's first team squad S&C sessions were longer in duration (Table 2), which may lead to greater differences in total time spent on S&C. This may be due to using S&C methods to prevent non-contact soft tissue injury (Talpey and Siesmaa, 2017), and national governing bodies encouraging greater levels of athleticism from their female players (Emmonds et al., 2019b). In contrast, female academy soccer players received less exposure to S&C than male academy players (Table 2). Although this may simply reflect the emerging status of S&C in women's soccer academies compared to women's first team or men's academy/first team, it may be the result of sharing facilities with men's first team and/or academy squads, limiting training opportunities (Valenti, 2019), it is worth exploring further as women athletes benefit similarly from S&C practices (Roberts et al., 2020), which can also be an effective injury prevention method (Talpey and Siesmaa, 2017).

An important factor to consider is the potential influence of the menstrual cycle, as this will affect most women players throughout their career. While strength and power metrics appear stable throughout a cycle (Julian et al., 2017), some research suggests gains in strength may be greater during the late follicular phase due to greater concentrations of oestrogen and testosterone (Sung et al., 2014). However, injury risk may be greater during the late follicular phase (Martin et al., 2021), due to increased joint laxity (Balachandar et al., 2017) and instability (Faude et al., 2005), perhaps linked to elevated circulating levels of oestrogen (Belanger et al., 2013), which inhibits collagen fibril cross-linking thus decreasing tissue stiffness (Lee et al., 2015). As discussed above, women academy soccer players have a greater frequency of non-contact soft tissue injuries than their first team counterparts (Faude et al., 2005, Le Gall et al., 2008), which may be linked to differences in circulating sex hormones that fluctuate during the menstrual cycle (Markofski and Braun, 2014). It is important to recognise that research on this topic is in its infancy and more work is required before practitioners can plan training based on the menstrual cycle.

This suggests that monitoring the menstrual cycle and oral contraceptive use (as the latter may be protective against risk of anterior cruciate ligament injury risk (Herzberg et al., 2017)) of female soccer players may be important. Although not asked directly about the menstrual cycle in the current study, only 4% women's coaches reported that they considered it when planning their programmes. This should be investigated further, as its potential influence on injury risk, performance, training adaptation and athlete well-being could change S&C practice in women's soccer.

Limitations

For the findings presented here, there are some limitations that need to be considered. Firstly, data were collected between 01 December 2019 and 01 July 2020, so the transformation, professionalisation and research within women's soccer may change S&C methodology rapidly. Secondly, the larger sample sizes from the UK and South America limit the generalizability of the data. However, the smaller global samples from other European countries (n = 17) and North America (n = 14) are similar to previous observations of S&C practice in soccer (Reverter-Masía et al., 2009) and still provide value. Finally, we analysed the years of S&C coaching experience the participants had accrued, however, this may not necessarily be exclusive to the population the S&C coaches were working with at the time of participation in our study, which may influence their current practice.

Conclusion

Our novel findings suggest key differences exist in S&C practice exist between coaches of men's and women's soccer squads, particularly at academy level. While it is feasible to improve strength and power following a single RT session per week in academy soccer players it may not be optimal (Maio Alves et al., 2010). The fewer weekly in-season S&C sessions for female academy players may have long-term implications for physical development and injury risk. However, the finding that more women's than men's academy S&C coaches use the Nordic hamstring exercise may be a direct result of the greater injury risk/frequency in youth female players, as this has previously been suggested to be an effective injury prevention exercise. Despite this, the greater use of subjective load prescriptions in both academy and first team women's squads (compared to academy and first team men's squads) may lead to sub-optimal adaptation to strength training, which may limit performance gains. Future research should aim to produce guidelines on S&C practice in soccer that are sex- and age-specific.

Future direction

To investigate the findings presented in this chapter further, semi-structured interviews could be utilised to provide a more in-depth explanation. As previously described (chapter four), the following questions have been developed following the guidance of Kallio et al. (2016), when designing a semi-structured interview.

i) *"How many weekly strength and conditioning sessions do you have with your squad in-season? What are the factors that influence this?"*

ii) *"What is your opinion of the Nordic hamstring exercise? If you incorporate it within your programme, why?"*

iii) “*When prescribing training intensity for resistance training what method do you use? And why?”*

iv) “*Do you think male and female players need a different approach when it comes to strength training? And why?”*

Chapter Six – Physical testing and strength and conditioning practices differ between coaches working in academy and first team soccer

6.1 Prelude

After identifying key differences in the training practices of S&C coaches working with men and women soccer players in the previous chapter, the next step was to investigate if practice differed between S&C coaches working with academy and first team squads. The primary focus of these environments differs greatly. For example, academies aim to develop young, talented soccer players into professional (first team) athletes, while success for first team soccer players' relates to improving and maintaining physical performance, which can ensure positive match outcomes. An important comparison to consider is how the S&C methods in academy squads compare with professional squads in relation to long-term athlete development. This comparison would not only highlight differences in strength training methods between senior and academy S&C coaches, but also how applied practice may differ from recognised scientific guidelines for optimising strength and power in soccer, both of which warrant investigation.

6.2 Abstract

Scientific guidelines exist regarding strength and conditioning (S&C) best practice, for both first team and academy level soccer. However, it is not known if these research-informed guidelines are followed in such applied settings. The aim of this study was to investigate current S&C practice in first team and academy level (men's and women's) soccer, worldwide. A total of 170 participants, who were involved with the delivery of S&C support at their soccer club, completed a comprehensive survey, describing their training methods. A greater proportion of academy *vs.* first team coaches assessed change of direction performance (78% *vs.* 60%, p=0.010) as well as conducting fitness testing during (85% *vs.* 71%, p=0.031) and post-season (58% *vs.* 42%, p=0.047). A greater proportion of academy (56%) *vs.* first team (21%) coaches prioritised bodyweight training (p<0.001). Relatively fewer women's academy coaches programmed weightlifting movements compared to their first team counterparts (6% *vs.* 35%, p=0.022). Overall, 44% S&C coaches reported using strength training intensities that were lower than S&C guidelines. This disparity may be due to perceived time restrictions (according to 51% S&C coaches in both first team and academy settings) and concerns of muscle soreness (71% and 39%, respectively). These novel findings suggest that physical development may be constrained in academy (particularly female) soccer players, which may under-prepare them for first team soccer. Moreover, increasing resistance training intensity and reducing repetition ranges in both academy and first team players may enhance physical performance gains in less time and with minimal muscle soreness.

6.3 Introduction

Soccer is a dynamic, high-intensity sport, where a player's strength, power and speed are important contributors to match performance (Faude et al., 2012, Wing et al., 2018). Notably, maximum strength correlates with acceleration, sprint and jump performance in both first team (Wisloff et al., 2004) and youth soccer players (Comfort et al., 2014). Additionally, increased strength may benefit sport-specific skills, such as winning tackles and headers (Wing et al., 2018). Beyond single instances within matches, professional soccer teams with greater lower-limb strength and power attain higher league finishing positions than their weaker competitors (Wisloeff et al., 1998). Furthermore, higher strength levels may reduce match-induced muscle damage (Owen et al., 2015) and injury risk in soccer (Owen et al., 2013). As such, there is an abundance of research examining training methods to improve a soccer player's strength capacity.

The current guidelines of strength and conditioning (S&C) suggest best practice in team sports, such as soccer, at both first team and academy levels (Turner and Stewart, 2014, Meylan et al., 2014b). However, this may not be representative of the programming S&C coaches actually implement with their athletes. In first team players, a narrative review by Turner and Stewart (2014) suggested a twice-weekly programme in-season, maintaining loads of 70-90% single repetition maximum (1RM), in order to maintain strength, alongside a variety of power modalities e.g. weightlifting and plyometric training. However, there may be perceived obstacles to the implementation of resistance training (RT) in soccer. For example, the frequency of RT sessions in the English Premier League and Championship has been reported to be less than recommended by Turner and Stewart (2014) for first team players (Cross et al., 2019). Beyond this, it is likely there are additional contrasts between research-based recommendations and actual applied practice in first team squads. This could be due to limited resources, such as training facilities, staffing, time available to perform RT (Read et al., 2018) and concerns over RT-induced muscle soreness influencing subsequent training/match performance (Draganidis et al., 2013).

In recent years, there has been an increase in research investigating RT in youth sport (McQuilliam et al., 2020, Legerlotz et al., 2016, Moran et al., 2017), particularly in soccer. Meylan et al. (2014b) created a model to develop muscular power in youth soccer players at various stages of biological maturity, following a similar structure to the long-term athlete development (LTAD) model proposed by Côté (1999). Initially focusing on fundamental movements (5-12 years old) and concluding with a focus on maximal strength training (16+ years old) (Meylan et al., 2014b), this model is progressive by design, with each stage building upon the last and laying the foundation for the next. This highlights the importance of long-term planning to optimise strength and power development in the maturing soccer player. However, similar to first team players, there are contrasts between these recommendations for academy players and actual reported practice. Meylan et al. (2014b) recommended 2-3 weekly sessions from 15 years of age onward. In contrast, it has been reported that an elite soccer academy does not undertake regular RT sessions until reaching the under 16 age group (Brownlee et al., 2018b), which is less than recommended. Soccer governing bodies have released their own LTAD structures, such as the Elite Player Performance Plan (EPPP) in England (The English Football Association, 2015). However, these guidelines are generic and open to interpretation by the practitioner. For example, the guidance for strength and power development consists of a "preliminary S&C programme" and "speed, strength, power" (The English Football Association, 2015). Similarly, little information is provided in the EPPP relating to physical performance testing (The English Football Association, 2015). This is a key part of the broader concept of talent identification, long-term athlete development and of high-performance environments (Dodd and Newans, 2018). This thesis has highlighted that strength training has a beneficial impact on many athletic actions. Consequently, it is important to know which key performance indictors practitioners are prioritising as part of the research process to inform the training interventions and research going forward. Though the limited detail is not necessarily negative, it allows for a wide variety of methods to be implemented, potentially explaining some of the differences in player development between academies (Morris et al., 2018b).

Up-to-date knowledge of the current landscape would aid transition of research into the applied environment, thus improving S&C practice and research going forward. Consequently, the primary aim of this study was to compare current S&C practice in soccer between first team and academy settings. To maximise ecological validity, these initial first team *vs.* academy analyses incorporated all participants (S&C coaches), regardless of whether they worked with either men's or women's squads, and regardless of which country they worked in. However, Chapter Three showed that S&C practice varied between global regions, while Chapter Four showed that practice also differed between coaches working with men's *vs.* women's squads. Thus, we followed up our initial analyses with first team *vs.* academy comparisons in specific countries, and then specifically in men's/women's squads to elucidate whether first team *vs.* academy differences existed in these specific settings. It was hypothesized that the methods used to develop strength and power as well as testing preferences would differ between academy and first team coaches due to the nature of LTAD- *vs*. performance-orientated training. It was also hypothesized that there would be disparity between RT guidelines from the scientific literature and current practice at both levels, which would be attributed to perceived time restrictions and concerns regarding high intensity loading during RT.

6.4 Methods

For details of the creation, development, data collection and analysis process please refer to chapter three and appendix 1. For this chapter, the final sample of 170 participants were grouped into either first team or academy staff for subsequent analysis (Table 1).

6.5 Results

Demographics

There were no differences between first team and academy S&C coaches regarding their academic education, overall (χ^2 (3, N = 170) = 5.13, p = 0.162), or within each of the geographic groups (Table 1). Overall, there was a greater proportion of academy coaches having 0-5 years' experience in S&C than first team coaches (59% *vs.* 37%, respectively) and relatively more first team coaches having >10 years' experience than academy coaches (32 % *vs.* 17% respectfully; χ^2 (2, N = 170) = 8.89, p = 0.012). There was also a greater proportion of men's academy coaches having 0-5 years' experience in S&C than first team men's coaches (53% *vs.* 33%, respectively). Overall, relatively more men's first team coaches had >10 years' experience than academy coaches (32% vs. 17% respectively; χ^2 (2, N = 170) = 9.60, p = 0.008). However, there were no differences in S&C experience between academy and first team coaches within each geographic group. Overall, there were no differences in the distribution of job roles (associated with the delivery of S&C) between first team and academy participants (S&C coaches = 72% *vs*. 63%, respectively, sport scientists = 23% *vs*. 32%, respectively, technical coaches = 5% *vs*. 5%, respectfully; χ^2 (2, N = 170) = 1.83, p = 0.400; Table 1). There were no differences in job role distribution between first team and academy within specific geographic or male/female sub-groups.

Table 1: Participant demographic data.

Country	Squad	Job Role	Years in S&C	Education (%)
United Kingdom	First Team *n* = 27	S&C/Fitness coaches = 74% Sport scientists = 26% Technical coaches = 0%	0-5 years = 48% 6-10 years = 33% >10 years = 19%	Bachelors: 3 (11%) Masters: 17 (63%) PhD: 7 (26%)
	Academy *n* = 43	S&C/Fitness coaches = 58% Sport scientists = 37% Technical coaches = 5%	0-5 years = 61% 6-10 years = 30% >10 years = 9%	Bachelors: 30% Masters: 56% PhD: 14%
Rest of Europe	First Team *n* = 4	S&C/Fitness coaches = 75% Sport scientists = 25% Technical coaches = 0%	0-5 years = 25% 6-10 years = 0% >10 years = 75%	Bachelors: 0% Masters: 50% PhD: 50%
	Academy *n* = 13	S&C/Fitness coaches = 92% Sport scientists = 8% Technical coaches = 0%	0-5 years = 46% 6-10 years = 23% >10 years =31%	Bachelors: 8% Masters: 77% PhD: 15%
South America	First Team *n* = 51	S&C/Fitness coaches = 72% Sport scientists = 18% Technical coaches = 10%	0-5 years = 33% 6-10 years = 31% >10 years =35%	Bachelors: 27 (53%) Masters: 10 (20%) PhD: 4 (8%)
	Academy *n* = 18	S&C/Fitness coaches = 67% Sport scientists = 28% Technical coaches = 5%	0-5 years = 50% 6-10 years = 22% >10 years = 28%	Bachelors: 8 (44%) Masters: 6 (33%) PhD: 1 (6%)
USA	First Team *n* = 10	S&C/Fitness coaches = 60% Sport scientists = 40% Technical coaches = 0%	0-5 years = 30% 6-10 years = 40% >10 years =30%	Bachelors: 0% Masters: 80% PhD: 20%
	Academy *n* = 4	S&C/Fitness coaches = 0% Sport scientists = 75% Technical coaches = 25%	0-5 years = 50% 6-10 years = 50% >10 years = 0%	Bachelors: 50% Masters: 50% PhD: 0%

* Difference between first team and academy within group comparison ($p < 0.05$)

Physical Testing

Overall relatively fewer first team coaches reported testing change of direction ability (COD) than the academy coaches (60 *vs.* 78%, respectively; χ^2 (1, N = 170) = 6.61, p = 0.010; Fig. 1), with no differences in 1RM testing (51% *vs.* 46%, respectively; χ^2 (1, N = 170) = 0.41, p = 0.521; Fig. 1), external power (38% *vs.* 39%, respectively; χ^2 (1, N = 170) = 0.003, p = 0.955; Fig. 1), jump testing (85% *vs.* 91%, respectively; χ^2 (1, N = 170) = 1.52, p = 0.218; Fig. 1), sprint performance (84% *vs.* 91%, respectively; χ^2 (1, N = 170) = 2.01, p = 0.156; Fig. 1), muscular endurance (30% *vs.* 21%, respectively; χ^2 (1, N = 170) = 2.17, p = 0.141; Fig. 1), anaerobic capacity (41% *vs.* 51%, respectively; χ^2 (1, N = 170) = 1.69, p = 0.193; Fig. 1) or aerobic capacity (79% *vs.* 87%, respectively; χ^2 (1, N = 170) = 1.83, p = 0.176; Fig. 1).

Relatively more UK first team coaches reported testing muscular endurance than their academy counterparts (48% *vs.* 14%, respectively; χ^2 (1, N = 70) = 9.81, p = 0.002). A greater proportion of SA academy coaches than SA first team coaches reported testing power with external load (61% *vs.* 39%, respectively; χ^2 (1, N = 69) = 4.03, p = 0.045) and COD (83% *vs.* 55%, respectively; χ^2 (1, N = 69) = 4.585, p = 0.032). In men's squads only, relatively more academy than first team coaches reported assessing sprint performance (95% *vs.* 81%, respectively; χ^2 (1, N = 108) = 5.11, p = 0.024) and COD (82% *vs.* 56%, respectively; χ^2 (1, N = 108) = 8.26, p = 0.004). No other differences were seen within geographic or male/female groups.

Collectively, there were similar proportions of first team and academy coaches conducting testing at the start of pre-season (83% *vs.* 91%, respectively; χ^2 (1, N = 170) = 2.56, p = 0.11) and end of pre-season (57% *vs.* 51%, respectively; χ^2 (1, N = 170) = 0.47, p = 0.49). There were differences between the proportions of first team *vs*. academy S&C coaches regarding fitness testing conducted in-season (71% *vs.* 85%, respectively; χ^2 (1, N = 170) = 4.66, p = 0.03) and at the end of the season (42% *vs.* 58%, respectively; χ^2 (1, N = 170) = 3.95, p =

0.047). In men's squads only, relatively fewer first team S&C coaches conducted fitness testing than academy coaches in-season (67% *vs.* 85%, respectively; χ^2 (1, N = 108) = 5.04, $p = 0.025$) and at the end of the season (33% *vs.* 55%, respectively; χ^2 (1, N = 108) = 5.05, $p = 0.025$).

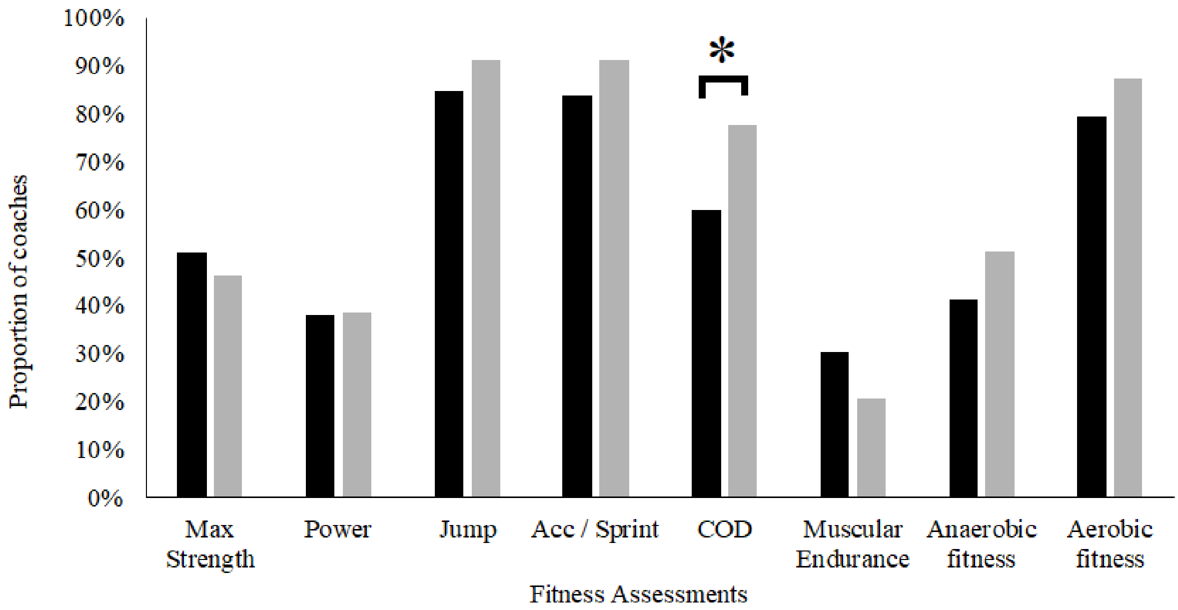

Figure 1: The proportions of first team (black bars) and academy (grey bars) coaches, who use each physical performance test in their practice with their soccer players.

* Difference between first team and academy ($p < 0.05$)

Training Prescription

There was a greater proportion of academy coaches, who prioritised bodyweight training than first team squad coaches (56% *vs.* 22%, respectively; χ^2 (1, N = 147) = 17.59, $p < 0.001$). This was consistent in both men's (academy = 52% *vs.* first team = 21%; χ^2 (1, N = 93) = 9.37, p = 0.002) and women's (academy = 69% *vs.* first team = 24%; χ^2 (1, N = 54) = 9.81, $p = 0.002$) comparisons but there were no differences within each geographic group.

Overall, there was a greater proportion of first team S&C coaches, who prioritised free-weight RT (first team = 65% *vs.* academy = 41%; χ^2 (1, N = 147) = 8.15, $p = 0.004$). This was consistent in both men's (first team = 67% *vs.* academy = 44%; χ^2 (1, N = 93) = 4.50, $p = 0.002$) and women's (first team = 63% *vs*. academy = 31%; χ^2 (1, N = 54) = 4.61, p = 0.032) comparisons but there were no differences within each geographic group.

Overall, there were no differences between the proportions of first team and academy coaches programming bi-lateral squats (81% *vs*. 86%, respectively; χ^2 (1, N = 156) = 0.51, p = 0.474; Fig. 2), bi-lateral hinges (79% *vs*. 84%, respectively; χ^2 (1, N = 154) = 0.77, p = 0.381; Fig. 2), weightlifting movements and derivatives (WL; 30% *vs*. 26%, respectively; χ^2 (1, N = 156) = 0.26, p = 0.609; Fig. 2), unilateral exercises (69% *vs*. 58%, respectively; χ^2 (1, N = 156) = 1.98, p = 0.159; Fig. 2) or plyometrics (30% *vs*. 36%, respectively; χ^2 (1, N = 156) = 0.54, p = 0.462; Fig. 2). Sub-group analyses showed a greater proportion of women's first team S&C coaches utilised WL than women's academy S&C coaches (35% *vs.* 6% respectively; χ^2 (1, N = 57) = 5.22, p = 0.022).

When the aim was to train strength in-season, there were no differences between first team and academy S&C coaches regarding the number of sets (t_{45} = 1.64., p = 0.109; Fig. 3A) or repetitions (t_{45} = -1.46., p = 0.153; Fig 3B) prescribed. However, first team S&C coaches prescribed a greater RT intensity when converted to a percentage of 1RM than academy S&C coaches (t_{45} = 2.35., p = 0.002; Fig. 3C).

When comparing the methods used to prescribe exercise intensity, there were no differences between first team and academy coaches, who used %1RM (41% *vs.* 40%, respectively; χ^2 (1, N = 170) = 0.02, p = 0.904), or who subjectively selected intensity (44% *vs.* 53%, respectively; χ^2 (1, N = 170) = 1.40, p = 0.237), or who allowed the athlete to subjectively selected intensity (44% *vs.* 56%, respectively; χ^2 (1, N = 170) = 2.82, p = 0.09). Overall, a greater proportion of first team S&C coaches utilised velocity measures to prescribe RT load than academy S&C coaches (33% *vs.* 19% respectively; χ^2 (1, N = 170) = 3.88, p = 0.049). At a sub-group level, a greater proportion of SA academy coaches utilised %1RM (69% *vs.* 31% respectively; χ^2 (1, N = 69) = 4.94, p = 0.03) than SA first team squads.

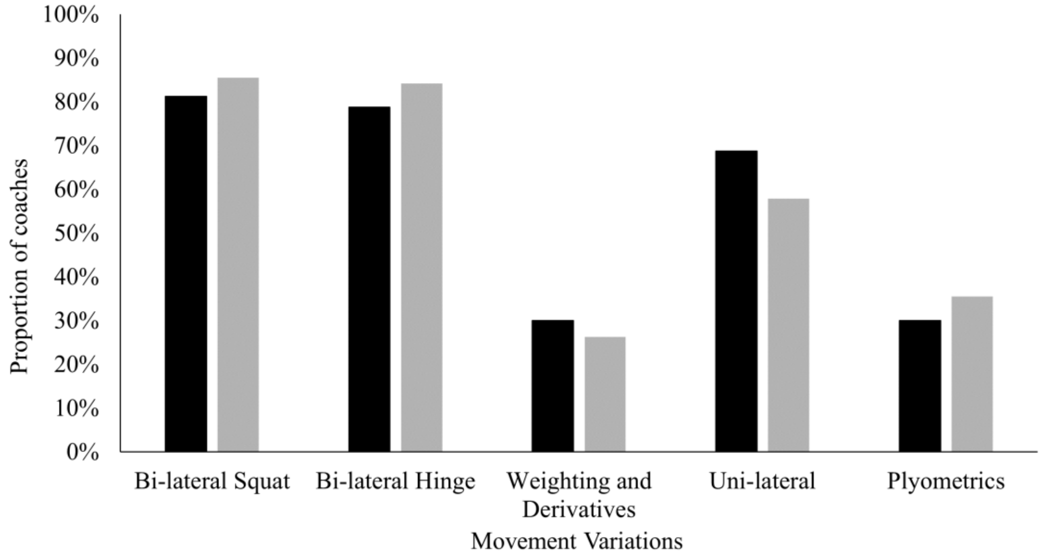

Figure 2: The proportions of first team (black bars) and academy (grey bars) coaches, who incorporate these movement patterns/exercise types into their practice to develop strength and/or power with their soccer players.

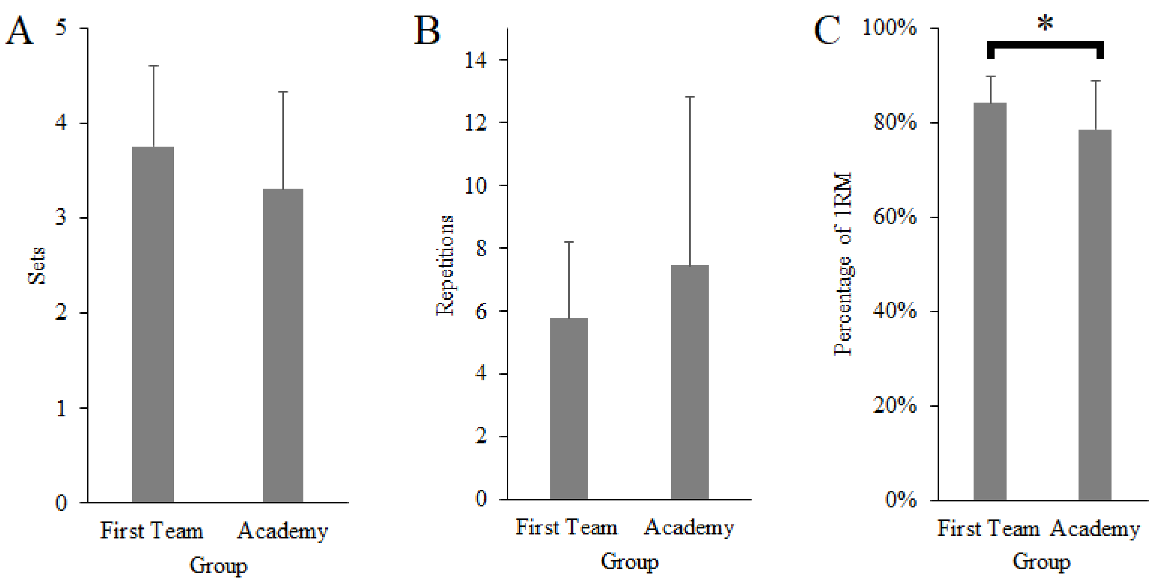

Figure 3: The sets (A), repetitions (B) and training intensity (C) first team and academy coaches prescribe to for strength training in-season.

* Difference between first team and academy ($p < 0.05$)

Periodization

Pre-season

First team squad coaches reported more weekly S&C sessions than academy coaches when compared overall (2.96 ± 1.05 *vs.* 2.39 ± 0.83, t_{163} = 3.74, $p < 0.001$), specifically in the UK (2.80 ± 0.96 *vs.* 2.37 ± 0.70, t_{64} = 2.12, $p = 0.04$; Table 2), specifically in men's soccer (2.85 ± 1.10 *vs.* 2.42 ± 0.79; t_{104} = 2.36, $p = 0.020$; Table 2), and specifically in women's soccer (3.07 ± 1.00 *vs.* 2.31 ± 1.01; t_{57} = 2.56, $p = 0.013$; Table 2). However, there were no differences in the number of weekly S&C sessions reported between first team and academy S&C coaches specifically in the SA group (3.10 ± 1.11 *vs.* 2.78 ± 0.94; t_{66} = 1.10, $p = 0.28$; Table 2).

Overall, there was no difference in session duration between first team and academy S&C coaches during pre-season (53 ± 17 min *vs.* 48 ± 18 min; t_{162} = 1.99, $p = 0.049$). However, women's first team S&C coaches reported a longer pre-season session duration than women's academy S&C coaches (58 ± 15 min *vs.* 48 ± 16 min; t_{58} = 2.22; $p = 0.030$; Table 2). There were no differences within other sub-groups.

In-season

Overall, there was no difference between first team and academy groups regarding the number of in-season weekly S&C sessions (2.17 ± 0.92 *vs.* 2.10 ± 0.87; t_{164} = 0.46, $p = 0.644$), and no differences within geographical groups. However, women's first team coaches reported a greater number of in-season weekly S&C sessions than women's academy coaches (2.20 ± 1.02 *vs.* 1.59 ± 0.62, t_{59} = 2.32, $p = 0.024$; Table 2). There was no difference in the average S&C session duration between first team and academy groups overall (48 ± 18 min *vs.* 46 ± 17 min, t_{161} = 0.49, $p = 0.488$), or within geographic or male/female groups (Table 2).

Table 2: Time spent in formal S&C sessions, Frequency – sessions per week				
Squad	Pre-Season		In-season	
	Frequency	Duration (min)	Frequency	Duration (min)
UK first team	2.80 ± 0.96 *	45 ± 9	2.12 ± 0.65	45 ± 12
UK academy	2.37 ± 0.70 *	47 ± 14	2.02 ± 0.78	46 ± 15
SA first team	3.10 ± 1.11	58 ± 19	2.32 ± 1.04	51 ± 20
SA academy	2.78 ± 0.94	49 ± 22	2.33 ± 0.69	47 ± 16
Men's first team	2.85 ± 1.10 *	48 ± 18	2.13 ± 0.81	58 ± 15 *
Men's academy	2.42 ± 0.79 *	48 ± 19	2.25 ± 0.88	48 ± 16 *
Women's first team	3.07 ± 1.00 *	58 ± 15 *	2.20 ± 1.02 *	53 ± 16
Women's academy	2.31 ± 1.01 *	48 ± 16 *	1.59 ± 0.62 *	44 ± 17

* Difference between first team and academy ($p < 0.05$).

Restrictions

Relatively more first team coaches were concerned with potential muscle soreness following an S&C session than academy coaches overall (71% *vs.* 39%, χ^2 (1, N = 170) = 17.74, $p < 0.001$; Fig. 4), solely in the UK (74% *vs.* 37%, χ^2 (1, N = 72) = 10.02, $p = 0.002$), SA (80% *vs.* 56%, χ^2 (1, N = 46) = 8.01, $p = 0.005$), solely in men's squads (65% *vs.* 35%, χ^2 (1, N = 108) = 9.35, $p = 0.002$) and solely in women's squads (77% *vs.* 50%, χ^2 (1, N = 62) = 4.47, $p = 0.034$). There were no differences in the percentage of first team and academy coaches, who felt their S&C practice was restricted by time (51% *vs.* 51%, χ^2 (1, N = 170) = 0.01, $p = 0.980$;

Fig 4) or facilities/equipment (29% *vs*. 36%, χ^2 (1, N = 170) = 0.83, $p = 0.363$; Fig 4). This was consistent within each geographic and male/female sub-group.

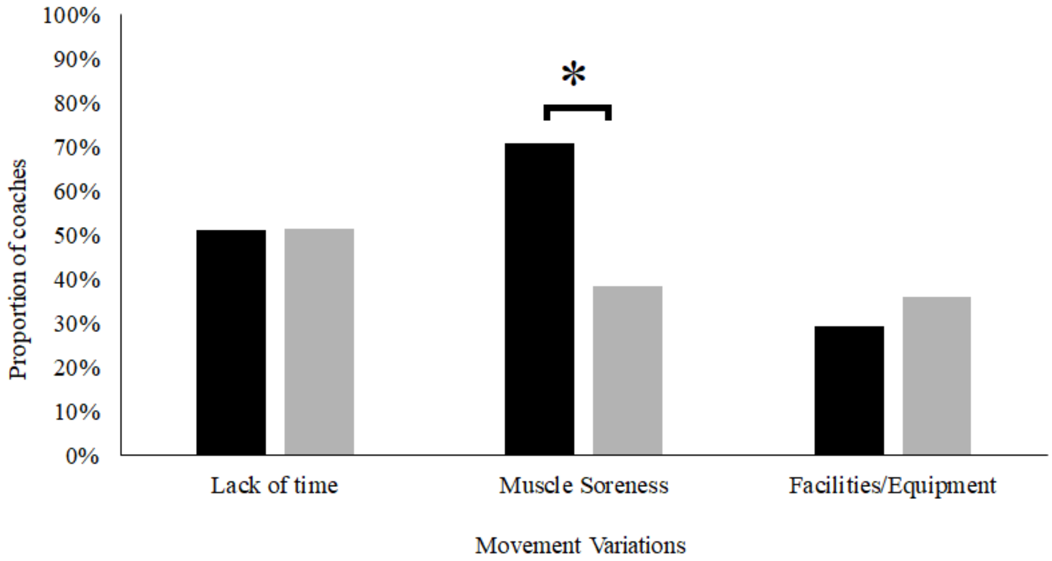

Figure 4: The proportions of first team (black bars) and academy (grey bars) coaches, who perceived their S&C practice to be restricted by lack of time, potential muscle soreness following training and facilities/equipment. * different to academy coaches ($p < 0.05$).

6.6 Discussion

The present study sought to conduct a comprehensive survey of S&C provision in soccer, specifically comparing the practices of first team and academy coaches, in both men's and women's soccer, all on a global scale. The weekly training structure differed between first team and academy groups, particularly within women's squads, with women's academy coaches reporting the lowest session frequency of all groups. Overall, a greater proportion of academy coaches prioritised bodyweight training compared to first team coaches despite a similar distribution of movement patterns. There were no differences in the number of prescribed strength training sets or repetitions between first team and academy coaches but training intensity (prescribed as a percentage of 1RM) was greater in first team S&C coaches. Relatively more first team S&C coaches prescribed external load for resistance training using velocity-based measures than their academy counterparts. Finally, a greater proportion of academy S&C coaches reported testing more frequently throughout the season than first team coaches. The methods used to develop strength and power, as well as testing preferences, differed between academy and first team S&C coaches, which was likely due to the nature of LTAD- *vs*. performance-orientated training.

When considering that soccer is dominated by aerobic metabolism (Bangsbo, 1994) and key moments can be defined by powerful actions (Faude et al., 2012), it is not surprising that sprint and jump performance, and aerobic fitness were the most assessed physical attributes by both first team and academy S&C coaches. However, our study showed that a greater proportion of academy S&C coaches assessed COD performance compared to first team coaches (Fig. 1). The assessment of COD commonly involves acceleration(s), deacceleration(s) and a variety of COD options. The greater proportion of academy coaches conducting COD as well as power, speed and aerobic fitness tests could be due to the concept of long-term athlete development and talent identification (Dodd and Newans, 2018), which is the predominant focus of soccer academies. This finding was supported by the increased regularity of testing by academy compared to first team S&C coaches. While coaches with first team and academy squads followed a consistent pattern of physical testing at the start and the end of pre-season, relatively more academy than first team coaches conducted testing during the season and at the end of the season. The physical development of academy soccer players can be non-linear and, consequently, regular testing can highlight the sporadic fluctuations apparent in physical performance and enable contextualisation (e.g. comparing with simultaneous measures of biological maturation) to further aid player development (Moran et al., 2020).

Other invasion games that are influenced by lower-body strength and power have had current S&C practice surveyed to help gain a better understanding of the training methods applied

(Jones et al., 2016, Simenz et al., 2005, Ebben and Blackard, 2001, Duehring et al., 2009). A greater proportion of academy coaches in this study prioritised bodyweight training compared to first team squad coaches (56% *vs*. 22%, respectively), although there appears to be a similar pattern between first team and academy coaches regarding exercise selection. This appears to be considerably different to the previously referenced studies, where over 90% of S&C coaches working with first team (Jones et al., 2016, Simenz et al., 2005) and youth athletes (Duehring et al., 2009) have reported utilising the squat in other sports, in comparison to 81% of first team and 86% of academy coaches here. This may be explained by the proportion of coaches using unilateral alternatives (Fig. 2). Unilateral RT is perceived to transfer better to sport-specific actions, such sprinting and change of direction (Stern et al., 2020). However, both bilateral and unilateral training produced similar improvements jump and sprint performance when matched for workload, suggesting training volume and intensity are more important factors than the exercise selection itself (Stern et al., 2020, Speirs et al., 2016, Appleby et al., 2019).

Like the squat, over 90% of S&C coaches working with both professional (Jones et al., 2016, Simenz et al., 2005, Ebben and Blackard, 2001) and youth (Duehring et al., 2009) athletes in other sports have previously reported using weightlifting movements. However, the proportions of first team and academy S&C coaches utilising weightlifting movements were much lower here (30% and 26%, respectively) than the 67% of S&C coaches in professional soccer recently reported by Weldon et al. (2020). This may explain the higher frequency of bi-lateral hinge movements in both groups in the current study (Fig. 2). Movements such as these target the gluteal and hamstring musculature, both of which contribute heavily during running, while the latter is also a common injury site in soccer (Hall et al., 2020, Morin et al., 2015). While traditional RT of the posterior chain can be an important part of a soccer S&C programme, the omittance of weightlifting by 72% of coaches overall and 93% of women's academy S&C coaches is a unique finding and future research should explore why fewer S&C

coaches in soccer programme weightlifting exercises than coaches in other sports, such as rugby union and basketball (Jones et al., 2016, Simenz et al., 2005).

The ability to maintain or even build strength throughout a season may be important to powerful sporting actions as well as increasing players' match availability (Owen et al., 2013, Comfort et al., 2014). In our study, the number of sets and repetitions prescribed for strength training did not differ between first team and academy coaches, however, there was a difference observed in training intensity prescribed (Fig. 3). Research does suggest a focus on technique and lower training intensities with less experienced youth athletes to develop training competency (McQuilliam et al., 2020) and may explain the difference in training intensity seen here. While the means in strength training prescription aligns with those suggested for first team (Turner and Stewart, 2014) and youth soccer players (Meylan et al., 2014b) the large range of repetitions (1 to 30) and exercise intensity (60 to 95% 1RM) highlight the variability between coaches' practice. This indicates that a large proportion of coaches deviate from development models in the scientific literature.

It is commonly accepted that training intensity is a crucial factor when the aim is to increase an individual's strength (Fry, 2004). There was a wide variety of methods used to prescribe RT load in first team and academy programmes, which may in part explain why there was little difference overall. Relatively more men's coaches than women's coaches used objective methods of training load prescription, such as measures of velocity (33% vs. 18% respectively). Due to instant feedback, velocity thresholds for different strength qualities and the ability to factor in daily fluctuations in strength and power this method has become increasing popular (Weakley et al., 2020). However, its adaptation appears limited within soccer, with only 27% participants using it to prescribe training intensity. This may be due to the financial cost of accurate units and the feasibility to implement this emerging technology within a training programme (Guerriero et al., 2018). The limited contact time with academy athletes may also restrict the opportunity to assess strength. This assumption is supported by both session frequency and duration being lower in UK women's academy squads than their first team counterparts in this study, and potentially highlights the early stages of development within the women's game (FIFA, 2018).

The manipulation of training variables is an important aspect for improving performance. Previously, it has been reported that one to two S&C sessions per week take place in-season in first team (Cross et al., 2019) and academy soccer squads (Brownlee et al., 2018b), with guidelines suggesting two to three sessions per week are required for optimal performance/adaptation (Meylan et al., 2014b, Turner and Stewart, 2014). Weekly training structure differed between first team and academy within groups, particularly during pre-season. During this time, first team coaches reported more S&C sessions than academy coaches (Table 2). This is likely reflective of the greater training demands of a full-time professional soccer programme. In contrast, there was no difference between first team and academy S&C session frequency in-season. On a sub-group level, however, S&C coaches of women's first team squads reported a greater number of sessions than their academy counterparts (Table 2), with women's academy squads having the lowest average of all groups. Despite the tremendous growth of female soccer in recent years, this is likely attributable to the ongoing development of women's soccer (FIFA, 2019). This lower exposure to S&C should be explored further, as young female players may be underpreparing for sporting demands which may increase the difficulty of progressing to first team soccer. This is especially pertinent given the high incidence of injury reported for this group (Le Gall et al., 2008).

Multiple factors can influence an S&C programme, including but not limited to a congested fixture schedule, which can result in the accumulation of fatigue and limited opportunities to train, particularly in an elite professional team (Dupont et al., 2010). The most common factors restricting the incorporation of RT into S&C sessions for first team coaches were concerns over muscle soreness (71%) followed by lack of time (51%), while academy coaches were more commonly restricted by lack of time (51%; Fig. 4). These findings were amplified in the UK. Muscle soreness and fatigue can be caused by different stimuli and managing the interplay of these is a key aspect to the implementation of RT alongside a technical sport-specific training programme. The large number of repetitions used by first team and academy coaches could potentially be causing greater muscle soreness and fatigue (Fig. 3 and Fig. 4), whereas high-intensity RT is associated with lower volume and, in turn, faster recovery (Bartolomei et al., 2017). Furthermore, time restrictions have previously been cited as a major factor when looking to implement injury prevention strategies in soccer (Read et al., 2018), with 32% of coaches in our study stating that limited time restricted their practice. A low-volume, high-intensity strength training protocol (90% 1RM) has previously been implemented in-season with professional soccer players (Rønnestad et al., 2011) and may be a potential solution to alleviating these perceived restrictions. Strength development needs to be effectively implemented alongside training other physical components important to soccer performance. Future research should investigate whether high-intensity, low-volume strength training has a meaningful impact in the applied setting, thus improving strength where time is perceived to be a limiting factor.

A limitation of the current study was that the survey only asked for training methods during a single match week. Successful soccer teams may play two or three matches per week for extended periods of time during the season, and this may influence the training methods implemented. However, standardising responses to a single match week allowed for a clearer comparison of the methods used by S&C coaches. Finally, when examining the answers provided for the prescription of sets, repetitions, and intensity, only 26% of the total responses could be used (n = 41). While the information provided by participants was rich with information, due to the wide variety of methods, it was not possible to convert all the information into traditional sets, repetitions, and percentage of 1RM that are universally recognised. This key finding suggests that methods of assigning RT load according to the established scientific principles and research in soccer is a priority area for development. This highlights the complexity of implementing quality strength and power training in a soccer environment.

Conclusions

This study compares S&C practices of coaches working with both first team and academy soccer players in Europe and North and South America, in both men's and women's soccer. Overall, a greater proportion of academy coaches prioritised bodyweight training compared to first team coaches (despite a similar distribution of movement patterns trained), which may limit physical development in academy players. Overall, 44% of S&C coaches reported using training intensities that were sub-optimal according to published strength training guidelines (≥80% 1RM), which may be due to perceived time restrictions and concerns of muscle soreness. The difference between S&C coaches working with women's academy and women's first team squads suggests that young female soccer players may be inadequately prepared to enter a first team environment. Further, coaches may use the information presented here as a reference point to compare and inform their own practice.

Future directions

To investigate the findings presented in this chapter further, semi-structured interviews could be utilised to provide a more in-depth explanation. As previously described (chapter four), the following questions have been developed following the guidance of Kallio et al. (2016), when designing a semi-structured interview.

i) *"As part of your normal practice do you perform physical performance testing? If so, what assessments do you utilise and why?"*

ii) *"What methods would you use to develop your players strength in-season?"*

iii) *"When prescribing training intensity during resistance training exercises what are you most common methods and why?"*

iv) "*What factors potentially influence you training programme and session design?"*

Chapter Seven – The Effect of High- *vs.* Moderate-Intensity Resistance Training on Strength, Power, Speed and Perceived Muscle Soreness in Youth Soccer Players

7.1 Prelude

One of the most consistent findings from Chapters Four, Five and Six was that S&C coaches working in soccer felt their practice was limited by both time and the potential for their players to experience muscle soreness following resistance training (RT). Free-weight RT is an effective method to improve strength and power in academy soccer players but the majority of academy S&C coaches in the previous chapter prioritised bodyweight training over free-weights. The current chapter used the findings from Chapters Four, Five and Six to design an ecologically valid study to test the hypothesis that high-intensity free-weight RT would elicit similar or greater gains in physical performance in male, academy-aged soccer players than either moderate-intensity RT (i.e. the most common type of RT in soccer, as reported in Chapters Four to Six) or soccer training alone. Furthermore, high-intensity RT would incorporate less volume, thus minimising perceived restrictions regarding limited time and the potential for muscle soreness. The initial intention was to approach elite academies once we had completed the training study in the academy used in chapter seven (as a proof of concept study to have immediate impact in elite academy soccer). Unfortunately, due to the COVID-19 pandemic, this training study was cut short (the intension was to run it for 12 weeks but the national lockdown in March 2020 forced us to cut it short to six weeks), and we had to restart it several times before successfully completing it in December 2021. Thus, it was not possible to replicate this (or a similar) study in elite academy cohorts. However, the academy used in this chapter was chosen as the participants played football at a high standard (many students have been category one academy players and the academy regularly competes against category one academies, and competes in the Dallas Cup tournament). Further, the participants were of academy age (16 – 19 years-old) and would have provided a sample size large enough for the originally planned investigation to be completed.

7.2 Abstract

The aims of this study were to investigate the impact of high- *vs.* moderate-intensity resistance training (RT) on changes in strength, power, and speed, and perceived muscle soreness, compared to soccer training alone. Twenty-one male academy soccer players (age: 18 ± 1 years) were assigned to either high-intensity RT (HRT: n=8), moderate-intensity RT (MRT: n 7) or control (CON: n=7). HRT completed two sets of four repetitions of parallel back squat at 90% 1RM, while MRT performed three sets of eight repetitions of parallel back squat at 80% 1RM, both once a week for six-weeks in-season, alongside regular pitch-based soccer training. CON performed pitch-based soccer training only. All groups completed the following assessments pre- and post-training: 3RM back-squat; bilateral vertical and horizontal countermovement jump (CMJ); squat jump (SJ); 20 m sprint. HRT and MRT experienced similar increases compared to CON ($p<0.05$) in absolute (16% *vs*. 27%, $p=0.38$) and relative to body mass back-squat strength (16% *vs*. 23%, $p=0.066$), SJ height (6% *vs*. 11%, $p=0.826$), CMJ height (8% *vs*. 10%, $p=0.587$) following training. Further, HRT (but not MRT or CON) improved horizontal CMJ (11%, 7% and 2%, respectively, $p=0.011$). No improvements in sprint time were observed in any group. The performance improvements by HRT were achieved with 58% less training volume compared to MRT ($p<0.001$) and similar muscle soreness to soccer alone. These findings suggest that just one HRT session a week is an efficient method for improving strength and power with minimal muscle soreness in academy soccer players in-season.

7.3 Introduction

Soccer is an intermittent sport requiring high-intensity dynamic movements, such as acceleration, sprinting, change of direction (COD) and jumping (Castagna et al., 2003, Murtagh et al., 2019). Youth soccer (under 18 year-old) players complete an average of 81 ± 18 powerful actions during a match, with the most common being initial and leading accelerations (~68), followed by a similar number of sprints (~8) and vertical jumps (~6) (Murtagh et al., 2019). Improvement in these key game elements can positively influence performance in professional soccer (Faude et al., 2012) and related test scores can separate elite from non-elite performers (Murtagh et al., 2018). Based on this, high levels of muscular strength and power are very important in youth soccer (Comfort et al., 2014). Therefore, effective training methods to develop these powerful movements are fundamental to improving performance.

Strength and conditioning (S&C) coaches in youth soccer actively seek to improve these sport specific actions through a variety of training methods, of which resistance training (RT) is a central component (see Chapter Five). Further results from Chapter Five show that men's academy S&C coaches in the UK incorporate 2 ± 1 S&C sessions per week, lasting 45 ± 14 minutes. Conclusions from a youth RT meta-analysis suggest that the most effective training frequency to develop strength and power in youth athletes is 2-3 sessions a week, while a single session may maintain established strength levels (Lesinski et al., 2016). However, a single RT session per week can be sufficient to improve strength and power performance in those with less experience (Maio Alves et al., 2010), whereas high-intensity RT may be required with increased training age (Rodríguez-Rosell et al., 2017). Moreover, results from Chapters four to Six suggest that limited time is one of the main reasons given by S&C coaches for not incorporating RT into their players' programmes. Thus, the inclusion of just one RT session per week may be perceived as being more practically feasible for some practitioners.

Youth soccer RT interventions that have followed the guidelines of Lesinski et al. (2016) have resulted in increases in soccer-specific athletic actions. When utilising training intensities ≥80% single repetition maximum (1RM) in-season, increases in strength, acceleration, sprint and vertical jump have been reported following eight-weeks (Chelly et al., 2009, Styles et al., 2016), with no change in muscle cross-sectional area (Hammami et al., 2018). Consequently, improvements in physical performance were attributed to neural adaptations rather than muscle hypertrophy (Hammami et al., 2018). This is an important consideration, as strength relative to body mass has strong correlations with improvements in acceleration and vertical jump performance (Styles et al., 2016, Comfort et al., 2014). Together, this suggests the implementation of strength-training programmes during the competitive period should be feasible. However, in-season soccer S&C coaches implement three sets of eight repetitions when aiming to develop strength (Chapter Five), which would typically be regarded as hypertrophy/strength-endurance training (>6 repetitions) rather than training to primarily improve strength (1 to 6 repetitions) (Haff and Triplett, 2015, Kraemer and Ratamess, 2004). Further, according to Chapters Four, Five and Six, the two limiting factors reported by coaches for not incorporating RT into soccer training are time constraints and concerns of athletes experiencing muscle soreness following training. As the volume of training may dictate both the time taken to complete a RT session and the degree of muscle soreness experienced by the athlete, limiting these factors may help maximise performance gains with minimal impact on time to complete soccer-specific training and discomfort felt by the players.

Beyond prescribing training volume and intensity, a key variable to consider is exercise selection and specific variations. In Chapter Five, bi-lateral squatting patterns were the most common movement prescribed by Academy S&C coaches (85% of responders). However, variations within this group of movements may impact training adaptations, for example, the range of movement implemented. Each of the cited training studies have implemented the half-squat, characterised by (80 – 100° knee flexion). This is potentially due to participants having inadequate technique, and concerns regarding lack of mobility and injury (Escamilla et al., 2001), or the belief that it is a more sport-specific range of motion (Rhea et al., 2016). However, full- (135 – 140° knee flexion) and parallel- (110 -120° knee flexion) squats have been shown to improve vertical jump, acceleration, and load-velocity characteristics more so than half- and quarter-squats (Hartmann et al., 2012, Pallarés et al., 2019, Bloomquist et al., 2013).

Consequently, the primary aim of this study was to investigate the impact of high-intensity, low-volume RT (HRT) *vs.* moderate-intensity, high-volume RT (MRT), on changes in strength, power and speed (and perceived muscle soreness) in youth soccer players, compared to pitch-based soccer training only. We hypothesized that performance benefits would be similar between HRT and MRT, but that HRT would elicit less perceived muscle soreness due to a lower training volume (making training sessions shorter, thus more effective).

7.4 Methods

Participants

To be eligible to take part, participants had to be young, healthy men, part of a regular soccer-training programme, free from lower-body injuries, and attend 100% of training sessions. Participants were recruited from an education and soccer college, which incorporated three soccer training sessions and at least one soccer match per week against soccer academies. Fifty-one soccer players volunteered to participate in the study and provided written consent prior to start of the intervention. Ten players dropped out due to injury sustained during soccer training/match-play (not as a consequence of the study) and a further 20 could not complete the post-training assessments due to the COVID-19 pandemic. An *a priori* power calculation was performed to estimate the required sample size using G*Power software (v3.1.9.6, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). Given the mixed design of this study, a repeated measures ANOVA, within-between interaction and two measurements (pre- and post-intervention), a total sample of 21 participants (7 per group) was required to detect a medium effect size (d = 0.50) per assessment. A total of 21 participants completed the study (age = 18 ± 1 years; height = 178.5 ± 6.5 cm; body mass = 71.4 ± 7.4 kg) and included one goalkeeper, six defenders, six midfielders and eight forwards. All took part in formal soccer training (eight hours per week) plus one or two competitive fixtures each week. Participants had prior experience of lower-body RT (1-3 years) but not of high-intensity training (>70 % 1RM).

Experimental approach to the problem

Testing pre- and post-intervention consisted of maturity offset assessment (Mirwald et al., 2002), 30 m sprint, squat jump (SJ), bilateral vertical and horizontal countermovement jumps (CMJ), and 3RM back squat. Participants were randomly assigned to either a high-intensity RT group (HRT: n = 8), moderate intensity RT group (MRT: n = 7) or a soccer only control group (CON: n = 7). Groups were matched according to their baseline 3RM, age, height and body mass. HRT completed two sets of four repetitions of parallel back squat at 90% 1RM (estimated from 3RM), while the MRT group performed three sets of eight repetitions of parallel back squat at 80% 1RM. The groups in the final sample did not differ regarding baseline body mass (p = 0.197), height (p = 0.068) or back squat strength (p = 0.063, Table 1). Final groups differed in age and maturity offset and relative strength at baseline (Table 1). Both HRT and MRT completed a six-week in-season strength training programme alongside regular soccer training, with one session a week on match day minus two (two days prior to a competitive fixture). CON performed their regular soccer training for the six-week period. The study complied with the Declaration of Helsinki and was approved by the Liverpool John Moore's University

Research Ethics Committee. All participants provided written informed consent prior to taking part in the study.

Table 1: Participant characteristics

	HRT (n=8)	MRT (n=7)	Control (n=7)
Chronological age (years)	18 ± 1	18 ± 1	19 ± 1
Body mass (kg)	68.2 ± 6.5	75.1 ± 8.4	71.6 ± 6.4
Height (m)	1.75 ± 0.06	1.83 ± 0.07	1.79 ± 0.05
Maturity offset	2.76 ± 0.76	2.82 ± 0.95	3.87 ± 3.93 *
Estimated 1RM (kg)	89.2 ± 18.7	78.5 ± 16.1	88.3 ± 7.5
Strength relative to body mass ($kg \cdot kgBM^{-1}$)	1.3 ± 0.2	1.1 ± 0.2	1.4 ± 0.1

1RM, single repetition maximum.

* different from other groups

Testing methodology

Participants attended two separate testing days (with a minimum of 48 hours between each session) before and after the six-week intervention period. To reduce the impact of fatigue participants were asked to abstain from high-intensity exercise for a minimum of 24 hours prior to each testing session.

Testing Day One

The first session comprised measurements of body mass (Digital flat scale, Seca, Hamburg, Germany) and standing and sitting height (Portable stadiometer, Seca, Hamburg, Germany), in order to calculate maturity offset using the previously proposed equation by Mirwald et al. (2002).

$$Maturity\ Offset\ =\ -29.769\ +\ 0.0003007\cdot$$
$$Leg\ Length\ and\ Sitting\ Height\ interaction\ -0.01177\cdot$$
$$Age\ and\ Leg\ Length\ interaction\ x\ 0.01639\cdot Age\ and\ Sitting\ Height\ interaction\ +$$
$$0.445\cdot Leg\ by\ Height\ ratio$$

Participants were familiarised with each jump assessment prior to testing. Participants completed three trials of each jump type, with 30 seconds rest between jumps, and approximately five minutes between jump types. For the SJ and vertical CMJ, participants were instructed to jump as high as possible, fully extending through hip, knee and ankle while keeping their arms akimbo to eliminate the effect of arm swing. Participants were asked to land on the balls of their feet followed by three small bounces on the indoor, gym floor. This was done to control jump and landing positions as jump height was calculated indirectly via flight time (Optojump, Microgate, Bolzano, Italy). This method has been shown to have excellent reliability (intra-class correlation (ICC) = 0.982 – 0.989) and low coefficients of variation (CV = 2.8%) in a similar cohort (Glatthorn et al., 2011). Horizontal CMJ testing was performed on an outdoor artificial grass surface. Participants started with both feet behind a straight line and were instructed to jump as far as possible. Participants were required to maintain balance upon landing with the measurement taken from the heel of the foot nearest the start line. This method has previously been shown to excellent reliability (ICC = 0.99) with low CV (1.9%) in a similar cohort (Dugdale et al., 2019). For each of the three jump types, if the third attempt was the best, participants were given additional attempts until results no longer increased. The peak value was used in subsequent analysis.

All participants completed a 15-minute standardised warm up prior to sprint testing. The warmup consisted of light jogging, dynamic bodyweight movements, submaximal sprints and decelerations. Participants completed three 30 m sprints on an outdoor 3G pitch while wearing appropriate soccer training kit. Sprints started in a static, split stance position with no countermovement one meter behind the start line. Timing gates (TCi System, Brower, Salt Lake City, USA) were placed 1 m from the start line, 11 m, 21 m and 31 m from the start line. Participants were instructed to sprint beyond the final gate to ensure no slowing down prior to completion. There was a three-minute rest between each sprint for full recovery (Miller, 2012). The fastest split for each sprint was used in subsequent analysis. These sprint distances have previously been reported to have good reliability (10 m, ICC = 0.78 (95% confidence intervals: 0.57 – 0.89); 20 m, ICC = 0.78 (0.85 – 0.97)) and low coefficients of variation (10 m = 2.4%; 20 m = 1.4%) in academy soccer players (Dugdale et al., 2019). The weather recording was taken from www.metoffice.gov.uk (The Meteorological Office UK, 2020).

Pre – Time: Midday, Dry, Wind: 4.97 mph Temp: 5 degrees Humidity: 86%

Post – Time: Midday, Dry; Wind 14.91 mph Temp: 10 degrees Humidity: 56%

Testing Day Two

Maximal lower limb strength was assessed via 3RM parallel back squat. Prior to the test, participants performed a standardised warm up of 10 repetitions with an unloaded bar, five repetitions with 50% body mass and three repetitions with 75% body mass with loads rounded to the nearest 0.25 kg. All squats were performed to parallel, i.e. where the tops of the thighs were horizontal to the ground (110 -120° knee flexion), which was assessed visually by the lead researcher. The load lifted was increased following each successful attempt based on the difficulty it was completed with. An attempt was deemed a failure if the participant did not achieve the required depth or was unable to complete a repetition without assistance. Maximum strength testing has been shown to be reliable (ICCs ≥ 0.90, CV <10%) assessment of lower body strength irrespective of RT experience and age (Grgic et al., 2020). Testing was visually monitored by the researcher and each participant rested three to five minutes after each attempt (Haff and Triplett, 2015).

Training Programme

Initially, participants completed four 30 min sessions over a two-week familiarisation period to refine the back-squat technique and participants were not permitted to start the study until their technique was considered to be appropriate by a National Strength and Conditioning Association (NSCA)-accredited S&C coach. All RT sessions and testing were led by the same NSCA-accredited S&C coach with a relevant Masters degree and >10 years' coaching experience (SM). Following baseline testing, participants in the training groups completed a once-weekly RT programme, implemented concurrently with regular soccer training on match day minus two. Each squat training session consisted of a bodyweight warm up (10 repetitions of squats, lunges glute bridges), barbell warm up sets of; 10 repetitions at 20 kg, 8 repetitions at 50% and 5 repetitions at 70% estimated 1RM, as described above, followed by the training protocol. HRT completed two sets of four repetitions at 90% 1RM, while the MRT completed three sets of eight repetitions at 80% 1RM to the nearest 0.25 kg. Loads were prescribed by using the Epley equation (1RM= ([0.033 x Repetitions] x Load) + Load) to estimate 1RM strength from the 3RM strength test (Epley, 1985). Both groups had three minutes rest between sets (Haff and Triplett, 2015). Squat technique and depth were monitored by the researcher and load was increased when the participant could safely and correctly complete the prescribed load.

Monitoring muscle soreness and training load

Throughout the intervention, participants were asked to report subjective muscle soreness prior to, immediately after, 24 hours and 48 hours after each training session using a visual analogue scale (VAS). The scale ranged from zero, referring to no soreness, up to 10 cm, which would indicate extreme muscle soreness. At the 24 hour and 48-hour post training time points, participants reported their muscle soreness via a Google form using the same standard VAS. Participants were asked to specify any sites of muscle soreness they could identify using a free-text box in the Google form. RT volume load was calculated by multiplying repetitions by sets and external load lifted.

Statistical Analysis

Following pre-testing, the smallest worthwhile change was calculated based on Cohen's effect size principle, with 0.2 representing a small effect size (Sullivan and Feinn, 2012). One-way between groups ANOVAs were used to detect differences between groups at baseline. Two-way mixed ANOVAs were used to assess the effect of the interventions on performance and monitored metrics. Muscle soreness scores from week three were excluded from analysis due to an external match fixture being played the day prior to the training session which convoluted the muscle soreness results that week. All data are expressed as mean ± standard deviation (SD) and statistical significance was set at $p < 0.05$.

7.5 Results

Body mass

There was a significant main effect for time ($F_{1, 19} = 6.08$, $p = 0.023$) with no effect for group ($F_{2, 19} = 2.23$, $p = 0.135$), but there was an interaction between time and group ($F_{2, 19} = 6.97$, $p = 0.005$). Post-hoc paired t-tests with Bonferroni correction demonstrated that only MRT increased pre- (75.1 ± 8.4 kg) to post-intervention (77.4 ± 9.5 kg, $p = 0.029$) compared to HRT (pre: 68.2 ± 6.5 kg, post: 68.7 ± 6.4 kg) or CON (pre: 71.6 ± 6.4 kg, post: 71.1 ± 6.0 kg).

Height

There was a main effect of time (F1, 19 = 17.52, p = 0.001), HRT increased from 174.8 ± 5.8 cm to 175.4 ± 6.0 cm, MRT from 182.5 ± 6.9 cm to 183.3 ± 6.7 cm and CON from 178.8 ± 5.1 to 179.8 ± 5.1 cm. There was no main effect of group (F2, 19 = 3.22, p = 0.063) and no interaction between time and group (F2, 19 = 0.31, p = 0.735).

Absolute Strength

There was a main effect for time ($F_{1, 19} = 89.64$, $p < 0.001$, Fig 1a), no main effect for group ($F_{1, 19} = 1.00$, $p = 0.38$) but there was an interaction between group and time ($F_{1, 19} = 18.02$, $p < 0.001$). Post-hoc paired t-tests with Bonferroni correction demonstrated that absolute back squat strength increased in HRT ($t_7 = -7.77$, $p < 0.001$, $d = 0.80$) and MRT ($t_6 = -6.49$, $p = 0.001$, $d = 1.35$) but not in CON ($t_6 = -1.27$, $p = 0.253$, Fig 1a). Pre-intervention testing established the smallest worthwhile change for estimated 1RM to be 3.39 kg.

Relative Strength

There was a main effect for time ($F_{1, 19} = 76.23$, $p < 0.001$, Fig 1b), for group ($F_{1, 19} = 4.07$, $p = 0.034$) and there was an interaction between time and group ($F_{1, 19} = 11.53$, $p = 0.001$). Post-hoc paired t-tests with Bonferroni correction demonstrated that relative back squat strength increased in HRT ($t_7 = -6.11$, $p < 0.001$, $d = 1.31$) and MRT ($t_6 = -6.64$, $p = 0.001$, $d = 1.11$) but not CON ($t_6 = -1.53$, $p = 0.176$, Fig 1b). Pre-intervention testing established the smallest worthwhile change to be 0.05 kg relative to body mass.

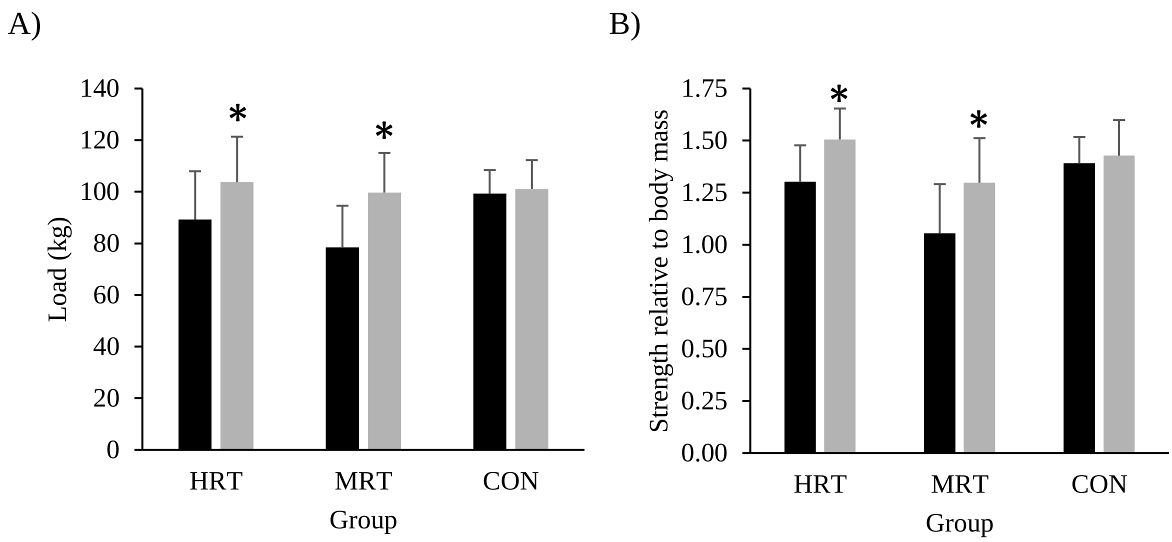

Figure 1: Changes in estimated one repetition maximum (1RM) back squat strength (A) and 1RM relative to bodyweight (B) from pre- (black bars) to post-training intervention (grey bars). HRT, high-intensity resistance training group; MRT, moderate-intensity resistance training group; CON, control group; * significantly different from pre-testing.

Squat jump

There was no main effect for time ($F_{1, 19}$ = 4.34, p = 0.051), or group ($F_{1, 19}$ = 0.19, p = 0.826) but there was interaction between time and group ($F_{2, 19}$ = 11.33, p = 0.001, Fig 2a). Post-hoc paired t-tests with Bonferroni correction demonstrated that squat jump height increased in HRT (t_7 = -2.60, p = 0.035, d = 0.71) and MRT (t_6 = -3.61, p = 0.011, d = 0.65) and decreased in CON (t_6 = 2.55, p = 0.044, d = 0.44, Fig 2a). Pre-intervention testing established the smallest worthwhile change to be 0.8 cm.

Vertical CMJ

There was no main effect for group ($F_{1, 19}$ = 0.55, p = 0.587) but there was a main effect for time ($F_{1, 19}$ = 6.42, p = 0.020) and an interaction between time and group ($F_{2, 19}$ = 6.33, p = 0.008). Post-hoc paired t-tests with Bonferroni correction demonstrated that CMJ height increased in HRT (t_7 = -3.81, p = 0.007, d = 0.86) and MRT (t_6 = -4.23, p = 0.005, d = 0.70) but not in CON (t_6 = 1.02, p = 0.346, Fig 2b). Pre-intervention testing established the smallest worthwhile change to be 0.9 cm

Horizontal CMJ

There was no main effect for group ($F_{1,\,17}$ = 0.96, p = 0.405) but there was a main effect for time ($F_{1,\,19}$ = 29.16, p < 0.001) and an interaction between group and time ($F_{2,\,19}$ = 6.02, p = 0.011, Fig 2c). Post-hoc paired t-tests with Bonferroni correction demonstrated that horizontal CMJ distance increased in HRT (t_6 = -6.40, p = 0.001, d = 1.12) but not MRT (t_5 = -1.91, p = 0.114) or CON (t_6 = -1.36, p = 0.223, Fig 2c). Pre-intervention testing established the smallest worthwhile change to be 3.18 cm.

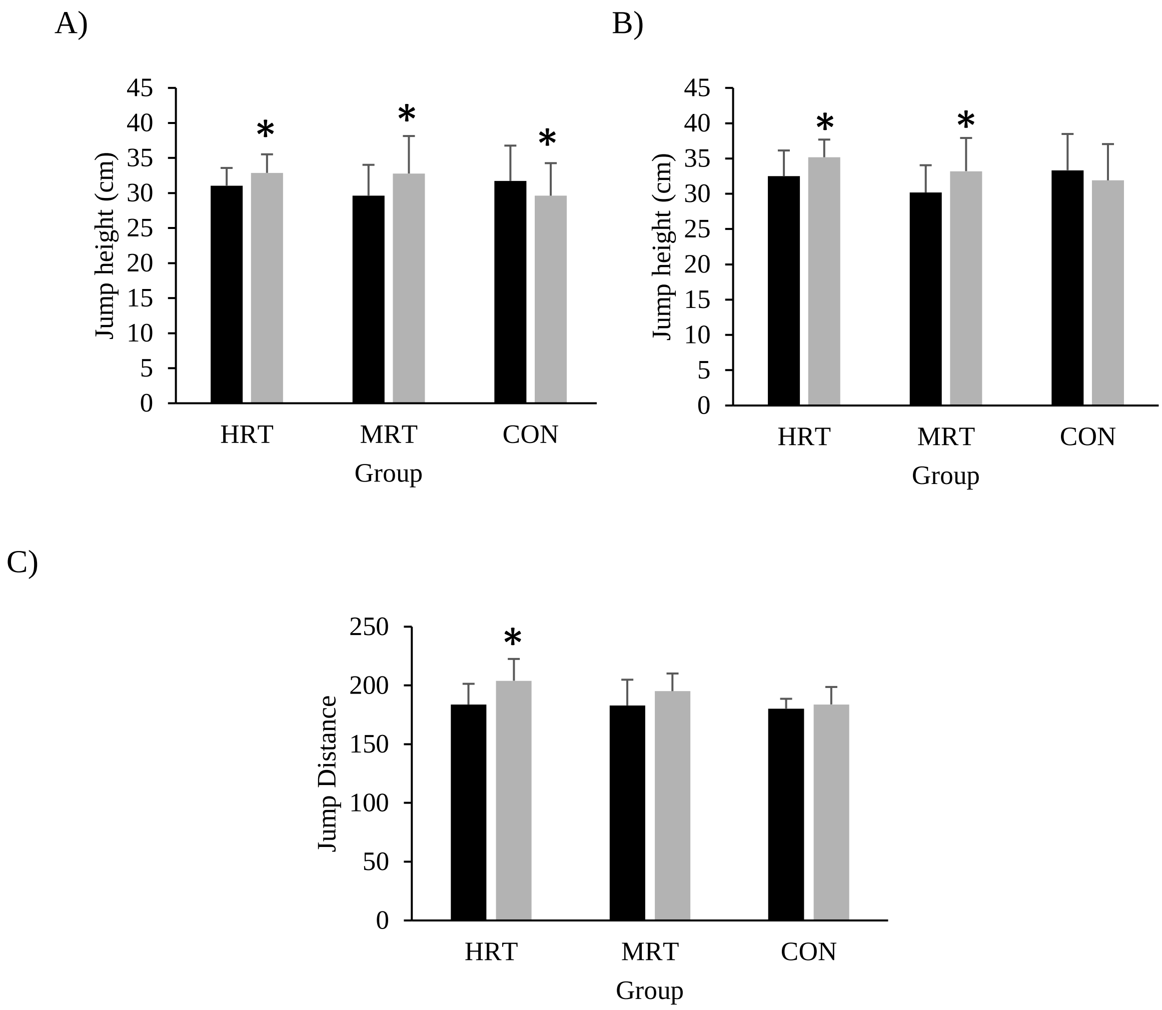

Figure 2: Changes in squat jump (A), countermovement jump (B) and horizontal jump (C) from pre- (black bars) to post-training intervention (grey bars); HRT, high-intensity resistance training group; MRT, moderate-intensity resistance training group; CON, control group; * significantly different from pre-testing.

10 m Sprints

There was no main effect for group ($F_{1, 17}$ = 1.59, p = 0.235), time ($F_{1, 17}$ = 1.49, p = 0.239) or interaction between group and time ($F_{1, 17}$ = 2.67, p = 0.098, Fig 3a). Pre-intervention testing established the smallest worthwhile change to be 0.02 s.

20 m Sprints

There was no main effect for group ($F_{1, 17}$ = 2.34, p = 0.127), time ($F_{2, 17}$ = 3.29, p = 0.088) or interaction between group and time ($F_{2, 17}$ = 3.13, p = 0.070, Fig 3b). Pre-intervention testing established the smallest worthwhile change to be 0.03 s.

30 m Sprints

There was no main effect for group ($F_{2, 17}$ = 1.45, p = 0.262), time ($F_{2, 17}$ = 3.29, p = 0.088) or interaction between group and time ($F_{2, 17}$ = 0.76, p = 0.481, Fig 3c). Pre-intervention testing established the smallest worthwhile change to be 0.05 s.

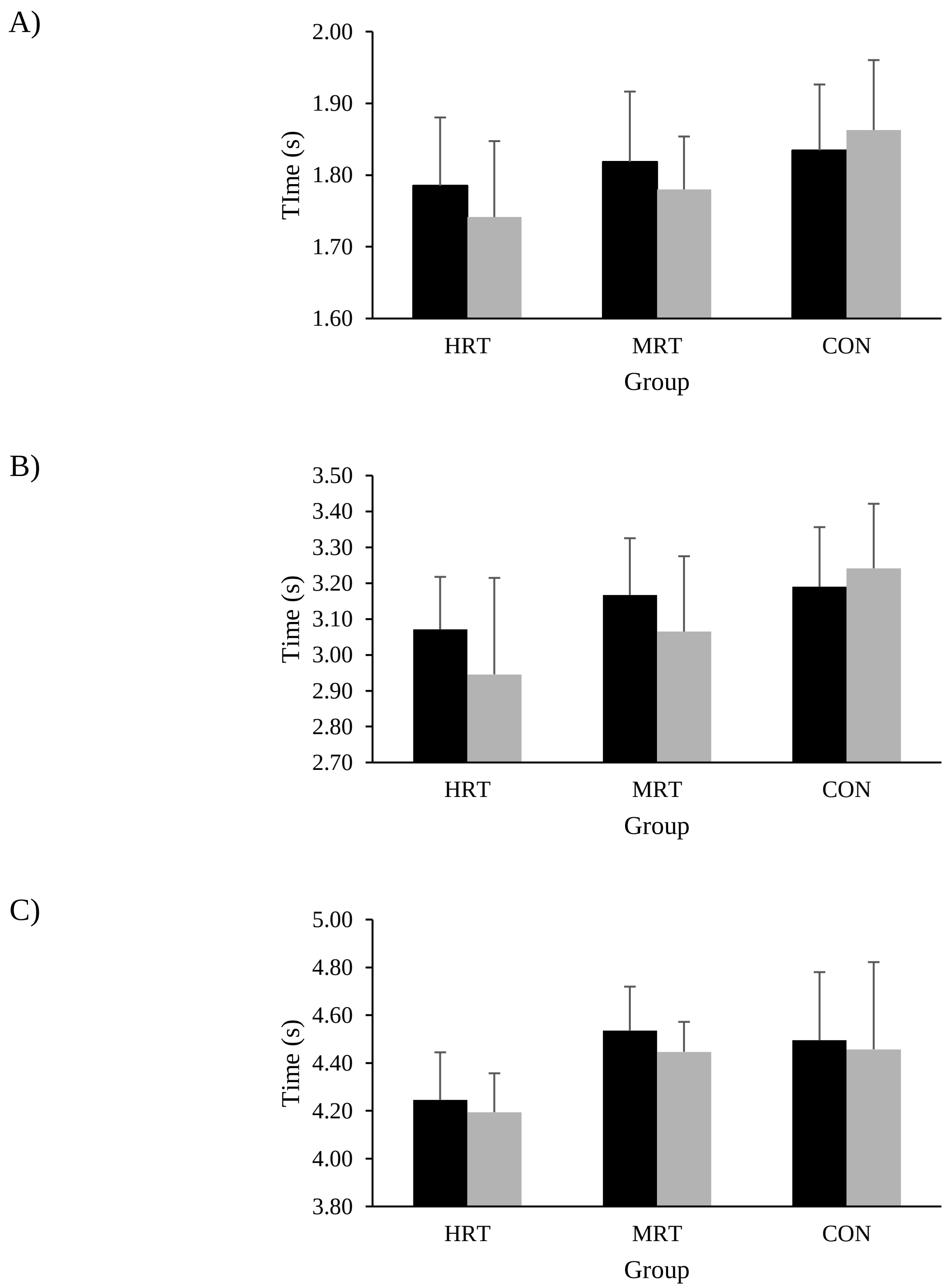

Figure 3: Changes in (A) 10 m, (B) 20 m and (C) 30 m sprint times pre- (black) and post-six-week intervention; HRT, high-intensity resistance training group; MRT, moderate-intensity resistance training group; CON, control group

Training volume

There was a main effect for group ($F_{1, 13}$ = 76.35, $p < 0.001$), time ($F_{5, 65}$ = 55.86, $p < 0.001$) and an interaction between group and time ($F_{5, 65}$ = 20.80, p = < 0.001). HRT started with a volume load of 633 ± 136 kg, increasing to 700 ± 128 kg per session, whereas MRT started with initial volume of 1491 ± 287 kg, increasing to 1749 ± 280 kg per session by week six.

Muscle soreness

There was no main effect for group ($F_{2, 110} = 0.24$, $p = 0.784$) but there was for time ($F_{2, 220} = 34.62$, $p < 0.001$) and a significant interaction between group and time ($F_{2, 220} = 10.71$, $p < 0.001$, Fig 4). When comparing the locations of muscle soreness there was similar frequencies between training groups for gluteus and all groups for hamstrings and hip adductors. However, MRT reported more quadriceps soreness counts than HRT did (Fig 5).

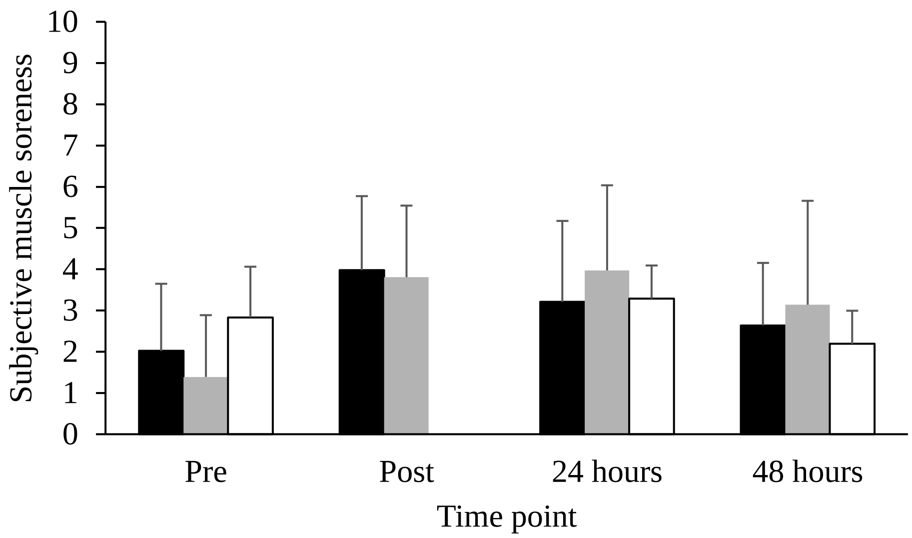

Figure 4: Time course of subjective muscle soreness from prior to RT session, immediately following RT session, 24 hours and 48 hours post session. High-intensity resistance training group, black bars; moderate-intensity resistance training group, grey bars; white bars, control group.

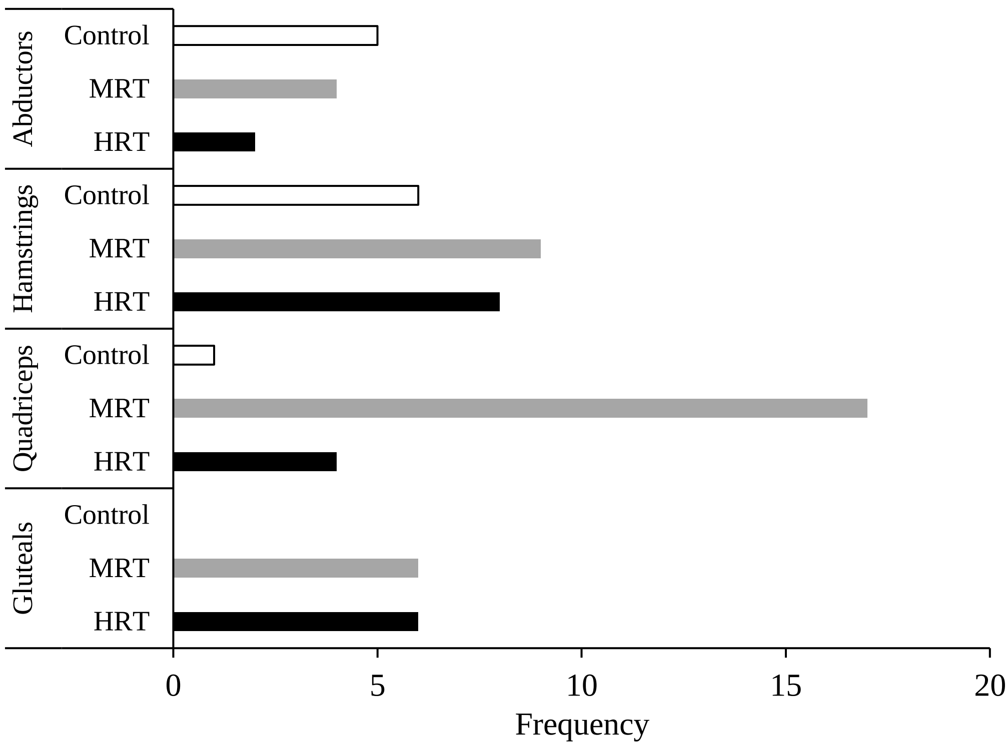

Figure 5: The count of where participants subjectively experienced muscle soreness in the 24- and 48 hours following resistance training sessions.

7.6 Discussion

The aim of this study was to compare the impact of high-intensity (low-volume) resistance training (HRT) against moderate-intensity (high-volume) resistance training (MRT), i.e. the most common sets, repetitions, and intensity paradigm derived from Chapters Three to Five. Following the training intervention period, there were similar increases in absolute and relative strength, squat jump and vertical CMJ in HRT and MRT compared to CON (i.e. pitch-based soccer training only). Further, HRT improved horizontal jump but there was no change in MRT or CON. Importantly, the increases seen in HRT were achieved with significantly less training volume and similar muscle soreness to CON. These findings suggest that HRT may be a more efficient and effective training method to increase strength and power in-season in youth soccer players compared to MRT (the main method currently used by S&C coaches in soccer).

As mentioned previously, increasing strength, particularly strength relative to body mass, can have a beneficial impact on a range of performance metrics (Comfort et al., 2014). Both HRT and MRT increased absolute and relative strength (Fig 1), which aligns with a similar HRT approach with professional soccer players in-season (Rønnestad et al., 2011). This is a key finding for academy S&C coaches, who may be restricted to a single session per week (according to 38% of our survey responders). Based on the results presented here, it is possible to increase strength in academy aged soccer players with a single RT training exercise per week.

Lower-body power is regularly assessed using jump assessments, with 95% of academy S&C coaches using them in practice (according to results from Chapter Five). Here, both HRT and MRT resulted in improvements in SJ (Fig 2), which is in line with previous research in soccer players aged 15-17 years old (Hammami et al., 2018), suggesting that concentric power production improved following training. However, changes in vertical bilateral CMJ following RT have previously shown mixed results in academy soccer players. Chelly et al. (2009) showed no changes following an eight-week high-intensity RT programme. In contrast, Hammami et al. (2018) implemented a comparable RT programme in youth soccer players and saw improvements in bilateral vertical CMJ. The inconsistency between results may be due to Hammami et al. (2018) programming a greater proportion of the training at a higher relative intensity. As bilateral vertical CMJ is a valid indicator of dynamic peak-power (Owen et al., 2014), and peak-power is the result of force (load) multiplied by velocity, the use of the parallel squat in the present study may explain how both HRT and MRT improved vertical CMJ and SJ performance. Greater squatting depths are associated with lower absolute loads than seen in a half-squat, which in-turn can increase movement velocity towards the end of the movement (Martínez-Cava et al., 2019).

While vertical CMJ assessment is commonplace in soccer, it only assesses power production in a single plane. Horizontal orientated jump assessments may be more appropriate to use in soccer due to the greater hamstring and gluteus activation (Nagano et al., 2007) and their relationship with acceleration and sprint performance (Dobbs et al., 2015), which are more common than vertical jumps during matches (Murtagh et al., 2019). Furthermore, horizontal jumps can be used to predict 10 m and 20 m sprint performance (Montalvo et al., 2021). Here, only HRT improved horizontal CMJ (Fig 2), however, neither intervention improved sprint times (Fig 3). This was surprising, as both groups increased absolute and relative strength, and change in strength correlates with improvement in acceleration performance (Styles et al., 2016). This may be due to several factors such as the time delay in greater strength levels transferring to increased power (Stone et al., 2003), and the technical element of sprint performance, as horizontal jump performance predicts 66% of 10 and 20 m performance. Therefore, other factors may have limited the transfer of the greater power production into faster sprint performance (Montalvo et al., 2021). While neither protocol improved sprint performance, HRT improved performance in all three jump types and may have improved sprint performance had the intervention period been longer.

As seen in previous chapters, potential muscle soreness following RT was a key concern of 54% S&C coaches working with a variety of soccer squads (Chapter 5). This may have been a result of the training volumes coaches were prescribing in-season, as shown by the greater muscle soreness scores with MRT compared to HRT (Fig 4). This lower muscle soreness 24 hours and 48 hours following a low-volume, HRT session may increase the feasibility of conducting high-intensity RT in-season. An unexpected finding were the sites where soccer players reported muscle soreness following their respective RT programmes. While distribution of the most common sites of soreness were similar between HRT, MRT and CON, MRT resulted in participants more regularly reporting quadriceps soreness (Fig 5). While many of the performance tests showed similar improvements between HRT and MRT, it is important to note that HRT achieved these with 58% less volume load. When volume load is matched, Uchida et al. (2009) showed no differences in subjective muscle soreness or plasma creatine kinase following training at 50%, 75%, 90% or 110% 1RM. This suggests that training volume, as opposed to training intensity, may help explain the reduced muscle soreness seen following HRT and be a more appropriate RT approach in youth soccer players in-season. Further, this low-volume training approach would take less time to complete, thus making it even more attractive to S&C coaches, who report limited time as one of the main restrictions regarding the incorporation of RT into youth soccer training programmes.

The primary limitation of this study is the relatively small sample size. Although 51 participants started the study, 30 were unable to complete due to injuries incurred during soccer matches (n=10) and COVID-19 restrictions (n=20). Consequently, where non-significant tendencies (e.g., $p = 0.05 – 0.10$) are reported, it is possible that with a slightly larger sample size, we may have led to a significant result. It is important to note than no participants dropped out due to the intervention itself, meaning that the high-intensity strength training was not a problem for the players themselves in-season. A second limitation of this study is the absence of training load information. An important factor that may have influenced the outcomes of this study, particularly the subjective muscle soreness results, is the pitch-based load within the wider training programme. Soccer training alone can result in muscle damage and soreness, particularly when large volumes of high-speed running are involved due to the high-eccentric forces during ground contact (Kenneally-Dabrowski et al., 2019). Therefore, this may help explain why subjective muscle soreness increased in the control group in the days following the RT sessions. Finally, match fixtures changed frequently, and on two occasions, there were two fixtures during the week. This resulted in RT not being performed on the same training day (match day minus two) for those weeks. While this may be considered a limitation, situations like this reflect those in professional soccer clubs and may strengthen the external validity of the study findings.

To conclude, six weeks' low-volume, high-intensity (90% 1RM), i.e. HRT, and moderate-intensity (80% 1RM), i.e. MRT, strength training interventions caused increases in lower-limb strength and power in youth soccer players in-season compared to pitch-based soccer training only. Importantly, HRT achieved this with 58% less training volume and similar muscle soreness to soccer training alone in the subsequent days after each training bout. These findings suggest that HRT may be a more efficient and effective training method for academy soccer players in-season than the most common training prescription currently used by coaches in soccer (i.e. MRT). Future studies should investigate the medium- to long-term effect of HRT on the physical development of youth soccer players.

Chapter Eight – Synthesis of Findings

8.1 Introduction

The purpose of this chapter is to provide an interpretation of the major findings from the preceding chapters in relation to the aims and objectives of this thesis. The key outcomes of the present thesis will be discussed in relation to the current scientific literature on strength training in soccer alongside the limitations of the current work. Further, owing to the applied nature of the work, this chapter will aim to provide practical recommendations for strength and conditioning coaches working in soccer in the previously discussed demographics. Finally, future research directions will be recommended that may aid in contextualising these findings and improve the strength training approach implemented within various demographics by coaches in soccer.

The aim of this thesis was to investigate the current practice of S&C coaches working with female and male soccer players at both academy and professional levels in different global regions, and to explore the impact of high-intensity, low-volume, lower-limb weight training in academy soccer players. Four main objectives were implemented to achieve this aim:

1) To compare current S&C practice in soccer between different global regions, and to highlight any differences in practice, specifically designed to improve strength and power. This was achieved through the work completed in Chapter 4.
2) To compare current S&C practice in soccer between coaches working with male and female players, specifically aimed at improving strength and power, or reducing injury risk. This was achieved through the work completed in Chapter 5.
3) To compare current S&C practice in soccer between coaches working with academy and professional (first team) players, and to highlight any differences in practice. This was achieved through the completion of Chapter 6.

4) To determine if a high-intensity, low-volume strength training approach is more effective at improving strength, power and speed in male academy soccer players than current S&C practice. This was achieved through the work performed in Chapter 7.

8.2 General discussion

Maximum strength is an important physical component for soccer players, as it has been shown to correlate with acceleration, sprint and jump performance in both first team (Wisloff et al., 2004) and youth soccer players (Comfort et al., 2014), improve sport specific skills (Wing et al., 2018), and influence league finishing positions (Wisloeff et al., 1998). As such, resistance training (RT) is an important component of many LTAD models for men/boys and women/girls (McQuilliam et al., 2020, Lloyd and Oliver, 2012). Soccer governing bodies have released their own LTAD structures (The English Football Association, 2015), however, these guidelines are generic and open to interpretation by the practitioner. Though the limited detail is not necessarily negative, it allows for a wide variety of methods to be implemented.

The findings presented in Chapter Four suggest that differences in S&C practice in soccer do exist between different geographic locations worldwide, irrespective of competitive match demands or fixture congestion. The S&C practice of coaches in the USA and South America (SA) appear to align better with the scientific guidelines for strength and power development in soccer, emphasising the importance of free-weight RT alongside regular sprint and plyometric training in contrast to coaches in Europe. While this does differ from the findings of Loturco et al. (2021), who suggested that the training volume and frequency prescribed by S&C coaches of Brazilian first team squads may not be sufficient to improve speed and power in first team soccer players. This was primarily due to the majority of S&C coaches not periodising training programmes, and the limited time for specific S&C sessions (2 sessions per week lasting 15-30 minutes, Loturco et al. (2021)). This is compared to 51 ± 27 minutes reported in Chapter Four, greatly limiting the opportunity for physical development in contrast. This limited duration has also been seen in soccer more broadly (Weldon et al., 2020), and it is recommended that soccer clubs and National Governing Bodies (NGBs) investigate the time devoted to physical development within the broader training programmes. Additionally, with football associations having their own policies in place regarding long-term athlete development, clear differences in training approach start to become apparent at academy level. Initially, SA academy players are introduced to formal S&C training at a later chronological age than those in the UK, most likely due to the later age SA players enter academies (Ford et al., 2012). Despite SA first team S&C practice generally aligning better with scientific guidelines for strength and power development in soccer, SA academy S&C coaches appear to miss a key opportunity with their soccer players. Therefore, our findings suggest that SA soccer clubs and NGBs explore the possibility of introducing formal S&C training at an earlier chronological age within SA academy environments to prepare players for the more complex training approaches seen in the first team setting. UK S&C coaches, on the other hand, introduce their players to S&C at an earlier chronological age, providing more time to accrue training experience. However, relatively more UK S&C coaches believed bodyweight training was the most important RT modality compared to coaches in SA (45% vs. 27%). As such, despite starting earlier, the RT approach of UK academy S&C coaches may not be as effective (Suchomel et al., 2018). It is therefore recommended that this is explored further, including key information, such as the age group the S&C coaches are working with, potential barriers to free-weight RT in academy settings, such as the physical and social environment, to improve the strength training practices in academy environments.

Beyond differences between global regions, results from Chapter Five suggest that differences exist in the approach S&C coaches take when working with male and female soccer players. A key difference at academy level was the use of the Nordic hamstring exercise (NHE), which may be a direct result of the higher injury risk in female *vs.* male players (Mufty et al., 2015), as this has been suggested to be an effective injury prevention exercise (Van Dyk et al., 2019). However, more recently, the effectiveness of the NHE and the review by Van Dyk et al. (2019) has been questioned (Impellizzeri et al., 2021). Further, of the fifteen research studies within the systematic reviews and meta-analyses, only two investigated the effect of the NHE in female populations, and both concluded that there was no beneficial reduction in injury rates in female soccer players (Soligard et al., 2008, del Ama Espinosa et al., 2015). This finding highlights the inappropriateness of assuming that findings in male soccer players can be transferred directly to female players. With conflicting evidence around the efficacy of the NHE in women soccer players, it is worth investigating why a relatively greater proportion of S&C coaches working with women players chose to implement it. Logistically, it is an easily implemented exercise, as it does not necessarily require any equipment or any financial investment. When specifically comparing academy S&C coaches, women's coaches had fewer formal S&C sessions to physically develop their players (1.58 ± 0.62 session per week, lasting 44 ± 17 minutes). While support for women's academy football has grown in recent years, the resources and organisational structure of women's soccer differs to men's in both academy and first team settings (Valenti, 2019). For example, in England, Regional Talent Clubs are the highest standard of women's youth football. Here, under 16 players complete eight hours of total training per week, consisting of pitch-based and S&C sessions (Emmonds et al., 2017). Comparatively, boy's academy players of the same age are expected to complete 12 to 16 hours of total training time per week (The English Football Association, 2015). Further, there may be situations where multiple squads are sharing facilities, limiting training opportunities (Valenti, 2019). These are just some examples of external influences that may result in different training frequencies and methods implemented between S&C coaches working with men's and women's soccer players to develop strength and power. Therefore, we recommend that soccer clubs and NGBs act to support the physical development of the players within their youth development pathways by increasing the time devoted to S&C methods within their guidelines by investigating the wider context around the training that takes place. Some of the differences highlighted here and in Chapter Five may be linked to sex-differences in injury risk, or due to structural/organisational differences in women's soccer. However, despite the physiological differences between male and female soccer players, there were several similarities in the methods S&C coaches used, such as the RT modality, movement patterns focused on and the prescribed repetitions, and training intensity during RT sessions. Regardless, more research is needed in women's soccer to continue the development of not only S&C but sport science support as a whole.

A soccer academy takes a long-term view regarding talent identification and athlete development (Dodd and Newans, 2018), with the ultimate objective to produce professional soccer players for the club's first team squad. Chapter Six described and compared S&C practices of coaches working with both first team and academy soccer players. The physical development of academy soccer players can be non-linear and, consequently, regular testing can highlight the sporadic fluctuations apparent in physical performance and enable contextualisation to further aid player development (Moran et al., 2020). This may explain why the prevalence of academy S&C coaches assessing sprints (91%), jumps (91%) and aerobic fitness (87%), as well as the greater proportion of academy compared to first team S&C coaches assessing change of direction performance (78% *vs.* 60%, respectively). It would be valuable to investigate why S&C coaches use these assessments and the processes used to provide greater context. However, there was limited use of 1 repetition maximum (RM) strength testing by both academy (46%) and first team (51%) coaches potentially due to the time required to obtain a player's 1RM and the unfamiliarity of the player with maximal loads (Niewiadomski et al., 2008). This may explain the use of subjective measures to prescribe RT load and the greater proportion of academy coaches who prioritised bodyweight training compared to first team coaches. Bodyweight training is an appropriate modality to help introduce young athletes to a formal S&C programme, although the improvement in strength and power is limited (McQuilliam et al., 2020, Suchomel et al., 2018). The predominance of bodyweight training as the most important RT methods to develop strength contradicts the recommendations of both NGBs (The English Football Association, 2015) and research studies (Meylan et al., 2014b, McQuilliam et al., 2020). Since RT has been shown to be safe and an effective modality to improve strength, power and reduce injury risk in sporting youth populations (McQuilliam et al., 2020), we recommend free-weight RT to be prioritised over bodyweight training in academy S&C programmes when appropriately supervised by qualified and experienced professionals. However, S&C coaches may not have the opportunity to do this due to the environment they work in, or may not see this as the most appropriate method for their athletes.

When observing practice, there are some consistent findings across chapters four, five and six. With similar movement patterns, and large variation in the sets, repetitions and intensity prescribed we conclude that when aiming to develop strength, the training approach used in soccer is not always appropriate. Furthermore, 51% and 55% of S&C coaches perceive their practice to be restricted by lack of time and the potential for muscle soreness following training, respectively. As this does not limit the implementation of high-intensity RT in other invasion game sports, such as rugby (Jones et al., 2016) and basketball (Simenz et al., 2005) a more in depth investigation is needed to understand why this might be. The use of the squat and its variations as well as the use of weightlifting and its derivatives is far greater in rugby (both ≥ 90%) and basketball (both ≥ 90%) than seen here in soccer (83% and 29%, respectively). There are contextual and sport-specific factors to consider, however, lower-body strength and power are key in several different sports, all of which appear to take a similar free-weight RT approach to each other, soccer appears to be an exception. How can we gain a better understanding of this and the previous findings?

To get a better understanding of the results in chapters four, five and six, we must consider the coaches' behaviour in a wider context. The capability, opportunity, motivation, and behaviour model (COM-B) suggests a certain behaviour will only happen when the individual has the capacity and opportunity to participate in said behaviour and is also more motivated to produce that behaviour than any other (Michie et al., 2011). The model places the S&C coach within a complex, interlinked, multi-component system. The COM-B models can help to understand why a coach may act/plan training in the way they have, and identify what would need to change in order to influence this. Understanding behaviours, and the settings in which they occur, is essential for the design of effective and efficient behavioural interventions (Davis et al., 2015).

Capability refers to the physical and psychological ability to complete an action, such as theoretical knowledge and practical skill in coaching. Opportunity relates to external factors that influence if a behaviour is possible, such as the physical and social environment. Capability and opportunity can both affect behaviour directly and indirectly through effecting an individual's motivation (Michie et al., 2011). This suggests that both capability and opportunity need to be present for any behaviour to be changed. In relation to S&C coaching practice, a coach's perception of their ability to implement a training methodology and the opportunity to implement it within the constraints of the training environment will heavily influence training programme design. Following the behaviour, the resulting outcome provides either positive or negative feedback, which is then related back to capability, opportunity, and motivation. For example, a S&C coach may aim to increase the time spent developing the physical qualities of the playing squad. However, the feedback received from senior management roles may be negative due to time-tabling constraints (opportunity).

The COM-B model can be used to help design effective behaviour change models (Michie et al., 2011). A strength of this model is the inclusion and consideration of both intra-individual, interpersonal, social, and physical environmental factors as well as interacting factors that influence behaviour (Michie et al., 2011). An intervention based on this may look to alter one or more of the components, making it important to consider what components of the model would need to be targeted to achieve change.

Based on the findings of Chapters Four, Five and Six, the design of an ecologically valid RT intervention based on scientific best practice was required. In Chapter Seven, the average, moderate intensity (80% 1RM) RT (MRT) approach seen in soccer (based on findings from Chapters Four to Six) was compared to a low-volume, high-intensity (90% 1RM) resistance training (HRT) intervention, and both training approaches increased strength, lower-body power, and sprint times above a pitch-based soccer training only control. Importantly, HRT achieved this with 58% less training volume and less perceived muscle soreness in the subsequent days after each session. Previously, there have been concerns surrounding high-intensity squat training due to the load experienced through the lumbar spine and knee joints in the half and quarter squat (Pallarés et al., 2019, Hartmann et al., 2013). When using greater squatting depths, as seen in Chapter Seven, a lesser external load was used, in turn reducing the stresses on these structures. Together, the use of a smaller absolute load, reduced injury risk with potentially greater improvements in performance when using greater squatting depth would be more appropriate for academy soccer. The greater squatting depth may explain how both intervention groups saw increases in acceleration, vertical and horizontal jump performance due to increased activation of the gluteal muscles (Caterisano et al., 2002), as previously seen by de Hoyo et al. (2016). These findings suggest that HRT may be a more efficient training method for academy soccer players in-season than the most common training prescription (MRT) currently used by S&C coaches in soccer. Given that 51% of S&C coaches working with Academy players (Chapter Six) perceived a lack of time to be a restricting factor to their practice, HRT may be an appropriate solution. Future research should investigate if this training approach is effective in other demographics.

8.3 Conclusion

This thesis is the first to observe global variation in S&C approaches in soccer (chapter four), between male and female (chapter five), first team and academy settings (chapter six), and that high-intensity strength training is more effective than common strength training practice currently used in soccer (chapter seven). To conclude, the application of scientific research-based resistance training principles varies widely with a large proportion of S&C coaches in soccer not following the repetition ranges, relative training intensity or most effective modality for maximal strength development or maintenance. This may be due to the perceived restrictions of limited time and the potential for muscle soreness following RT. However as seen in other sports and shown in chapter seven, when employing scientific research-based strength training principles, a high-intensity, low-volume RT programme is not only feasible in-season but more effective than current practice and helps manage perceived restrictions.

8.4 Limitations and Future Research

The research described within this thesis provides new information on the current S&C practice of coaches working with first team and academy, male and female soccer players from different global locations. While novel, there are some limitations to the work presented here. This section aims to discuss these limitations and provide recommendations for future research related to each experimental chapter of this thesis.

Suggestion one

To build upon the findings within this thesis semi-structured interviews could be used to explore the key components of the COM-B model to get an understanding of key factors that influence S&C coaches' decisions relating to their practice. Similar to previous work exploring behaviour in elite sports nutritionists (Bentley et al., 2019), this approach allows for focused investigation into the COM-B components as well as open discussion relating to the participants' own opinions and topics of interest (Sparkes and Smith, 2013).

Following chapter four, future research of current S&C practice should aim to investigate the wide variation of methods implemented within global regions and between the different demographic groups presented here. Using the three components of the COM-B model, researchers would be able to identify specific areas for targeted behaviour change (Michie et al., 2011).

Suggestion Two

In chapter five, a comparison of S&C practice in men's and women's soccer was undertaken. Future research should further investigate the training practices of women soccer players at both youth (academy) and senior (first team) level. Within this, there should be a specific focus on female-specific factors, such as the menstrual cycle, how it might (and whether it should) influence an S&C coach's programming. This is a growing area of research and there are currently practitioners manipulating training variables based on limited information.

Suggestion Three

In chapter six, we collated all responses from academy coaches into a single group, whereas it would be more appropriate to look at chronological age bands that the soccer squads are currently organised into. This would provide an overview of how LTAD models are implemented within youth soccer and explore important variables that influences the S&C coach's decision regarding training prescription.

Suggestion Four

The results presented in chapter seven show the benefits of HRT and MRT regarding strength and power performance metrics with minimal training volume. Future research should investigate the efficacy of this training approach over a greater intervention period as performance differences may start to become apparent between the two groups. Additionally, future research may investigate increasing the training frequency from a single session to twice weekly, which may further augment the training response and align with the average weekly training frequency seen in chapter six.

8.5 Practical applications

It is hoped that this thesis will help improve the current practices of S&C coaches and, in turn, increase the athleticism and reduce injury risk of their players. The application of scientific research-based resistance training principles varies widely within and between the global regions and demographics presented here, giving the opportunity for researchers and national governing bodies to help target training interventions within their global region.

The physical performance improvements following both high- and moderate intensity RT and not soccer in chapter seven highlight that a low volume strength training programme can have a positive impact in as little as six weeks. This is important to recognise when we consider that 51% of all survey responses identified a lack of time as a restriction to RT practice. This time efficient approach may also give practitioners more time to focus on other components of athleticism. It is hoped that this may further improve the translation of science into practice and enhance the athletic development of soccer players, both men and women, at both professional (senior) and academy levels.

Overall, S&C coaches may benefit from applying scientific research-based strength training principles with a high relative intensity and lower repetition ranges from current practice. With lower training volume, similar perceived muscle soreness to soccer alone and improved physical performance in-season, a high-intensity RT programme may be a viable option for S&C practitioners working in soccer.

Chapter Nine - References

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Chapter Ten - Appendix

Current resistance training practice in soccer

Page 1: Introduction

You are being invited to take part in a study which aims to evaluate the current methods strength and conditioning coaches use to develop physical attributes such as strength and power within football. Through this, we hope to gain a better understanding of the environment, the influences on current practice and how long-term athlete development is facilitated as part of the training process.

Participation is entirely voluntary, all questions are optional to answer and it is up to you whether to take part or not.

For a copy of the participant information sheet please *click here*.

To be eligible you must be:
- 18 years old or over
- Working within a soccer team (professional club, university, National Governing Body, etc.)
- Involved with the delivery of strength and conditioning support

For alternative languages please select an option below:

- French
- Spanish
- German
- Italian
- Portuguese

I have read the participant information sheet and I consent to participate in this survey

- ○ Yes
- ○ No

Page 2: Country

What country is your soccer club in?

If you selected Other, please specify:

Page 3: Background Information

What would you consider to be your current job role at you club?

- ○ S&C Coach
- ○ Sport Science Support
- ○ Technical Coach
- ○ Other

If you selected Other, please specify:

[ ]

How long have you been in this current job role at your club? (In years)

[ ]

What is the current highest academic qualifications you possess?

- ○ Bachelor's degree
- ○ Master's degree
- ○ PhD (select if enrolled)
- ○ Other

If you selected Other, please specify:

[ ]

Have you obtained a specific strength and conditioning certification/accreditation from a recognised governing body? (Tick all that apply)

- ☐ UKSCA
- ☐ BASES Accredited
- ☐ CSCS
- ☐ ASCA
- ☐ Other

If you selected Other, please specify:

How many years experience do you have working in soccer?

If your job involves it, how many years' experience do you have delivering S&C support?

Do you predominately work with male or female squads?

- Male
- Female

What kind of organisation do you work in?

- Professional / Amateur Club
- National Governing Body
- University / College
- Other

If you selected Other, please specify:

At first team level, which division is your club in?

- First division (top league)
- Second division
- Third division
- Fourth division
- Other

If you selected Other, please specify:

Which do you predominately work with?

- Academy squads
- 1st team squad

What age group squads do you primarily coach?

Under 9s	Under 10s	Under 11s
Under 13s	Under 15s	Under 14s
Under 16s	Under 17s	Under 18s
Under 19s	Under 23s	Other

If you selected Other, please specify:

What category is your academy? - English teams only

Category 1	Category 2	Category 3
Category 4		

Page 4: Physical Testing

At what time points throughout the season do you conduct fitness testing? Please select all that apply.

- ☐ Start of pre-season
- ☐ End of pre-season
- ☐ Mid-season
- ☐ End of season
- ☐ Other

If you selected Other, please specify:

What specific components do you test for? Please select all that apply.

- ☐ Maximum strength
- ☐ Power (with external load e.g. a barbell)
- ☐ Jump testing
- ☐ Acceleration / Sprint speed
- ☐ Change of direction ability
- ☐ Muscular endurance
- ☐ Anaerobic fitness
- ☐ Aerobic fitness
- ☐ Body composition
- ☐ Flexibility
- ☐ Other

If you selected Other, please specify:

Page 5: Programme Design

To what extent do you agree strength and power training can positively influence soccer performance?

Please don't select more than 1 answer(s) per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree
Tick one	☐	☐	☐	☐	☐

At what age do your academy players start training to develop strength and/or power? (In years) (For academy staff only)

What form of resistance training do you use in your programmes? (Tick all that apply)

- ☐ Free-weights
- ☐ Resistance machines
- ☐ Bodyweight
- ☐ Resistance Bands
- ☐ Plyometrics
- ☐ Other

If you selected Other, please specify:

Of the methods selected in the previous question, please rank them in order of importance. Starting with the most important.

Rank the top 5 resistance exercises most important to your programmes. E.g. back squat, power clean, leg press, ect.

	Top 5 exercises
1	
2	
3	
4	
5	

How is training load determined for these primary resistance exercises?
(Tick all that are used)

- ☐ Percentage of 1RM
- ☐ Velocity measures
- ☐ Repetitions in reserve
- ☐ Athlete selected
- ☐ Subjectively by coach
- ☐ RPE
- ☐ Other

If you selected Other, please specify:

When looking to build strength with the previously mentioned exercises, what sets, repetition schemes and intensities do you use?

When looking to build power with the previously mentioned exercises, what sets, repetition schemes and intensities do you use?

Page 6: Plyometric Training

Do you incorporate plyometric training?

- ○ Yes
- ○ No

Why do you include plyometrics in your training programs?

[ ]

How many times a week will this be included?

[ ]

If you selected Other, please specify:

[ ]

When are they used? Please select all that apply.

- ☐ During specific S&C sessions
- ☐ Prior/during pitch sessions
- ☐ Seperate sessions
- ☐ Other

If you selected Other, please specify:

[ ]

Page 7: Speed Development

Do you include speed development?

- ◯ Yes
- ◯ No

Why is this?

How many times a week will this be included?

If you selected Other, please specify:

When are they used? Please select all that apply.

- ☐ During specific S&C sessions
- ☐ Prior/during pitch sessions
- ☐ Seperate sessions
- ☐ Other

If you selected Other, please specify:

Page 8: Training Periodisation

Do you use periodisation to structure your training programs?

○ Yes ○ No

If yes, please state which periodisation model you use and why.
If no, what guides the way you structure your training and why?

Concurrent training is defined as the combination of resistance and aerobic training in a periodised program. Do you consider the influence session order may have on strength and power development?

○ Yes ○ No

How important is it to consider the concurrent training effect?

Please don't select more than 1 answer(s) per row.

	Not important	Somewhat important	Neutral	Somewhat important	Very important
Select your answer	☐	☐	☐	☐	☐

What order do you consider to be more conducive to strength and power development?

- ○ Strength before endurance training
- ○ Endurance training before strength

Do you have an influence on when gym sessions take place?

- ○ It's my decision
- ○ I decide with the coach
- ○ No
- ○ Other

If you selected Other, please specify:

Page 9: Pre-season

During pre-season how many days a week is strength & power resistance training performed in each squad?

During pre-season on which days during the week is resistance training done? (e.g. two days before match day (MD-2)). Please select all that apply.

- [ ] MD+1
- [ ] MD+2
- [ ] MD-4
- [ ] MD-3
- [ ] MD-2
- [ ] MD-1

During pre-season, on average how long do these sessions last? (minutes)

When looking to build strength during pre-season, what sets, repetition schemes and intensities do you use?

When looking to build power during pre-season, what sets, repetition schemes and intensities do you use?

Page 10: In Season Training

In-season during a week with one game, how many days per week is strength and power resistance training performed by your primary squad typically?

[ ]

In-season on which days during the week is resistance training done? (e.g. two days before match day (MD-2)). Please select all that apply.

- ☐ MD+1
- ☐ MD+2
- ☐ MD-4
- ☐ MD-3
- ☐ MD-2
- ☐ MD-1

In-season on average how long do these sessions last? (minutes)

[ ]

Are there any factors that limit the volume and intensity of resistance training within the weekly schedule?

- ○ Yes
- ○ No

If yes, what are the factors limiting this? If you select "Other" please indicate what they are.

- ☐ Lack of time between training sessions and matches
- ☐ Concern over potential muscle soreness
- ☐ Limited facilities and/or equipment
- ☐ Other

If you selected Other, please specify:

[ ]

When looking to build strength during the season, what sets, repetition schemes and intensities do you use?

When looking to build power during the season, what sets, repetition schemes and intensities do you use?

Page 11: Review

You have completed the questionnaire

At this point you may go back to previous questions to review and/or change any answers you have given if you would like to.

Continue to the next page to submit your answers.

Page 12: Final page

Thank you for taking time to participate in this questionnaire. We hope the results will help inform future practitioners in their work and the development of new ideas.