An examination of the resistance training practices within an elite senior English Premier League professional football club.

David Rydings

A thesis submitted in partial fulfilment of the requirements of Liverpool John Moores University for the degree of Doctor of Philosophy

November 2017

Abstract

Limited research data is available outlining the resistance training characteristics of elite football players. The aim of the first study (Chapter 3) was to compare approaches to calculating resistance training volume during 4 weeks of pre-season training in 23 English Premier League footballers. Volume was calculated using four different methods of quantification; Repetition volume (RV), Set Volume (SV), Volume Load (VL) and Maximum Dynamic Strength Volume Load (MDSVL). Overall there was a significant difference between resistance training volumes calculated by the different methods used to monitor resistance training load ($P < 0.001$). More specifically, significant differences were observed between RV and SV methods ($P < 0.001$), RV and MDSVL ($P = 0.001$), SV and VL ($P = 0.010$), SV and MDSVL ($P = 0.033$) and VL and MDSVL ($P = 0.002$). Only RV and VL methods were similar in the information they provided on training load ($P = 0.411$). While the lack of a gold standard measure of volume makes it is unclear which, if any, method represents the most accurate measure of volume the discrepancies between methodological approaches highlight that these different approaches are not directly transferable as strategies to monitor resistance training. The understanding of the differences between each method may therefore enable appropriate, situation specific, approaches to be designed and implemented for both practical and research purposes.

The aim of the second study (Chapter 4) was to analyse the resistance training loads completed by an elite professional football team across a competitive season. Resistance training data was collected from 31 elite football players competing in the English Premier League over a 46 week period in the 2012-2013 season. A total of 1685 individual training observations were collected during the pre-season and in-season competition phases, with a median of 42 training sessions per player (range = 9 – 124). Training load data was separated into 7 blocks of 6 weeks for analysis. These periods included pre-season (6 weeks duration) and in-season (40 weeks duration) phases. Set volume was selected as a measure of total volume. Data was analysed using 3 separate linear mixed modelling analysis using the statistical software package R (Version 3.0.1). Weekly resistance training frequency (mean±SD) ranged from 1±1 to 2±1 sessions per week during the pre and in season phases. Significant differences

in session frequency were seen between weeks 1-6 and weeks 7-12 (pre-season) ($P < 0.05$), weeks 7-12 and weeks 13-18 ($P < 0.05$), and weeks 7-12 and weeks 37-42 ($P < 0.05$). Mean weekly training volume ranged from 18±16 to 30±24 sets$\cdot$wk^{-1}. The total training volume demonstrates a clear minimum during weeks 7-12. Significant differences in total training volume were also observed between weeks 1-6 and weeks 7-12 (pre-season) ($P < 0.01$), weeks 7-12 and weeks 13-18 ($P < 0.05$), and weeks 7-12 and weeks 19-24 ($P < 0.05$). There was no significant difference in training intensity between weeks 1-6 (pre-season) and weeks 7-12. Training intensity during weeks 1-6 however was significantly lower than during weeks 13-18 ($P < 0.05$), 19-24 ($P < 0.01$), 25-30 ($P < 0.01$), 31-36 ($P < 0.05$), and 37-42 ($P < 0.01$). Training intensity during weeks 7-12 was also significantly lower than during weeks 13-18 ($P < 0.01$), 19-24 ($P < 0.05$), 25-30 ($P < 0.05$), 31-36 ($P < 0.05$), and 37-42 ($P < 0.001$). The findings would suggest that resistance training loading is limited during different periods of the season. This is predominantly as a consequence of low training frequency, potentially due to a high prevalence of competitive fixtures.

The aim of the third study (Chapter 5) was to attempt to quantify the impact of resistance training completed by players, through evaluating the change in the lower body power outputs of an elite professional football team across a competitive season. Resistance training data was collected from 22 elite football players competing in the English Premier League over a 38 week period. A total of 246 individual power output observations were collected during the in-season competition phase. Power output of the lower body was assessed using a pneumatic resistance leg press machine with software and digital display (Keiser Sports Health Equipment Inc., Fresno, Ca). Data was analysed by means of linear mixed modelling analysis using the statistical software package R (Version 3.0.1). Power outputs ranged from 2200W to 4078W with a mean value of 3022±374W. Linear mixed effects show a significant effect of week on power output across the season (coefficient= 7.76W, p=0.0132). Specifically, when accounting for within player effects, power output increased 7.76W per week during the season. Individual weekly power coefficients ranged from +39.9W to -18.13W per week, thus indicating that the trend for increased power output across the season is not uniform for all the players. These data may suggest that lower body power performance is maintained or minimally enhanced over the course of a full competitive season in elite football players. Combined with the training load data previously examined in this thesis it can be concluded that whilst one resistance training session per week may be sufficient to avoid in season de-training or minimally improve power performance in elite football players, a frequency of two sessions per week may be necessary to obtain significant performance enhancements.

In our fourth study (Chapter 6) we provide two case studies that outline and evaluate a structured approach to increasing resistance training loading with the primary goal of developing strength and power during the competitive season in elite football players. The purpose of our initial case was to examine a resistance training programme to enhance strength and power performance, alongside body composition during a period of rehabilitation from injury. The study intervention commenced following two weeks of recovery following the "Laterjet" surgical procedure. Initial assessments were performed for body composition via dual-energy x-ray absorptiometry (DXA) (QDR Series Discovery A, Hologic Inc., Bedford, MA) and lower body power output via using a pneumatic resistance leg press machine with software and digital display (Keiser Sports Health Equipment Inc., Fresno, Ca). Assessments were repeated 8 weeks post-surgery, i.e. following 6 weeks of resistance training. The six-week intervention consisted of three strength training sessions per week for the initial 3 weeks, followed by 2 sessions per week for the subsequent 3 weeks. Training volume (number of sets) equalled a total of 20 sets total per session. Total increase in body mass over the intervention period equated to 5.4kg, of which 4.2 kg increase in lean mass and a 1.3 kg increase in fat mass. Peak power output increased by 21%. Power to weight ratio also increased by 4.4 %. These data illustrate that it is possible to increase physical performance when rapid short-term increase in resistance training load is completed.

The purpose of our second case was to examine a resistance training programme to enhance both strength and power performance parameters during a full competitive season. The player plays as a goalkeeper, regularly playing for his club 1st team. Prior to the onset of this case study this player did not present with any current injuries. This season long intervention consisted of two phases of training. Phase 1 was 16 weeks in duration and represented the beginning to the mid-point of the season. During this phase the goal was to gradually and safely increase resistance training loading. Phase

2 was 20 weeks in duration and represented the mid-point to the end of the season. This phase represented a period of consistent high loading following the initial systematic increase in these variables. Assessment data was collected at the beginning, mid-point and end of the 2013-14 season. The player was first assessed for body composition via DXA (QDR Series Discovery A, Hologic Inc., Bedford, MA). Secondly, lower body power output was assessed using a pneumatic resistance leg press machine with software and digital display (Keiser Sports Health Equipment Inc., Fresno, Ca). Finally, the player's upper body strength was assessed via 6 repetition maximum assessments of the dumbell bench press and prone row. The player completed a mean weekly volume of 41±24 sets per week and a mean frequency of 2±1 sessions per week for the initial phase of the study. The player completed a greater mean weekly volume in the later phase of the season compared to the initial training period (65±28 set per week vs. 41±24 sets per week in the initial phase of the season). A greater mean session frequency was also associated with the second training phase (3±1 vs. 2±1 session per week). There was a total decrease in body mass over the initial intervention period of 4kg, of which 2.7kg decrease in fat mass and a further 0.9 kg decrease in lean mass. Over the second phase of the intervention there was a total increase in body mass of 1.2kg, of which 2.4kg increase in lean mass and 1.2kg decrease in fat mass. During the initial phase of training peak power output increased by 25%, whilst power to weight ratio increased by 30%. During the later phase peak power output increased by a further 9% whilst the power to weight ratio increased by a further 10%. Upper body pressing (Dumbell Bench press) and upper body pulling (Dumbell Prone pull) strength was also increased by 14% and 21% respectively during the initial phase and a further 19% and 24% respectively during the later phase of the season. Although it is difficult to compare the findings of these individual cases to broader outcomes associated with a squad, in general, this data does seem to indicate that if resistance training programme variables are manipulated to increase training load it is possible to successfully increase physical performance parameters in both short, focused interventions and more long term, gradual approaches.

Acknowledgements

Firstly I would like to thank my Director of Studies, Professor Barry Drust. I have been really lucky to have you as my supervisor and I apologise for all those times I have been hard work for you! You have always gone well above and beyond for me, from being willing to work around my schedule, regularly agreeing to meetings at weekends and unsociable hours, to being there to offer guidance and support in both my professional and personal life. I will always be grateful for everything you have done to support me, thank you.

Secondly I would like to express my thanks to Dr. James Morton and Dr. Graeme Close, who formed the rest of my supervisory team. It was an honour to have two of the world’s best academic leaders and applied practitioners as supervisors. Your advice, especially when getting this thesis ready for submission was highly valuable and much appreciated.

Thirdly I would like to give a special thank you to Jordan Milsom of Liverpool FC. You not only gave me the opportunity to join Liverpool FC and start my PhD, but you have mentored me, helping me develop both personally and professionally, become a good friend and always had my back since day one of this journey. Thank you, I wouldn’t be where I am now without your support along the way. In addition to Jordan, other Liverpool FC staff who I have been lucky enough to work with and who have helped me achieve during the PhD journey that I would like to express my sincere thanks to are: Dr Darren Burgess, Dr Ryland Morgans, Glen Driscoll, Andreas Kornmayer, Andy OBoyle and Conall Murtagh.

Fourthly I would like to thank all the other PhD students I have worked alongside at Liverpool FC. Dr. James Malone and Dr.Alec Scott, the original LFC PhD students. In their day, the funniest interns in the Premier League! Liam Anderson and Paddy Orme also. I have learnt loads off all four of you and had a great laugh along the way. Thanks for all your help and support over the years and it’s great to see you all doing so well now.

A special mention should go to my Mum and Dad. I can always rely on you for help and advice, and no matter how much I tried to avoid conversations about my PhD you always supported me and kept me moving forward in the right direction.

Finally, I would like to express my gratitude to my girlfriend, Tamara. Not only have you put up with the long unsociable working hours during our last three years, but you have encouraged me to work hard to complete this thesis. I want you to know that your constant support has allowed me to juggle the PhD, work and general life commitments effectively, and I would like to express my sincere appreciation for your patience and love during this time.

Table of Contents

List of Abbreviations

Repetition Volume (RV)

Set Volume (SV)

Volume Load (VL)

Maximum Dynamic Strength Volume Load (MDSVL)

Dual-Energy X-Ray Absorptiometry (DXA)

Cross Sectional Area (CSA)

Anatomical Cross Sectional Area (ACSA

Physiological Cross Sectional Area (PCSA)

Union of European Football Associations (UEFA)

1 Repetition Maximum (1RM)

Countermovement Jump (CMJ)

Resistance Training (RT)

Central Defender (CD)

Wide Defender (WD)

Central Midfielder (CM)

Wide Midfielder (CM)

Attacker (AT)

Goal Keeper (GK)

Kilograms (KG)

Standard Deviation (SD)

Standard Error of Measurement (SEM)

Coefficient of Variation (COV)

Match Day (MD)

List of Figures

Chapter 3

Chapter 4

Chapter 5

Chapter 6

List of Tables

CHAPTER 1

General Introduction

Successful performance in football comes about as a result of a multitude of factors, including technical, tactical, physical and psychological components (Bangsbo, 1994). From a physical perspective, players compete for 90 minutes per game, a time period which is divided into two 45 minute halves. During this playing period, at the elite level, players are reported as covering between 8000 to 12000 meters per game (Rampinini et al 2007). However, whilst players do cover large total distances, football is regarded as a highly intermittent sport as around 1000-1500 movement changes occur per match, with these movement changes taking place every 5-6 seconds (Reilly, 2003; Strudwick et al., 2002). The physical demands of a game in the Danish league illustrated that whilst most time (≥80%) is spent performing low intensity movements (Standing, walking, jogging), up to 20% of time may be spent performing higher intensity activities such as running and sprinting (Mohr et at., 2003). In the English Premier League, a league widely recognised for its demanding nature, approximately 19 maximal sprints occur per game, with these taking place every 4-5 minutes, further illustrating the high intensity, intermittent nature of the sport (Drust et al., 2000) and the nature of the activity profile. These movement types and patterns drastically alter the bioenergetics requirement to the sport over those observed in more continuous type endurance exercise. The high intensity movements by which football performance is characterised are thought to be critical to the outcome of a game as these movements often relate to match winning moments (Faude et al., 2010) and are a key discriminator between elite and sub elite players (Bangsbo et al., 2008). Based upon this information it would suggest that any physical training needs for the players within the sport should focus on improving the ability to produce high intensity actions as well as movements such as accelerating, decelerating, jumping and cutting.

These high intensity movements such as sprinting, stopping, changing direction rapidly and jumping are all strongly correlated with the ability to generate maximal force (Alexander, 1989; Anderson et al, 1991; Peterson et al, 2006). Maximal strength therefore appears to be a key underpinning physical quality to the successful performance of these actions. Resistance exercise induces potent changes in the muscle metabolism, cross sectional area (CSA) and neuro-muscular adaptations necessary for improved sports performance (Philips, 2000; Folland and Williams, 2007; Channell and Barfield 2008). Numerous studies have shown that when strength is increased through the use of heavy resistance training there is an accompanying improvement in the performance of football specific assessments such as jump height, sprint speed, agility times and aerobic economy (for e.g. Stone et al., 1991, Paavolainen et al., 1999, Aagaard et al., 2010). Resistance training has therefore become a common training modality in the professional football setting. These practices, usually assumed to follow evidence based approaches to resistance training practices attempt to facilitate the development of a competitive advantage to the individual players and the teams during games. As numerous guidelines exist (specifically the frequency, volume and intensity of training) regarding the manipulation of resistance training variables in order to achieve improvements in specific performance and physiological qualities (Tan et al, 1999; Bird et al, 2005; Ratamess and Triplett-McBride, 2002) it is possible that approaches to resistance training within football are variable. To date however no research is available outlining the resistance training characteristics of elite football players.

The application of different resistance training methods and the associated loading will impose diverse stresses on an athlete's neuromuscular system. These stresses will in turn influence both the resultant adaptive signal and accumulated level of fatigue (Killen, Gabbett and Jenkins, 2010). The ability to accurately monitor the stress associated with an acute bout of resistance exercise, as well as the chronic exposure to a training programme is therefore vital for athlete development and the evaluation of programmes. Of the training variables listed above training volume is considered one of the most influential (Tan, 1999) as greater volumes of training elicit greater levels of strength adaptation in athletes when compared with lower volume programmes (Fernando et al 2013). Whilst a greater volume of resistance training may be beneficial for enhancing performance adaptations it may also increase injury incidence (Gabbett and Jenkin., 2002). This careful balance between adaptive and maladaptive training volumes may suggest it is important that training volume needs to be carefully monitored. However, the complex interaction of training variables in resistance exercise (such as sets, reps, resistance, movement speed, etc.) makes it difficult to apply a standardised method of determining the volume associated with resistance-training (Drinkwater et al., 2005).

The aim of this thesis therefore is;

To evaluate the resistance training practices in an elite premier league football team.

This aim will be achieved through the completion of the following objectives;

1. To establish an appropriate approach to monitor resistance training volume in English Premier League footballers.

2. To quantify the frequency of resistance training in an elite professional football team across a competitive season. Such information would provide detail of the training periodisation strategies currently used in elite level football.

3. To quantify the change in lower body power outputs of an elite professional football team across a competitive season. Such information would provide detail of the response to training strategies currently used in elite level football.

4. To investigate the effectiveness of periods of modified resistance training prescription in elite football players on performance

CHAPTER 2

Review of Literature

The format of this review of literature is based around producing a review for publication. Reviews of literature in scientific journals (such as Sports Medicine) are limited in word count (typically 6000-8000) words. As such they represent an attempt to present a focussed yet critical perspective on a targeted subject area. This approach has been adopted in an attempt to provide a more specific development experience targeted at refining writing skills that are specifically relevant to the future production of publishable reviews.

2.0 Overview of Football

Successful performance in football is underpinned by a multitude of factors that include technical, tactical, physical and psychological components (Bangsbo, 1994). Players compete for 90 minutes per game; this time period is divided into two 45 min halves. During this playing period, at the elite level, players are reported to cover between 8000 to 12000 m per game (Rampinini et al 2007). This total distance does not however truly reflect the "true" physical demands of the sport as between 1000 and 1500 movement changes occur per game, with these movement changes taking place every 5-6 seconds (Reilly, 2003; Strudwick et al., 2002). This activity profile means that football is regarded as a highly intermittent sport. Whilst the majority of time (≥80%) in the game is spent performing low intensity intermittent movements (standing, walking, jogging), up to 20% of time may be spent performing higher intensity activities such as running and sprinting (Mohr et at., 2003). In the English Premier League, it has been shown that approximately 19 maximal sprints occur per game, with each taking place every 4-5 min. This evidence not only further illustrates the high intensity, intermittent nature of the sport (Drust et al., 2000) but also suggests that the energetic provision for the activity is complex. These movement types and patterns therefore drastically alter the bioenergetics requirements of the sport when compared to more continuous endurance exercise patterns (Tschakert and Hofmann., 2013).

The high intensity movements that are thought to characterise football performance are thought to be critical to the outcome of a game as these activities often relate to match winning moments (Stolen et al., 2005). The capacity to perform high intensity actions is also a key discriminator between elite and sub elite players further supporting the potential importance of these movements (Bangsbo et al., 2008). This would suggest that the physical training completed by players would benefit from focussing on improving the ability to produce (and maintain) the performance of high intensity actions included related activities such as accelerating, decelerating, jumping and cutting, activities that would support the avoidance of non-contact injuries should be another important priority when planning team and individual training in football. Player availability is often considered key to team success (Hagglund et al., 2013) as it is suggested, and seems logical, that if key players are unavailable to play through injury, there will be a negative impact on team performance (Henderson et al., 2010). Eskstrand et al., (2009), in a UEFA injury survey, reported an injury incidence of 8 injuries per 1000 hours with a 6 times greater injury occurrence in games compared to training. This equates to a player sustaining on average 2 injuries per season or approximately 50 injuries per playing squad per season. The hamstring muscle group are the most commonly injured area, accounting for the most time loss of all specified sub groups (Arnason et al., 2004; Walden et al., 2005; Eskstrand et al., 2009). Whilst it is acknowledged that many injuries are unavoidable within a sport such as football (e.g. traumatic or contact injuries) there is a growing body of evidence to suggest that it is possible to reduce the incidence of non-contact soft tissue injuries such as hamstring strains (Peterson et al., 2011; Mjølsnes et al., 2004; Arnason et al., 2008) through appropriate preparation strategies. Such strategies are predominantly related to adaptations that are a consequence of the repeated exposure of individuals to a specific training stimulus.

2.1 Strength and Power in Football

An athlete’s strength is an important underpinning physical characteristic in the completion of high-intensity related movements. An athlete’s strength level is also an important physical characteristic in the avoidance of injury as several studies have shown an inverse relationship between strength levels and injury incidences (Bahr and Holme, 2003, Hrysomallis, 2009).”Strength” refers to a broad category of physical attributes that relate to the force generating capacity of muscle. A key aspect for physical performance in football is power. Power is the product of force and velocity, thus power represent an athletes ability to produce high forces at fast movement speeds. The relationships between an athlete's strength/power and performance in sports specific tasks are also positive as studies have shown a strong correlation between one repetition (1RM) back squat and sports performance tests (R=0.71-0.96)- such as the countermovement jump (CMJ), broad jump, T-Test, 10m acceleration and sprint velocity (Nuzzo et al., 2008, Peterson et al., 2006, McBride et al., 2009, Stone et al., 2004, Wilsoff et al., 2004). Performance in such sports specific tasks can be considered an indirect determinant of high-level soccer performance if elite players present greater perfromance than those who have never been selected to play at the elite level (Cometti et al., 2001).The CMJ is frequently used as a performance test of maximal power in elite soccer players (Alves et al., 2010, Arnason et al., 2004, Chelly et al., 2010b, Comfort et al., 2014, Rønnestad, Nymark and Raastad, 2011). Arnason and colleagues (2004) found a significant relationship between average CMJ height and success among seventeen teams in the 2 highest divisions in Iceland. Similarly, Rosch and colleagues (2000) reported lower BV CMJ performance in amateur players compared with top level and third division players. This relationship may suggested that an athletes strength underpins power performance, which in turn underpins performance in sports specific tasks.

Numerous studies using untrained individuals have shown that when strength is increased using heavy resistance training there is an associated increase in power and performance variables (Augustsson et al., 1998, Channell and Barfield 2008, Robinson et al., 1995, Sanborn et al., 200, Stone et al., 1980). This would seem to add further support to the link between strength, power and performance, though the lack of suitable methodological controls (such as a control group) frequently makes it difficult to conclude that performance changes were a result of the specific resistance training intervention and not other extraneous factors that have the potential to influence performance outcomes. This it review will attempt to provide a critical analysis of the importance of strength for football performance. This will include a initial discussion of the adaptations to resistance training and then a insight into monitoring and evaluation of resistance exercise with specific relevance to football.

aluation of resistance exercise with specific relevance to football.

2.2 Physiological Adaptations to Resistance Training: Implications for football

The ability to generate strength (defined as the ability to generate force) during football specific movements is largely dictated by the contractile capacity of the muscles involved (Hakkinen et al., 1985). The contractile capacity of a muscle is influenced by a series of morphological and neurological factors. This section will attempt to provide a focussed outline of the underpinning morphological and neural mechanisms associated with strength/power adaptations following resistance training. This information is presented to provide some content on the underpinning changes that may support positive influence of strength training on performance in elite football.

2.2.1 Changes in muscle size

The force produced by a maximally activated muscle (fibre) is determined by the number of sarcomeres arranged in parallel, i.e. the cross-sectional area (CSA) of the muscle (fibre) (Jones, Rutherford and Parker, 1989). As muscular power is the product of force and contraction velocity, muscle CSA is an important determinant of power. Whole muscle anatomical CSA (ACSA) has been shown to be proportionate to maximal voluntary isometric force (Ikai and Fukunaga, 1968, Maughan, Watson and Weir, 1983, Maughan, Watson and Weir, 1984) and maximal knee extension force has been observed to strongly correlate with quadriceps ACSA (Jones, Rutherford and Parker, 1989, Rutherford and Jones, 1986).

The PCSA represents the total area of all fibres within that muscle at right-angles to their long axes, and therefore the maximum force-generating capacity of that muscle (Close, 1972, Degens, Hoofd and Binkhorst, 1995). In parallel-fibred muscles, the ACSA may provide an accurate estimation of the muscle PCSA (Davies et al., 1988, Kawakami et al., 1994). However, in pennate-fibred muscles, where the muscle fibres are arranged at an angle to the line of pull of the tendon, the ACSA has been shown to underestimate the PCSA (Alexander and Vernon, 1975, Wickiewicz et al., 1983). Hence, normalising maximum force to PCSA will provide a more accurate calculation of muscle specific force (maximum force per unit PCSA) and provide an in vivo estimation of the single fibre specific tension (maximum force per fibre CSA). Such information provides an insight into the intrinsic contractile capacity of the muscle fibres (Erskine et al., 2009). Muscle volume (Vm) is the product of fascicle length x muscle PCSA (Erskine et al., 2009). With PCSA being a main determinant of muscle force and fascicle length being a major determinant of contraction velocity, it follows that Vm should be a major determinant in maximum muscle power. Indeed, quadriceps femoris Vm has been shown to be strongly related to mean power produced during CMJ (O'brien et al., 2009). Elite soccer performance requires the application of explosive force in multiple directions. Murtagh et al (2007) have demonstrated that greater knee extensor strength and quadriceps femoris size (Vm and PCSA) may be important indicators of competitive level in elite soccer players. Moreover, it was shown that the size of the quadriceps femoris muscle group contributed to unilateral vertical and unilateral medial CMJ, but not unilateral horizontal-forward CMJ performance. Thus it can be concluded that physiological factors such as Vm and PCSA may underpin the performance of multi-directional powerful actions in elite soccer players and can distinguish between playing level.

It is commonly reported that ACSA (6%-9%), PCSA (6%-8%), and Vm (7%-11%) are increased in the vastus lateralis and the gastrocnemius muscles following various resistance training interventions ranging from 3 to 18 weeks in duration (Aagaard et al., 2001, Alegre et al., 2006, Duclay et al., 2009, Blazevich etal., 2007, Campbell et al., 2013, Seynnes et al., 2007, Potier et al., 2009). It would therefore seem that these parameters are flexible and responsive to periods of chronic training. While these changes are well characterised in normal healthy adults and some athletic groups the available information on elite football players are somewhat limited. This would suggest that the completion of research projects that attempt to identify if these changes are important in supporting the development of strength and power in football would be beneficial.

2.2.2 Changes in muscle architecture

Assuming a constant level of stimulation, the maximal contractile velocity of a muscle fibre is proportional to its length (Macintosh and Holash, 2000, Sacks and Roy, 1982, Spector et al., 1980, Wickiewicz et al., 1983). The length of a muscle fibre is in turn determined by the number of sarcomeres arranged in series. Due to a longer muscle fibre being able to contract faster than a shorter fibre (Wickiewicz et al., 1983), and maximum shortening velocity being one component of maximal power (Edgerton et al., 1986, Jones, Rutherford and Parker, 1989), a longer muscle fibre will generate a higher maximal power output, all other things being equal (Macintosh and Holash, 2000, Wickiewicz et al., 1983).

However, muscular power is the product of both contraction force and velocity. The force produced by a maximally activated muscle (fibre) is determined by the number of sarcomeres arranged in parallel, i.e. the cross-sectional area (CSA) of the muscle (fibre) (Jones, Rutherford and Parker, 1989). Muscle CSA is there also an important determinant of power. The angle between the muscle fibres and their insertion into the aponeurosis defines the muscle fibres pennation angle (Huijing, 1985, Powell et al., 1984, Spector et al., 1980). This may also play an important role in the production of muscular power output. An increase in angle of pennation is thought to occur in response to an increase in muscle fibre CSA, due to limited attachment space on the aponeurosis (Aagaard et al., 2001, Degens, Erskine and Morse, 2009). Therefore, a larger pennation angle allows more contractile material to attach to the aponeurosis, thus increasing the whole muscle physiological CSA (PCSA) and allowing the muscle to produce more force (Aagaard et al., 2001).

Resistance training has also been shown to alter muscle fascicle length. Indeed, following 13 weeks of lower body resistance training, fascicle length of the vastus lateralis significantly increased by 10% (Alegre et al 2006) . Furthermore, Blazevich and Giorgi (2001) have shown 12 weeks of upper body resistance training to increase fascicle length of the triceps brachii by 16%. In contrast however, following 16 weeks of resistance training of the elbow extensors, no changes in fascicle length of the triceps brachii long head were observed (Kawakami et al., 1995).

Muscle pennation angle has also been shown to be altered following resistance training interventions. An increases of 30% to 33% in pennation angle of the vastus lateralis has been observed following both 10 and 14 week resistance training programmes (Aagaard et al., 2001, Franchi et al., 2014). Furthermore, Kawakami (1995) has shown an increase of 29% in pennation angle of the triceps brachii long following 16 weeks of resistance training for the elbow extensors. Similar increases in pennation angle of the triceps brachii lateralis have been found after 12 weeks of upper body resistance training (Blazevich and Giorgi., 2001). In contrast, a non-significant reduction of 2.4% of vastus lateralis pennation angle have been observed subsequent to 13 weeks of resistance training for the lower body (Alegre et al., 2006). Comparable non-significant reductions in vastus lateralis pennation angle have also been found following 12 weeks of resistance training of the leg extensors (Rutherford et al., 2003).

These differences in findings may be the result of differences in training program content. For example, studies that have used programmes that are focussed on maximum strength development have found close correlations between pennation angle and various measures of muscular size (Kawakami et al. 1993; Kawakami et al. 2006; Wakahara et al. 2013) indicating a close association between the training stimulus and the morphological change. Whilst there is promising evidence on the influence of changes in penation angle and its impact on athletic performance, more research is needed to enable a greater understanding of the specific responses to different exercise regimes in elite athletes and how these programmes may impact on sports specific training programme design.

2.2.3 Changes in Muscle Fibre Type

Due to the unique characteristics of each muscle fibre, the strength/power of a muscle may be partly determined by the specific make up of fibres within the whole muscle (Tihanyi et al 1982). Type II fibres have a significantly greater capacity to produce force than type I fibres (Bottinelli et al 1999., Wildrick et al 2002). Muscles with a higher percentage of type II fibres therefore display greater strength/power in comparison to muscles with a high percentage of type I fibres (Tihanyi et al 1982).

Furthermore there appears to be a difference in the sub-types of type II muscle fibres. A greater proportion of type IIa (the type II fibres that are associated with the highest force production) and a smaller proportion of type IIb fibers (the fibre type that contracts at the highest velocity) are seen in elite strength/power athletes when compared to control subjects (Fry et al. 2003., Fry et al. 2003b., Kesidis et al. 2008). The composition of a muscles type I and type II fibres is however believed to be largely inherited (Simoneau et al 1995) and so may not be indicative of an adaptive change. This is supported by observations that resistance training programs do not seem to lead to a shift between type I and type II muscle fibers in trained subjects (Hakkinen et al. 2001; Hakkinen et al. 2003). Some of the available research in this area has suggested that alterations in type II fibre profile (conversion of IIB fibres to IIA) can occur via resistance exercise in untrained subjects (Fleck and Kraemer 1988 and Kraemer et al., 1988). In contrast, Anderson and Colleagues (1994) demonstrated that whilst soccer players who commence resistance training do display minor alterations in muscle-fibre type composition, this study showed an increase in the proportion of type IIB fibres following resistance training, as opposed to an increase in type IIA. This was also accompanied with improvements in isometric strength. However, the training intervention implemented in this study was performed over a 12 week off season phase, whereby players did not perform any team based football sessions and instead completed a relatively low volume of resistance training. We can therefore not be sure whether these changes were a consequence of an increased exposure to resistance training or a decreased exposure to the higher speed and maximal acceleration demands of soccer match play (Reilly, 2003; Strudwick et al., 2002). Therefore, whilst muscle fibre type may play an important role in strength and power performance via the conversion of certain fibre types following resistance exercise the exact mechanisms of this in soccer are unclear. More research is required in this specific population to understand both the fibre type changes and the potential implications of such adaptations for performance.

2.2.4 Neural Factors

Improvements in muscle strength have been observed without noticeable increases in CSA (Gabriel 2006). This provides evidence for the neural involvement in adaptations to strength training. The ability to generate maximal strength/power during a movement is clearly not only a function of muscles morphology, but also of the ability of the nervous system to appropriately activate the muscles involved. The nervous system controls the activation of muscles primarily through changes in motor unit recruitment, firing frequency and synchronisation as well as inter-muscular coordination (Henneman et al., 1974, Enoka., 1995, Sale., 2003, Milner-Brown et al., 1975).

2.2.5 Motor Unit Recruitment

The force produced by a muscle is related to the number and type of motor units recruited (Duchateau and Hainaut 2003). According to the size principle (Henneman et al 1965), motor units are recruited in size order during contractions of increasing force. Relatively small motor neurons that innervate type I fibres are initially activated at low force levels while progressively larger motor neurons that activate type II fibres are typically activated at higher thresholds of force (Burke 1981). Thus the force capacity of a given movement is affected by the motor units activated with the recruitment of high-threshold motor units clearly being beneficial during strength/power production. The preferential recruitment of high-threshold motor units following training is therefore a common theory of neural adaptation in the available literature (Kraemer and Newton 2000., Duchateau and Hainaut 2003).

It has been suggested that well trained athletes can activate high-threshold motor units in place of low-threshold motor units during ballistic movements. This may lend support to the concept of a preferential recruitment of high threshold motor units been associated with resistance training (Kraemer and Newton 2000). Although the timing of motor unit activation can be changed with resistance training (Cracaft and Petajan 1977), it has been shown that following isometric or dynamic training that motor units still follow the size principle during a graded contraction rather than “preferential recruitment” strategies (Hainaut et al., 1981). Research by Van Cutsem (1998) supports this idea by illustrating that the order of recruitment during rapid contractions does not change following 12 weeks of resistance training. Little conclusive research is available, especially in relation to elite athletic populations, as to whether training can change motor unit recruitment or not following training. As a consequence the importance of this area to underpin adaptive change in elite athletes is unclear.

2.2.6 Firing Frequency

The motor unit firing frequency represents the rate at which neural impulses are transmitted from a motor neuron to muscle fibres (Folland and Willaims., 2007). The firing frequency of a motor unit can impact the ability of a muscle fibre to generate force in two ways. Firstly, it can increase the total magnitude of force produced during a contraction. Data shows that the magnitude of force developed during a contraction can increase by up to 15 times when the firing frequency of a motor unit is increased from its minimum to maximum rate (Enoka 1995). Changes in firing frequency can also change the rate at which force is produced during muscle contraction. For example, during ballistic contractions, motor units may take less time to begin firing at very high frequencies (Zehr 1994). Therefore, an increased firing frequency not only enhances the ability of muscles to produce force but also increases the rate at which this can be developed (Miller 1981). This increase in rate of force development has large potential benefits to the application on force within athletic movements due to the rapid speed required to perform a number of tasks effectively in real world activities. For example, Saplinskas et al (1980) found that elite sprinters have higher motor unit firing frequencies than long distance runners and untrained controls. These results have been used to suggest that increases in maximal motor unit firing frequency may contribute to improved strength/power performance following specific training. Training studies have also shown motor unit firing frequency to increase following strength training programmes in the lower body (Duchateau et al. 1998; Kamen and

Knight 2004; Knight and Kamen 2008). Patten et al (2001), conversely, reported no adaptations to firing frequency following 2 weeks of strength training. This study is however limited by its low subject numbers, short training period, and the unfamiliar movements involved and as a result this data may be limited. Motor unit firing frequency may therefore be an important neural adaptation in the development of the strength and power associated with resistance training programmes.

2.2.7 Motor Unit Synchronisation

Motor unit synchronisation describes the co-activation of different muscle groups to enhance the magnitude and rate at which muscle force is developed in a specific action (Semmler et al 2002). It has been observed that strength trained subjects display greater motor unit synchronisation than untrained subjects (Milner-Brown et al 1975., Semmler and Nordstrom 1998) thus suggesting the motor unit synchronisation is enhanced with training. It has been hypothesised that motor unit synchronisation may be a mechanism to coordinate the activation of muscles in order to control the efficient timing and effective application of force. Optimising motor unit synchronisation may therefore enable a greater transference of muscular strength/power into complex sporting movements (Mellor and Hodges 2005).

Though a distinct lack of studies have examined adaptations in motor unit synchronization following resistance training there is evidence that synchronization can be altered through training. Milner-Brown et al (1975) cited that motor unit synchronization in finger muscles increased after 6 weeks of resistance training in untrained subjects. Additionally, Semmler and Nordstrom (1998) examined the effect of physical activity level on motor unit synchronization also in the finger muscles of weightlifters, musicians and controls. They found that motor unit synchronization was greatest in weightlifters – the group who were most physically active (who did not specifically train the hand muscles but whose activity required high levels of grip strength). Semmler (2002) hypothesised that an increased motor unit synchronization does not directly alter maximal muscle strength but may rather positively impact the rate of force development. As a consequence it may be of great importance to force output during rapid contractions, such as are performed in sporting movements. This data would suggest that motor unit synchronization may play a role in the functional adaptation to resistance training though a lack of comprehensive evidence clearly indicates the need for more research.

2.3 Monitoring Resistance Training

The application of different resistance training methods and any associated loading patterns will impose diverse physiological stresses on an athlete's neuromuscular system. These stresses will in turn influence both the resultant adaptive signal and the accumulated level of fatigue (Killen, Gabbett and Jenkins, 2010). The ability to accurately monitor the stress associated with an acute bout of resistance exercise, as well as the chronic adaptation to a training programme, is therefore vital for athlete development and the evaluation of programmes.

Athlete monitoring is primarily concerned with evaluating the demands of exercise. Its useful in this respect to for Training to be conceptualised in a dose-response paradigm , whereby the 'dose' is the training completed and the 'response' is the resultant adaptation and its subsequent impact on performance (Lambert and Borresen, 2010). Chronic adaptations or the "response" can be measured via a change in performance or a change in the outcome of assessments which evaluate a particular aspect of an athlete's physical capacity (e.g. a laboratory-based test). Quantifying the acute "dose" in resistance training specifically is problematic. This is due in part to the vast array of training modalities often employed to develop strength for example

2.4 Methods of Quantifying Resistance Training

Training volume is considered one of the most influential variables to monitor in RT (Tan, 1999). This is because greater volumes of RT are associated with the development of greater levels of strength adaptation in athletes when compared to lower volume programmes (Fernando et al 2013). A greater volume of resistance training may also have negative consequences as it may also increase injury incidence (Gabbett and Jenkin., 2002). This careful balance between adaptive and harmful training volumes may suggest that training volume needs to be carefully monitored to ensure suitable programming for all athletes. However the complex interaction of training variables in resistance exercise (such as sets, reps, resistance, movement speed, etc) makes it difficult to apply a standardised method of determining the volume associated with resistance-training (Drinkwater et al., 2005). Numerous methods of reporting resistance training volume have been both reported in the literature and then subsequently employed in the applied setting. Despite the existence of these various approaches a comprehensive understanding of each approach is still required for the effective utilisation of the most appropriate method for a given situation.

2.4.1 Repetition volume

Repetition volume is the term used to describe the total number of repetitions performed in a given training period. It is one of the simplest methods of quantifying the volume of RT performed, as it merely requires the number of repetitions to be first counted and then noted. It is also one of the most readily manipulated training variables in both research design and applied training programmes.

Quantifying the number of repetitions as a marker of volume in RT has been commonly used in the literature due to its ease of application. Numerous studies have examined how various physiological responses, such as strength, power, and body composition are affected by the manipulation of the number of repetitions performed (Marx et al., 2001, McBride et al., 2003, Ronnestad et al., 2007, Marshall et al., 2011, Ronnestad et al., 2007, Wernbom et al., 2007).

Many of these studies have manipulated the number of repetitions, thus resulting in concurrent alterations in other acute programme variables, i.e. and increase in repetitions will lead to a decrease in load lifted. It impossible to alter the number of repetitions without other acute programme variables changing, the inverse relationship between volume and intensity in this case, demonstrates the fundamental integration of all training variables.

Across the literature, manipulation of the number of repetitions has been shown to cause fluctuations in a wide range of acute and chronic responses to RT. Fry et al (2000), found that the number of repetitions was a factor in the correlation between pre/post RT testosterone:cortisol ratio and adaptations to weightlifting performance. Earlier work by the same group (Fry et al., 1994) showed that not only can the repetition volume influence hormonal response to RT but that this response is also affected by the training age of the individuals involved. They concluded that, the weightlifting performance of elite athletes was more sensitive to a reduction in repetition volume compared with that of less skilled athletes. This may therefore support the monitoring of repetition volume as a measure of RT volume, especially in elite athletes, such as within this thesis.

Repetition volume however, may not fully quantify the external training load in relation to the overall stimuli of RT. Therefore it may not be able to detect the required amount of detail between dose and response. Wernbom et al. (2007) in their review, concluded that RT sessions of 30-60 repetitions led to a greater hypertrophic adaptation than those performing both lower or higher repetition sessions. However, when the intensity of RT was increased only 12-14 repetitions were necessary to achieve similar gains (Wernbom et al., 2007), again demonstrating the fundamental integration of all training variables. If additional acute programme variables (i.e. intensity) are incorporated with the number of repetitions then the sensitivity of this method should improve.

2.4.2 Set Volume

Set volume is the term used to describe the total number of sets performed in a given training period. It is another simple method of quantifying the amount of RT performed, as it merely requires the total number of sets to be counted. Similar to repetition volume it is a readily and easily manipulated acute programme variable in both the research and applied settings (Kramer et al 2000., Galvao and Taaffe 2004., Marshall et al. 2011., and Krieger 2009). Many studies show the use of multiple-set programs in resistance training to produce superior gains in strength, power, and athletic performance, especially in trained individuals, when compared with single-set programs (Kramer et al 2000., Galvao and Taaffe 2004., Marshall et al. 2011., and Krieger 2009). Indeed, in a review by Krieger (2009) it was concluded that multiple sets of repetitions can lead to 48% greater strength gains than in single set programmes in both trained and untrained participants. Unfortunately, much of the data included in this review used individuals from non-elite populations (i.e. they were untrained or low training age). Additionally many of these studies utilised experimental designs comparing either one or three sets, and thus may not be fully representative of RT performed by athletes who often perform greater than 3 sets of a given exercise (Cormie et al., 2011). This may limit the applicability of such research findings to the evidence base associated with the the RT of athletes.

A recent report published by Marshall et al. (2011) provides greater evidence for the efficacy of quantifying the number of sets in RT prescription. Marshall et al., (2011) made comparisons between one, four and eight sets of RT at an intensity of 80 % of 1RM twice per week. A 10-week training period was employed with measures of 1RM back squat, quadriceps muscle activation and contractile rate of force development taken at three, six and ten weeks. The results indicated that strength increases in the group performing eight sets was significantly greater than those performing a single set at all points following the baseline assessment (37.0 vs. 17.4 kg increase in squat 1RM by week 10) or those completing 4 sets of training. These data also suggested that performing four sets per session resulted in increases in strength above those performing a single set, though this difference did not reach statistical significance. The number of exposures to a given stimulus is therefore of greater importance than the extent of the overall stimulus as this appears to be what drives the adaptation to RT. Calculating volume via the quantity of exposures to a stimulus (i.e. set volume) is there of greater value when evaluating a training programme than the overall extent of a stimulus (i.e. repetition volume).

2.4.3 Volume Load

Volume load (VL), provides an indication of training volume through an estimation of the total load (kg) lifted within a training session. Peterson et al. (2011) identified that VL is one of the most widely accepted measures of the quantity of RT performed.This statement is however against a backdrop of considerable debate amongst scientists and practitioners in the field. Peterson et al. (2011) examined the predictive ability of VL to detect changes in muscle strength and hypertrophy over a 12 week training programme. Measures of neuromuscular performance and hypertrophy were taken pre- and post-training, whilst VL was calculated for the whole training period. VL was strongly associated with the change in 1RM in both male and female participants (Peterson et al., 2011). As such this study is unique in identifying the discrete influence of VL on neuromuscular adaptation to RT. However, the findings of Peterson et al. (2011) need to be replicated in a more athletic population using training methods more representative of elite populations to confirm the applicability of these results for such populations.

Both Häkkinen et al. (1987) and Haff et al. (2008) reported data showing that blood hormonal concentrations were related to manipulations in VL in elite weightlifters. Additionally Haff et al. (2008) demonstrated that isometric peak force was influenced by manipulations in VL also suggesting its importance as a variable to monitor in training sessions. Whilst these studies demonstrate data supporting the influence of VL on both the acute fatigue and chronic adaptations to RT, the VL method is also highly limited in its application. The major limitation of this method is that it does not accurately quantify the workload during body mass only exercises. During body mass only exercises, no external load is lifted, and as such this equation provides no quantification of training load in this scenario, this will therefore vastly underestimate the total volume of exercise completed in a training programme where body mass only exercises are regularly utilised. This is confirmed by the research of McBride et al., (2008). This method is therefore probably unsuitable for use in sports that regularly implement body mass only exercises during resistance training sessions.

2.4.4 Maximum Dynamic Strength Volume Load

A limitation of the VL method is that it does not take into account body mass in the quantification of RT. This has been addressed by some authors (McBride et al. 2009) who have attempted to incorporate body mass within the VL method. This measure, has been named “Maximum dynamic strength volume load” (MDSVL) and is defined as “the sum of the external mass lifted including a proportion of body mass displaced in each repetition” (McBride et al., 2009).

McBride et al. (2009) used MDSVL in the comparison of four different methods of RT quantification. The other methods included in this investigation were VL, mechanical work and time under tension. In this study participants performed three RT sessions using variations of the back squat exercise. One of the three resistance training sessions focused on hypertrophy (4 sets of 10 repetitions at 75 % 1RM), while the others targeted maximum strength (11 sets of 3 repetitions at 90 % 1RM) and power development (8 sets of 6 repetitions of jump squat with no external mass). No significant differences were observed between the hypertrophy and maximum strength protocols when quantifying RT using the MDSVL method , though these training approaches both resulted in significantly greater training loads than was associated with the power protocol. This led the authors to conclude that MDSVL underestimated the quantity of RT in the power session because of an inaccurate representation of the actual force production (McBride et al., 2009). The mechanical work method was concluded to be most valid approach to the assessment of load as there were no significant differences between the quantity of training for the different sessions. The efficacy of this conclusion is however questionable as it is unknown whether training protocols are in fact of similar volume despite providing highly differing stimuli.

Furthermore, in the study of McBride et al (2009) the proportion of body mass that is included in the calculation of MDSVL may not have been determined in a robust manner. In this study, 88 % of body mass was included, in addition to external mass, for the squat exercise based on the rationale that the feet and shanks are relatively static during the active phase of this exercise. This was based on the citation of Cormie et al., (2007). Cormie however presented no data to support the assumptions made regarding segmental weights and kinematics of body segments during this exercise, further research would therefore be needed before this method could be considered valid.

Whilst MDSVL does offer value in that it can quantify RT performed without any additional external load. A further limitation of the MDSVL method in the applied setting is the highly time consuming nature of processing data. In the applied setting this makes feedback to players and coaches extremely slow and therefore not appropriate.

2.4.5 Quantifying Intensity in Resistance Training

The ability to represent the training intensity of an exercise or training bout is also of great importance when evaluating training. Intensity can relate to a single repetition or a whole session and therefore does not solely represent a single attribute. Whole session intensity dictates the total stimulus for adaptation and is therefore considered more relevant in the overall quantification of resistance training. Whilst methods exist to evaluate intensity in a single repetition, this becomes more complex when trying to quantify intensity across an entire session. When examining the original periodisation literature it is clear that there is a distinct interplay between the volume of training and the intensity of the training bouts encountered (Bompa and Haff., 2009, Matveyev., 1965, Nadori., 1962). Furthermore, more recent empirical investigations have shown that high intensity training is more related to strength enhancement, whilst high volume training protocols may be more related to enhancing muscle hypertrophy responses (Brandenburg and Docherty 2002; Schoenfeld et al. 2014). However, some methodological limitations (e.g., program design and hypertrophy assessment) raise questions regarding the efficacy of each program type in stimulating strength and hypertrophy increases. Traditionally intensity in resistance training is expressed as a percentage of 1 repetition maximum (%1RM) (Garhammer., 1993). One major limitation of this approach is that after performing an initial set at a desired intensity the capacity of the athlete is reduced in subsequent sets, regardless of recovery (Stone et al., 2007). Thus, by the second or third set it is likely that the athlete may not be actually training within the assumed intensity range. A further limitation of this approach to quantifying resistance training intensity is that it is unable to quantify whole-session intensity. For example a training session which employs different exercises, loaded at different intensities, cannot be appropriately represented by %1RM. To the authors knowledge the only alternative method of objectively quantifying whole session intensity is via the Average Load method (Haff., 2010). This is calculated as the total load lifted per session divided by the total number of repetition performed. Whilst a major advantage of this method is its representation of exercise intensity for all the exercises performed, it is also importation to note that smaller muscle mass exercises and body weight only exercises will result in a decrease in the average intensity for the training day due to the lack of external load lifted. This is an important factor to understand when interpreting loading data utilising this method.

2.5 Strength and Power Assessment following chronic exposure to resistance training

The development of power in the lower limb is a crucial component in the physical preparation of elite football players, due to its underpinning of the successful completion of high intensity actions (Hakkinen et al., 1985). The accurate assessment of these qualities is therefore vital for both diagnostic purposes (thus informing the prescription process) and the overall monitoring of a training programme to ensure its effectiveness. Sport-specific maximal power assessments provide objective measurements, which represent the ability of the athlete to achieve the greatest instantaneous power during a single sport-related movement. To assess this quality it is necessary for this movement to be performed with the aim of achieving maximal effort during the repetition (Cormie, Mcguigan and Newton,2011).

Numerous methods such as repetition maximum testing, isokinetic dynamometry, jump testing and power measurement during commonly used exercises (such as jump squats and leg press) have been used to provide a measure of variables such as force and power both in the literature and applied settings. To serve the purpose of informing applied practice in elite football, it is important that muscular power assessments provide the greatest diagnostic information in the shortest amount of time. Within this context, assessments of muscular power should be specific and measured using tests that are biomechanically similar to the specific movement patterns common in football (Coburn, 2012, Harman, 1993, Maulder and Cronin, 2005).

Isokinetic dynamometry testing is widely regarded as a gold standard method for assessing muscle performance in both research, and applied environments (Gleeson and Mercer 1996). Information on a variety of variables underpinning muscle performance is provided via this method (e.g., torque, joint angles, work, and power) (De Ste Croix et al., 2003). In research specifically, this method is well used, potentially because it has been shown to discriminate between both competitive levels and those of different training ages (Cometti et al., 2001) as well as highlighting physical differences between playing positions in football players (Cotte and Chatard 2011 and Tourney-Chollet et al., 2000).

Research has examined the relationship between strength measured using isokinetic methodologies and measures of functional performance, including sprint (Cotte and Chatard 2011), repeated sprint ability (Newman et al., 2004), and vertical jumping (Cronin and Hansen 2005, Iossifidou et al., 2005 and Menzel et al., 2013). Unfortunately, little relationship has been found between isokinetic performance and functional performance in football to date. Iossifidou et al (2005) hypothesised that this is likely due to differences in the movement patterns performed, whereby muscle are activated differently and power developed at different rates, during isokinetic knee flexion/extension as opposed to during functional movements. Whilst Isokinetic testing may provide generic strength information it may therefore however be inappropriate as a measure of assessing football specific functional strength/power performance.

Repetition maximum testing (RM) has long been used as a method to assess strength and power in athletes. Its use has gained support based on the concept that assessing strength in specific , multi joint movements may best reflect functional strength of an athlete. Numerous studies have shown a strong correlation between back squat 1RM with sports performance tests such as the countermovement jump (CMJ), broad jump, T-Test, 10m acceleration and sprint velocity (Nuzzo et al., 2008, Peterson et al., 2006, McBride et al., 2009, Stone et al., 2004, Wilsoff et al., 2004). Additionally, it has been suggested that evaluating the effects of training within its specific context (i.e. utilising resistance training exercises) may best represent an accurate evaluation of strength gain from RT (Abernethy et al., 1995).

Despite its anecdotal value as a testing method for athletes, the available literature on 1RM testing in football is sparse. Indeed, to the authors knowledge only 2 existing studies have utilised this method in football players (Christou et al., 2006 and Sander et al., 2013). Furthermore, both of these studies have utilised youth athletes (13–17 years), therefore highlighting that there may be issues surrounding the implementation of this method in elite adult football players. Regardless of the lack of data currently existing in football players, it has been suggested that RM testing in explosive movement (such as Olympic lifts) is a valuable method of assessing strength performance in athletes. No research exists utilising RM testing in Olympic movements in football players however research in other sports is more readily available. The hang power clean has been shown to correlate to sprint performance more favourably than the back squat in Australian Rules Football players (Hori et al., 2008). Furthermore, the power clean has been shown to be a reliable measure in rugby players (Comfort et al., 2013) and both youth and collegiate American football players (Faigenbaum et al., 2012 and Malliaras et al., 2009), to date however there appears to be no equivalent data in football players. This lack of empirical evidence could highlight some of the shortcomings of this method for use in elite football. It has been recommended that football players only engage in RM testing if they are highly familiar with an exercise in order to both increase the test reliability (Benton et al., 2013), and to reduce the risk of injury (Hammami et al., 2013). A further explanation for the lack of RM data in football could revolve around the demanding nature of the assessment and the time constraints of a congested fixture calendar.

The assessment of power output during isoinertial exercise has previously been found valuable to assist in understanding the underlying mechanisms responsible for maximal power output and training adaptation (Rahmani, Viale, Dalleau, & Lacour, 2001;Samozino, Rejc, Di Prampero, Belli, & Morin, 2012; Cormie, McGuigan, & Newton, 2010a, 2010b). Historically the vertical jump has been a commonly used movement to assess isoinertial leg power. Countermovement jumping (CMJ), in particular, has been considered one of the most featured tests used within football clubs. The frequency of jumping task performed in both training and match play makes testing for this component easier to rationalise and therefore implement in comparison to other assessment methods such as isokinetic dynamometry and RM testing (Cormie et al., 2011). Recently dynamometers such as linear position transducers and accelerometers have been gaining popularity and have been found to be reliable in combination with RT equipment and methods (Cronin & Henderson, 2004). These enable the assessment of load/velocity (Jidovtseff et al., 2011) and load/power profiles (Cronin, Jones, & Hagstrom, 2007; Harris, Cronin, & Hopkins, 2007).

Loaded and unloaded RT movements (jump squats) have been found to be a reliable assessment of force-velocity-power capabilities in athletes (Cormie et al., 2010a, 2010b; Sheppard, Cormack, Taylor, McGuigan, & Newton, 2008). Previous studies have also demonstrated the safety of performing ballistic RT movements (Leg press exercises) with both novice and experienced weightlifters (Cronin & Henderson, 2004; Samozino et al., 2012). As this movement mimics the triple extension nature of sprinting and jumping, it may offer a valuable and safe alternative to loaded jumping exercises in elite football players.

2.6 Periodisation and Programming

The planning of training programmes in elite football needs to include all training, competition and monitoring/assessment actions scheduled to take place over a training block, often coinciding with an entire season. Periodisation simply refers to a logical, phasic method of manipulating training variables in order to increase the potential for achieving specific performance goals (Stone et al., 2007). Thus, periodisation is a concept used to structure training schedules into timelines coinciding with specific fitness goals. With regard to improving strength and power performance, periodised training programmes have been shown to produce greater benefits compared to non-periodised training (Williams et al., 2017). Typically, periodisation requires training plans to be consolidated into distinct phases (e.g. preparatory, competitive, and transitional phases) which are used to induce specific physiological adaptations in a sequential manner which exploits specific performance qualities at desired periods of a competitive season (Bompa and Haff., 2009). These phases are performed over designated timelines (e.g., macrocycles, mesocycles, and microcycles), which are used to define the length of time invested in developing or accentuating certain performance qualities. Similarly, various programming strategies can be used to stress desired fitness characteristics and effectively manage fatigue (DeWeese et al., 2015).

2.7 Summary

In summary, this section describes the importance of monitoring in resistance training to enhance football performance. Several methodologies for the acute monitoring of resistance training load have been discussed, specifically focusing on SV, RV, VL and MDSVL. These three methods of training load monitoring will therefore be assessed and employed in the current thesis in order to accurately quantify the training load and seasonal periodisation of resistance training load within an elite football team.

CHAPTER 3

A comparison of methods to evaluate the training load during a resistance training programme in English Premier League football players.

3.0 Introduction

High-intensity movements in football performance are thought to be critical to the outcome of a game as these movements often relate to match winning moments (Stolen et al., 2005). The capacity to perform high intensity actions is a key discriminator between elite and sub elite players (Bangsbo et al., 2008). This key discriminator further supports the importance of such movements to top-level performance. High intensity movements such as sprinting, decelerating, changing direction rapidly, and jumping are all strongly correlated with the ability to generate maximal force (Alexander, 1989; Anderson et al, 1991; Peterson et al, 2006). Therefore maximising strength appears to be a key method to successfully improve the execution of these actions. Numerous studies have shown that when strength is increased through the use of heavy resistance training there is an accompanying improvement in the performance of football specific assessments such as jump height, sprint speed, agility times and aerobic economy (for e.g. Stone *et al.*, 1991, Paavolainen *et al.,* 1999, Aagaard *et al.,* 2010). Thus, resistance training has become a common training modality in the professional football setting.

There are various guidelines that inform the prescription of resistance exercise (Ratamess and Triplett-McBride, 2002). These recommendations relate to the application of training variables such as volume, intensity, frequency and modality. The application of different resistance training methods and the associated loading will impose diverse stresses on an athlete’s skeletal muscle and neuromuscular systems. These stresses will in turn influence both the resultant adaptive signal and the accumulated level of fatigue (Killen, Gabbett and Jenkins, 2010). The ability to accurately monitor the stress associated with an acute bout of resistance exercise, as well as the chronic exposure to a training programme is vital for athlete development and the evaluation of programmes. Of the training variables listed above training volume is considered one of the most influential (Tan, 1999). Greater volumes of training elicit greater levels of strength adaptation in athletes when compared with lower volume programmes (Fernando et al 2013). Whilst a greater volume of resistance training may be beneficial for enhancing performance adaptations it may also increase injury incidence (Gabbett and Jenkin., 2002). This careful balance between adaptive and maladaptive training volumes suggests that it is important that training volume is carefully monitored.

The complex interaction of training variables in resistance exercise (such as sets, repetitions, load, movement speed, etc) makes it difficult to apply a standardised method of determining the volume associated with resistance-training (Drinkwater et al., 2005). Total work (Force(N) x Displacement(m)) has been suggested as the most valid method to quantify the overall training volume in resistance training (McBride et al., 2008). However, not only has this approach not been validated, it is also highly impractical in the applied setting due to the requirement for laboratory-based technologies to collect the data and the prolonged time needed to process the results. Several more accessible measures of quantification have been used within the literature as a best estimate of training volume. These measures include repetition volume (RV), set volume (SV), volume load (VL), and maximum dynamic strength volume load (MDSVL) (Cormie et al., 2007, Gonzallez-Badillo et al., 2005, Tran et al., 2006, McBride et al., 2008). Whilst none of these approaches seem to provide comprehensive information on all of the factors that may stimulate an adaptive response in the neuromuscular system, they potentially provide important information regarding the single training variable of volume.

To date, no study has compared methods of estimating resistance training volume by contrasting methods during an actual training programme for elite athletes. The aim of the present study was therefore to assess the differences in approaches to the calculation of resistance training volume during 4 weeks of preseason training in English Premier League footballers. We hypothesise that, there will be significant difference between all examined methods to monitor resistance training load.

3.1 Methods and Materials

This investigation was based on an observational study completed during 4 weeks of pre-season training in a Premier League football team. To compare and analyse differences in weekly resistance training volume the volume of resistance training was determined using 4 different methods commonly reported in the literature; RV, SV, VL and MDSVL. An analysis of each methods ability to detect changes in the resistance training volume completed by players across 4 weeks was determined to provide a basis for the comparison of approaches.

3.1.1 Participants and training observations

Resistance training data was collected from 23 elite football players competing in the English Premier League over a 4 week period of the 2011-2012 season. The physical characteristics of the players (mean ± SD) at the end of the pre-season phase were as follows: 24 ± 5 years; height, 1.84 ± 0.7 m; body mass, 82 ± 7 kg. A total of 234 individual training observations were collected with a median of 10 training sessions per player (range = 7 – 14). Player resistance training activity during each session was monitored and recorded manually. A custom-built spreadsheet (Excel, Microsoft, Redmond, WA see appendix 1) was used to record the full content of each individual training session. The exercise and the sets and repetitions completed, as well as the external load lifted (kg) per set was recorded on completion of the session. All data collection for this study was carried out at the football club's gym facility at the training ground. All players were made aware of the purpose of the study and provided written, informed consent. The study was approved by the University Ethics Committee of Liverpool John Moores University.

3.1.2 Resistance programme design

During the 4 week training period each player followed an individualised resistance training programme. The content of each training session was planned by the team's strength and conditioning coaches in line with the physical goals for each player. Such physical goals included programmes to develop increases in lean muscle mass, maximum strength and maximal power output. Training sessions typically consisted of a combination of 2 to 4 upper body exercises and 3 to 6 lower body exercises. Repetitions ranged from 4 to 8 per set depending on the exercise and training goal. Sets ranged from 1 to 3 per exercises (See Table 3.1 for an example of a resistance training programme).

Table 3.1. Example of a typical resistance training session used within the training programme for an individual player. * Players all followed an individualised training programme. Repetitions ranged from 4 to 8 per set depending on the exercise and training goal. Sets ranged from 1 to 4 per exercises.

Exercise	Sets	Reps	Load
Blue Belt Squat	3	6	15kg
Nordic Curl	3	6	0kg
Stiff Leg Deadlift	3	6	60kg
Single Arm Shoulder Press	3	6	14kg
Chin Up	3	6	0kg
TRX Row	3	6	0kg

3.1.3 Volume Calculations

Each player's daily resistance training data was used to calculate weekly resistance training volume. Volume was calculated using four different methods of quantification; RV, SV, VL and MDSVL. Repetition volume was calculated as the sum of all completed repetitions. Similarly, SV was calculated as the sum of all completed sets. Volume load was calculated as the result of completed repetitions and the external load lifted (repetitions (no) x external load (kg)). This provided training volume as the total external load (kg) lifted. The MDSVL method used the following equation: (repetitions (no) x (external load (kg) + bodyweight – limb mass (kg)) to provide volume. Limb masses were estimated using the percentage of bodyweight ratios of Dempster and Gaughan (1967). The MDSVL method displays volume as the sum of body mass and external load (kg) lifted. The output from the RV and SV methods were expressed as count·wk^{-1} and VL and MDSVL as kg·wk^{-1}.

3.1.4 Statistical analysis

Data were expressed as the weekly sum of training load. Descriptive statistics were used to summarise and explore the data initially. For a comparison of each method the change in workload across the 4 weeks was calculated for each monitoring approach. This change was expressed as the weekly % change in volume. This procedure enabled the data to be presented in uniform units of measurement to enable an evaluation of the differences to be made. A two-way (monitoring method×week) repeated measures ANOVA was used to analyze the relationship between percentage change in all monitoring methods over time. Tukeys post hoc comparisons were used to detect differences between both monitoring methods and weeks. Data is presented as means ± Sd with statistical significance was set at $P < 0.05$. SPSS Statistical Software Package version 21 (SPSS Inc., Chicago, USA) was used for all statistical analysis.

3.2 Results

Table 3.2 outlines the weekly % change in training load for all 4 methods of monitoring resistance training. Figure 3.1 illustrates the mean weekly training load for all 4 methods of monitoring resistance training. Overall there was a significant difference between the methods used to monitor resistance training load ($P < 0.001$). More specifically significant differences were observed between RV and SV methods ($P < 0.001$), RV and MDSVL ($P = 0.001$), SV and VL ($P = 0.010$), SV and MDSVL ($P = 0.033$) and VL and MDSVL ($P = 0.002$). Only RV and VL methods were similar in the information they provided on training loads ($P = 0.411$).

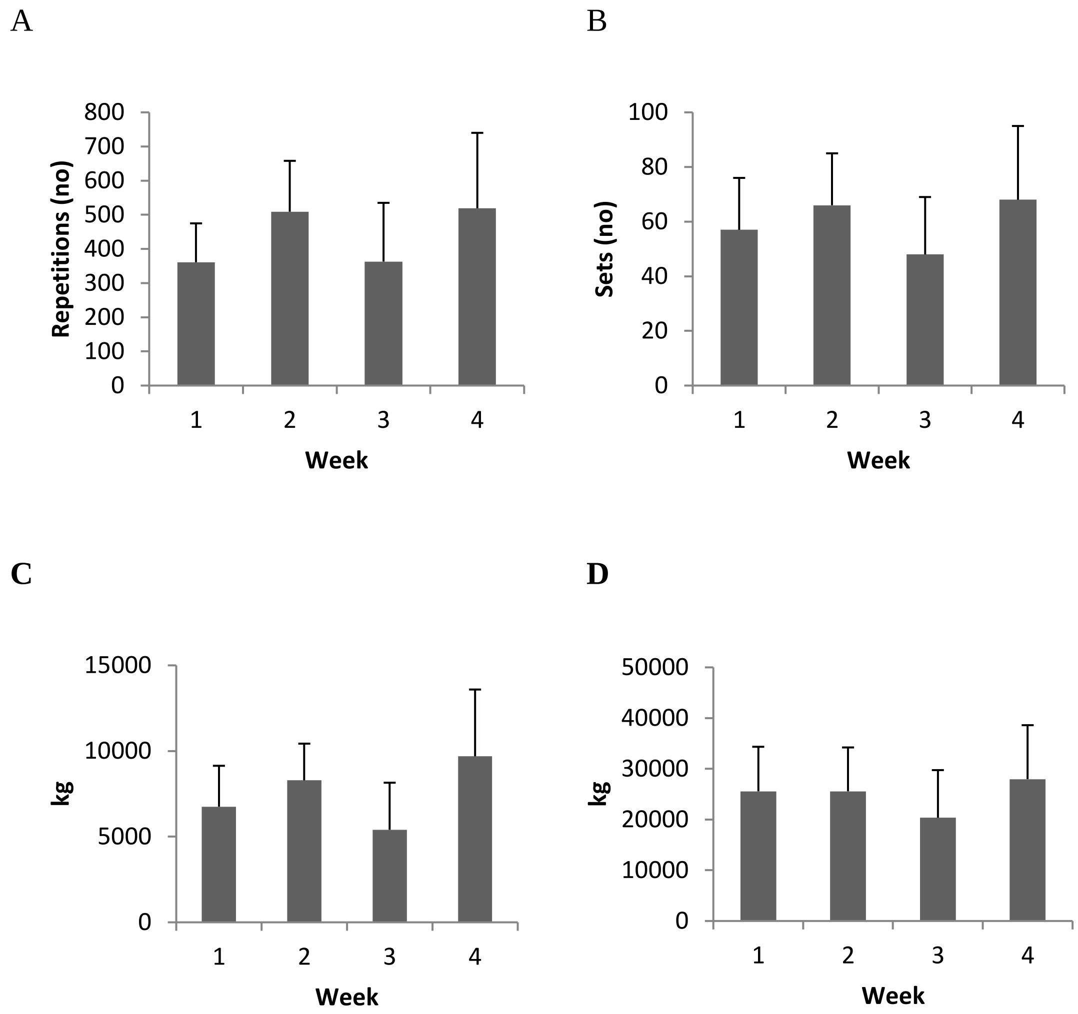


Figure 3.1. Resistance training volume data presented across 4 methods of calculation a) repetition volume b) set volume c) volume load and d) maximum dynamic strength volume load (MDSVL) across 4 weeks of pre- season training.

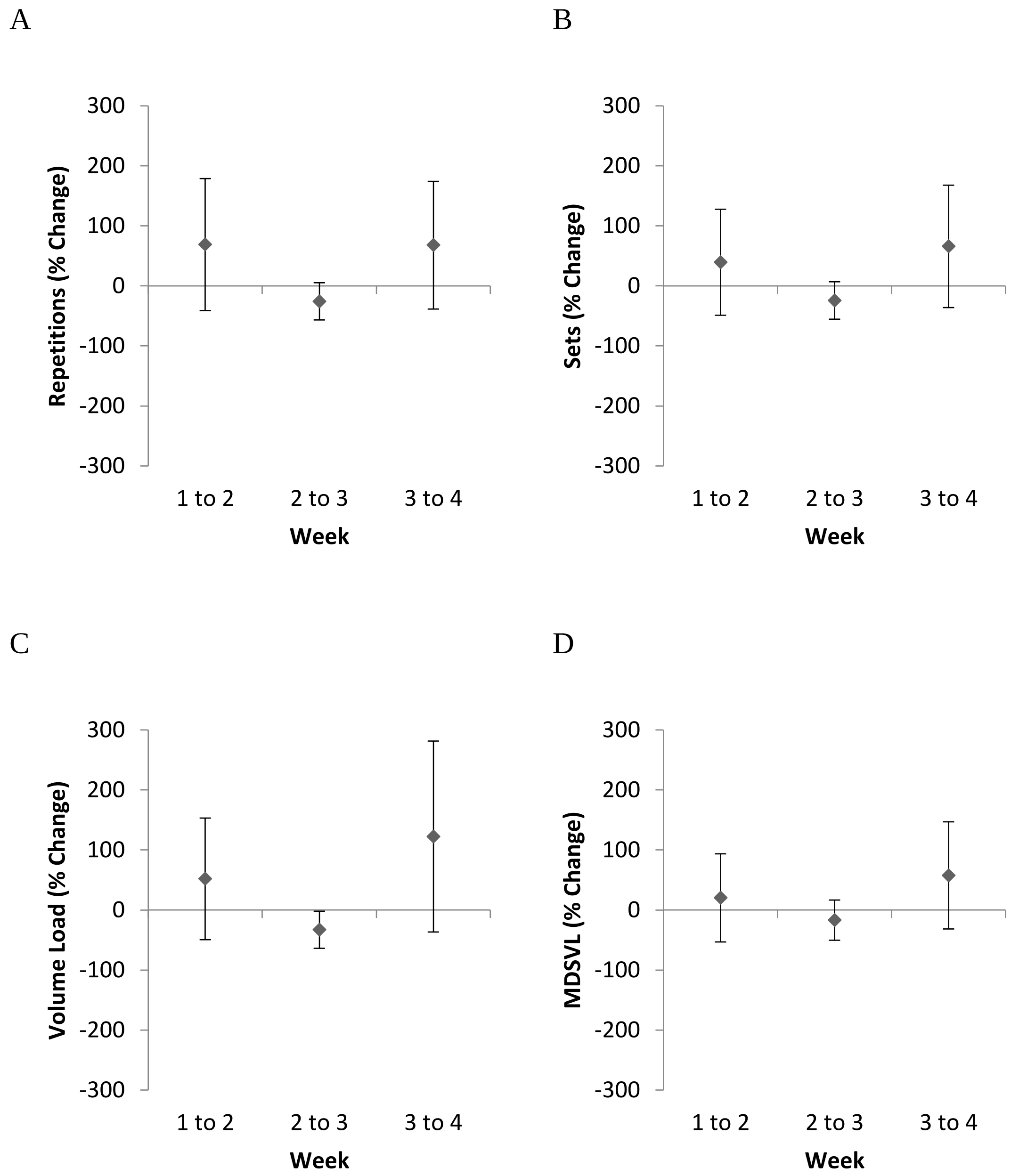


Figure 3.2. Resistance training volume data presented as percentage change per week, across 4 methods of calculation a) repetition volume b) set volume c) volume load and d) maximum dynamic strength volume load (MDSVL) across 4 weeks of pre- season training.

Table 3.2. An overview of mean±SD weekly % change in resistance training volume across 4 methods of calculation a) RV b) SV c) VL and d) MDSVL. * [A] Denotes significant difference from RV, [B] denotes significant difference from SV, [E] denotes significant difference from VL ($P < 0.05$).

	Rep Volume (RV)	**Set Volume (SV)**	**Volume Load (VL)**	**MDSVL**
Weekly Change (%)	37 ± 99	27 ± 88 [A]	47 ± 126 [B]	20 ± 75 [A] [B] [E]

3.3 Discussion

This study was designed to compare approaches to calculating resistance training volume during 4 weeks of preseason training in English Premier League footballers. These data illustrate significant differences between methods of monitoring resistance training. To the authors knowledge these are the first data characterising the differences between methods of monitoring resistance training during an applied training programme in elite athletes. A limitation of this study is the absence of performance testing data and its relation to training load. Performance testing data may have supported the evaluation of methods via the direct assessment of relationship between training load and adaptation. Due to the lack of a gold standard measure and/or performance testing data it is unclear which, if any, method represents the most accurate measure of volume. These discrepancies between methodological approaches do however highlight that these methods cannot be used interchangeably as they do not report training load in a similar way. The understanding of the data generated by these methods limitations may therefore enable appropriate, situation specific, method selection and therefore lead to the more effective evaluation of training.

The observed weekly percentage changes in resistance training volume between the 4 methods of calculation were significantly different in most cases. For example significant differences were observed between RV and SV methods ($P < 0.001$), RV and MDSVL ($P = 0.001$), SV and VL ($P = 0.010$), SV and MDSVL ($P = 0.033$) and VL and MDSVL ($P = 0.002$). Only RV and VL methods were similar in the information they provided on training loads ($P = 0.411$). This is of course due to the fact that all these methods estimate the overall resistance training volume and as a consequence may either under or over-estimate resistance training volume at any given point depending on the nature of the delivered training stimulus. Volume load and MDSVL are both approaches that provide an indication of training volume through an estimation of the total load (kg) lifted within a training session. When critically evaluating the VL method, this approach is limited as it does not accurately quantify the training load during body mass only exercises. This may vastly underestimate the total volume of exercise that is completed in a training programme where body mass only exercises are regularly utilised. Such findings confirm those available in other similar previous research (McBride et al., 2008). This method is therefore probably unsuitable for use in elite football due to the regular implementation of body mass only exercises during resistance training programmes. Maximum dynamic strength volume load, begins to account for such limitations due to its inclusion of body mass in its calculation. As such, it potentially represents a more sensitive method of estimating total volume during resistance training in this specific population. The requirement for data on specific limb masses for each individual players limits this approach practically. A further limitation of the MDSVL method in the applied setting is the highly time consuming nature of processing data. This makes feedback to players and coaches extremely slow and therefore of limited "real world" value.

Neither RV nor SV share the same issues as VL or MDSVL. Both RV and SV are able to quantify volume during body mass only exercises and are not based on assumption based calculations of limb mass as MDSVL is. Repetition volume provides a quantification of the overall magnitude of the stimulus in that it accounts for all repetitions completed. Volume as calculated by RV represents volume as the total number of contractions that are performed by specific muscle groups and/or individual muscles. Set volume, however, quantifies the total number of sets completed, therefore representing the number of repeated bouts of contractions associated with a given training stimulus. These differing approaches to representing training volume therefore provide diverse, although potentially highly valuable, information regarding the precise nature of the training stimulus. Many studies show the use of multiple-set programs in resistance training to produce superior gains in strength, power, and athletic performance, especially in trained individuals, when compared with single-set programs (Kramer et al 2000., Galvao and Taaffe 2004., and Rhea et al 2002). This evidence may suggest that volume calculated via the quantity of exposures to a stimulus (i.e. SV) is of greater importance when evaluating a training programme than the overall extent of a stimulus (i.e. RV). These observations may support the use of SV as an important indicator of total resistance training volume.

To summarise, the present study evaluated the differences between methods of quantifying resistance training volume during 4 weeks of preseason training in elite Premier League football players. The results demonstrated significant differences between methods in the estimation of training load during this training programme. These data highlight the importance of understanding the differences in data associated with different approaches used in training monitoring. The inability of VL to detect volume in body weight only exercises makes it inappropriate for the use in the current setting. The MDSVL method overcomes this limitation but is limited both by the number of theoretical assumptions as well as being time consuming in its nature. These factors continue to make it practically inappropriate. Repetition volume and SV methods may therefore be the most applicable to a football specific training programme as used in these population. As repeated bouts of resistance exercises seem to be important in maximising the training stimulus and therefore shaping the adaptive process (Kramer et al 2000., Galvao and Taaffe 2004., and Rhea et al 2002), it would therefore seem logical to suggest that SV would provide the most valuable data concerning a resistance training programme in such settings. Therefore, this approach would be most useful in quantifying resistance training volume in longitudinal experimental studies that attempt to analyse resistance training loads in elite level football, as per in this thesis.

3.4 Practitioner Reflection

There is no gold standard measure of volume in resistance training. Of the methods which are available, each have their individual limitations. When implementing and interpreting volume data it is important to be aware of these limitations. Despite being a popular and widely utilised method, due to VL's inability to quantify volume in bodyweight only exercises this method is likely to vastly underestimate volume in elite football. We believe therefore that SV may therefore offer the best method currently available for use in elite football.

CHAPTER 4

A quantification of the resistance training load and periodisation strategies in an elite professional football team during one season.

4.0 Introduction

Resistance exercise induces significant changes in muscle metabolism, cross sectional area (CSA) and neuro-muscular adaptations leading to improved sports performance (Philips, 2000; Folland and Williams, 2007; Channell and Barfield 2008). Numerous guidelines exist regarding the manipulation of resistance training variables in order to achieve improvements in specific performance outcomes and physiological qualities (Tan et al, 1999; Bird et al, 2005; Ratamess and Triplett-McBride, 2002). These guidelines typically relate to the frequency, volume and intensity of training. The nature of modern professional football has led to the application of sports- specific and scientifically informed approaches to resistance training. These strategies have been employed in an attempt to gain a competitive advantage. To date, however, no detailed research is available outlining the resistance training characteristics of elite football players.

Many of the existing guidelines regarding resistance training prescription relate to the specific sequencing of training factors, a concept known as periodisation (Bompa & Haff 2009). The goals of periodisation are to optimise a players performance at a specific time point whilst managing training stress to minimise the potential for over training. A meta-analysis by Rhea and Alderman (2004) showed periodised resistance training to be more effective than non-periodised training. Traditionally, the concept of periodisation was developed for individual sports, i.e., weightlifting where the athletes have several months to prepare for one or two competitions per year (Bondarchuk 1986; Matveyev 1981; Verkhoshansky 1985). However, the application of traditional concepts of training periodisation in football, has received less attention. This is mainly due to the weekly (often bi-weekly) nature of competition. Such factors may impact the number of specific exercise sessions associated with resistance training though the extent of this has never been investigated in detail. Uncovering resistance training patterns (i.e. frequency) in elite football will enable a more detailed analysis of the resistance training loads completed by players to be obtained. This type of data will provide a platform for a more systematic analysis of the training stimulus and subsequently enable a basis for the refinement of training prescription.

The purpose of this study was to quantify the frequency of resistance training and subsequently analyse the training loads of an elite professional football team across a competitive season. Such information would provide detail of the training periodisation strategies currently used in this elite level football club, thus enabling strength and conditioning coaches to optimise the resistance training prescription for players.

4.1 Methods and Materials

In order to investigate the frequency of resistance training in elite professional football the gym based training completed over a one season period was quantified and analysed.

4.1.1 Participants and training observations

Resistance training data was collected from 31 elite football players competing in the English Premier League over a 46 week period of the 2012-2013 season. The physical characteristics of the players (mean ± SD) at the end of the pre-season phase were as follows: 24 ± 5 years; height, 1.84 ± 0.7 m; mass, 79.5 ± 8.6 kg. A total of 1685 individual training observations were collected during the pre-season and in-season competition phases with a median of 42 training sessions per player (range = 9 – 124). Players were assigned to one of 6 positional groups; central defenders (CD) (training observations = 364), wide defenders (WD) (training observations = 318), central midfielders (CM) (training observations = 390), wide midfielders (WM) (training observations = 186), attackers (AT) (training observations = 89) and goal keepers (GK) (training observations = 158). The full content of each training session was recorded and the data derived from individual gym-based training sessions was analysed. Data collection for this study was carried out at the football club's gym facility. All players were made aware of the purpose of the study and provided written consent. The study was approved by the University Ethics Committee of Liverpool John Moores University.

4.1.2 Experimental design

Data collection for the study was carried out on a daily basis throughout the 2012-2013 football season. The content of each training session was planned by the team's strength and conditioning coaches in line with the physical goals for each player. In order to investigate the periodisation strategies employed throughout both the pre-season and competitive season, the training load data was separated into 7 blocks of 6 weeks for analysis. These periods included pre-season (6 weeks duration) and in-season (40 weeks duration) phases. Pre-season was maintained as 1 x 6 week block whilst the in-season phase was divided into 6 x 6 week blocks. This enabled the analysis of loading patterns included within a period of time defined as a mesocycle (Bompa & Haff 2009).

4.1.3 Training data collection

The content of the player's resistance training activity during each session was monitored and recorded manually. A custom-built spreadsheet (Excel, Microsoft, Redmond, WA) was used to log individual player data. Sets and repetitions completed and external load lifted (kg) per set was recorded on completion. Set volume (total number of sets completed) was selected for analysis as a measure of total volume based on data from Chapter 3. Given the absence of an agreed method of reporting resistance training session intensity, average load (mean external load lifted per repetition per session) was chosen for analysis as the measure of session intensity.

Logged exercises were characterised into 3 sub types; upper body, lower body and additional exercises. Additional exercises are those that can be classified as targeting the core and proprioception. These categories were employed to enable the further interpretation of exercise type.

In a week with only one match, the team typically had a day off after the game followed by four to five consecutive training days (MD-5, MD-4, MD-3, MD-2 and MD-1) leading into the next match. Training data was collected for each training session completed and retrospectively coded appropriately as to number of days away from the player next appearing in a competitive fixture. This included both when a player started or was a substitute. In addition, training data was also coded as to whether the player was fully fit or in rehab following injury, enabling the additional analysis of resistance training during rehab.

4.1.4 Statistical analysis

Data was analysed using 3 separate linear mixed modelling analysis using the statistical software package R (Version 3.0.1). In the first 2 analyses, session frequency and training load variables (total set volume, lower body set volume, upper body set volume, additional set volume and intensity) were analysed respectively for "fit" sessions. Player's position (GK, CD, WD, CM, WM and AT) and seasonal period were treated as categorical fixed effects. A third analysis concerned a "fit" vs "rehab" for session frequency, total volume and intensity. This analysis included a random effect for individual player only. When one or more fixed effects were statistically significant in the selected model ($P < 0.05$), Tukey post-hoc pairwise comparisons were performed to examine contrasts between pairs of variables with significant differences. Data is represented and analysed as mean ± SD.

4.2 Results

4.2.1 Seasonal Quantification of Resistance Training Loads

The training load data for the 6 separate 6 week mesocycle periods are represented in Table 4.1. The frequency of sessions demonstrated it's lowest value during weeks 7-12 with the maximum number in weeks 37-42. Significant differences in session frequency were seen between weeks 1-6 (pre-season)and weeks 7-12 ($P < 0.05$), weeks 7-12 and weeks 13-18 ($P < 0.05$), and weeks 7-12 and weeks 37-42 ($P < 0.05$). The total resistance training volume was lower during weeks 7-12, compared to weeks 1-6 ($P < 0.01$), 13-18 and 19-24 ($P < 0.05$). Lower body training volume also similarly demonstrated minimum values during weeks 7-12, though there were no significant differences between any periods for this variable. Upper body training volume was lower during weeks 7-12 compared to weeks 13-18 ($P < 0.01$), weeks 19-24 (P <

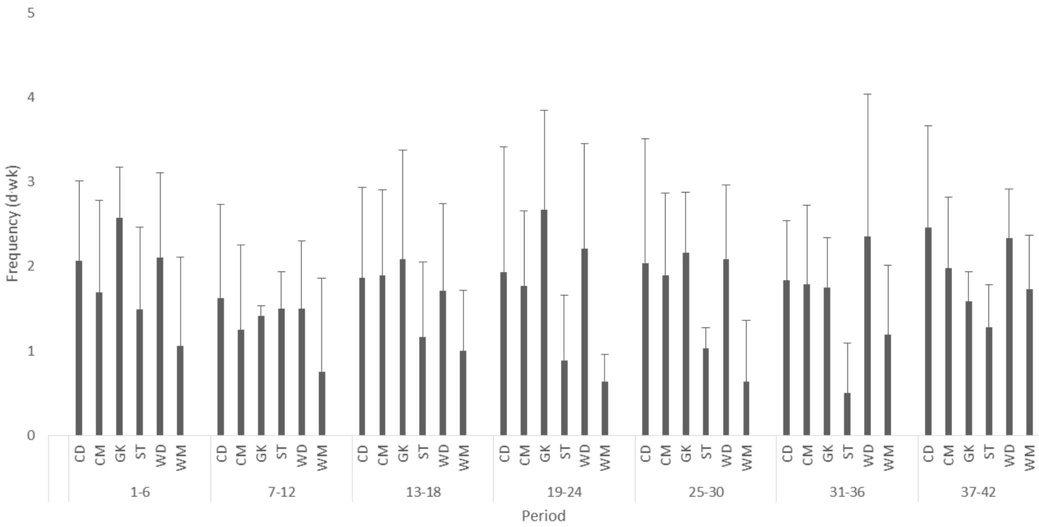
0.001), weeks 25-30 ($P < 0.01$) and weeks 37-42 ($P < 0.05$). Additional training volume was highest during weeks 1-6, compared with all other periods ($P < 0.01$). There were no significant differences for additional training volume between any other periods of this study.

The total training intensity was lowest during weeks 1-6 (pre-season) and weeks 7-12 with a trend for a gradual increase in intensity throughout the remainder of the season. Specifically, training intensity during weeks 1-6, was significantly lower than during weeks 13-18 ($P < 0.05$), 19-24 ($P < 0.01$), 25-30 ($P < 0.01$), 31-36 ($P < 0.05$), and 37-42 ($P < 0.01$). Similarly, training intensity during weeks 7-12 was also significantly lower than during weeks 13-18 ($P < 0.01$), 19-24 ($P < 0.05$), 25-30 ($P < 0.05$), 31-36 ($P < 0.05$), and 37-42 ($P < 0.001$).

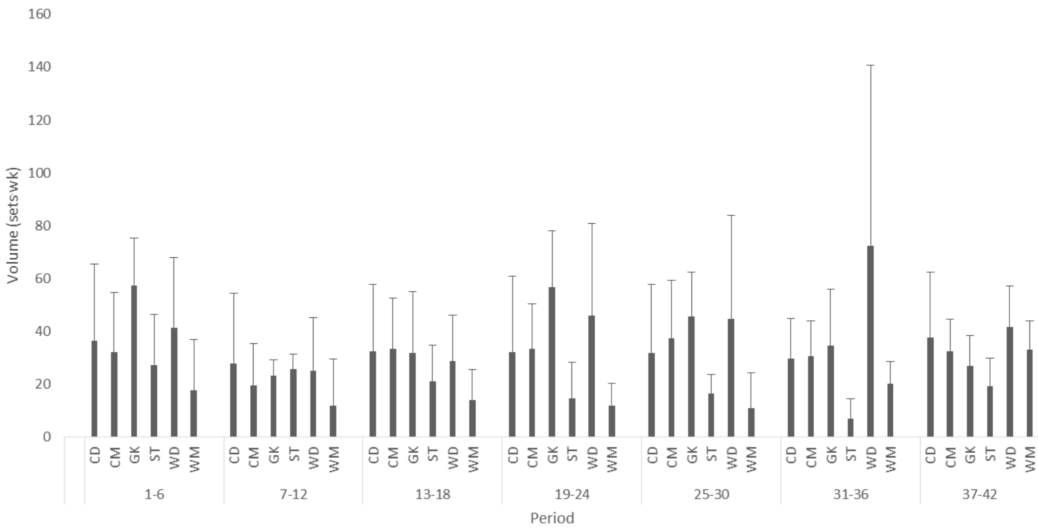
Table 4.1. Training load data represented across 6 separate, 6 week mesocycle periods during pre-season (week 1-6) and in-season phases. A) Frequency; b) total volume; c) lower body volume; d) upper body volume; e) additional volume; f) total intensity.

Week	Frequency ($d \cdot wk^{-1}$)	Total Volume ($sets \cdot wk^{-1}$)	Lower Body Volume ($sets \cdot wk^{-1}$)	Upper Body Volume ($sets \cdot wk^{-1}$)	Additional Volume ($sets \cdot wk^{-1}$)	Total Intensity ($kg \cdot rep^{-1}$)
1-6	2±1	30±24	5±6	14±13	11±11	15±13
7-12	1±1	18±16	3±3	11±10	5±6	17±19
13-18	2±1	27±19	5±5	17±12	5±6	29±24
19-24	2±1	28±20	4±4	20±13	4±6	29±25
25-30	1±1	26±21	4±3	18±14	4±7	27±24
31-36	1±1	23±14	4±5	16±10	3±4	33±29
37-42	2±1	28±17	6±4	20±13	2±4	48±39

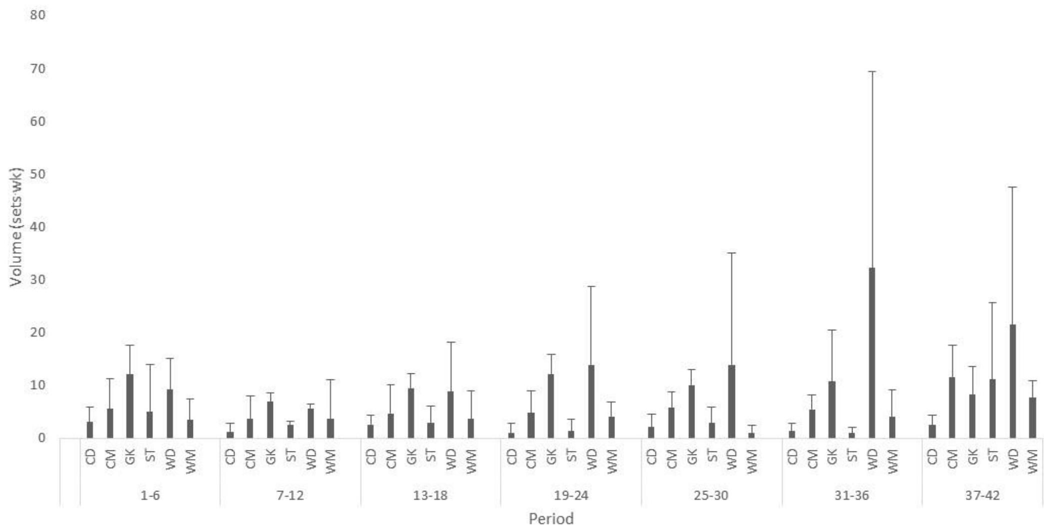
Figure 4.1 represents the training load as a function of team and positional role across 6 separate 6 week mesocycle periods. No significant differences were observed between playing positions for session frequency, total training volume, upper body training volume, additional training volume or training intensity. GK players, however, performed significantly greater lower body training volumes than CD ($P < 0.01$), ST ($P < 0.01$) and WM ($P < 0.01$). Significant greater lower body training volumes were also seen for CM players compared to CD ($P < 0.01$), ST ($P < 0.05$) and WM ($P < 0.05$). GK and CM players would therefore seem to show higher lower body training volumes than all positions with the exception of WD players.



a)

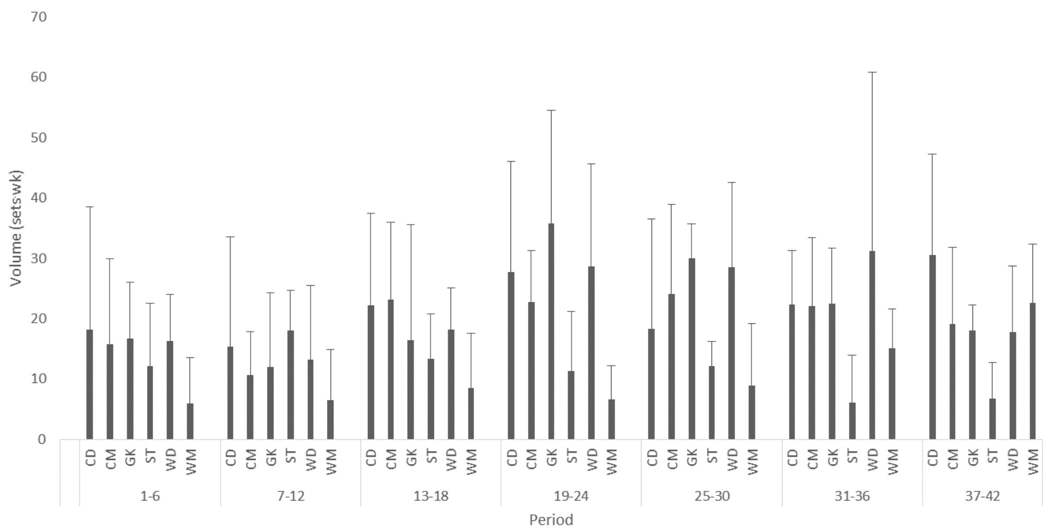


b)



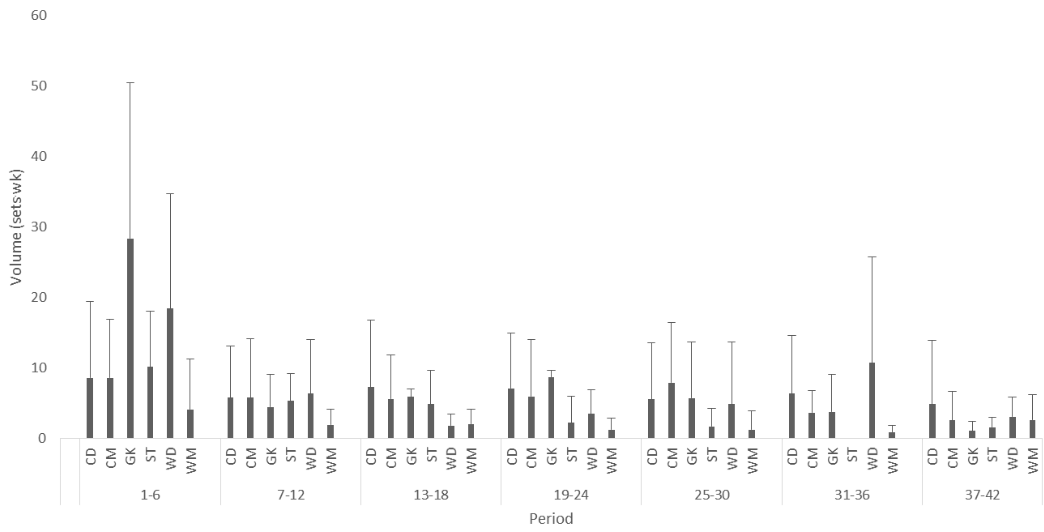
80
70
60
50
40
30
20
10
0
Volume (sets wk)
CD CM GK ST WD WM
1-6
7-12
13-18
19-24
25-30
31-36
37-42
Period

c)

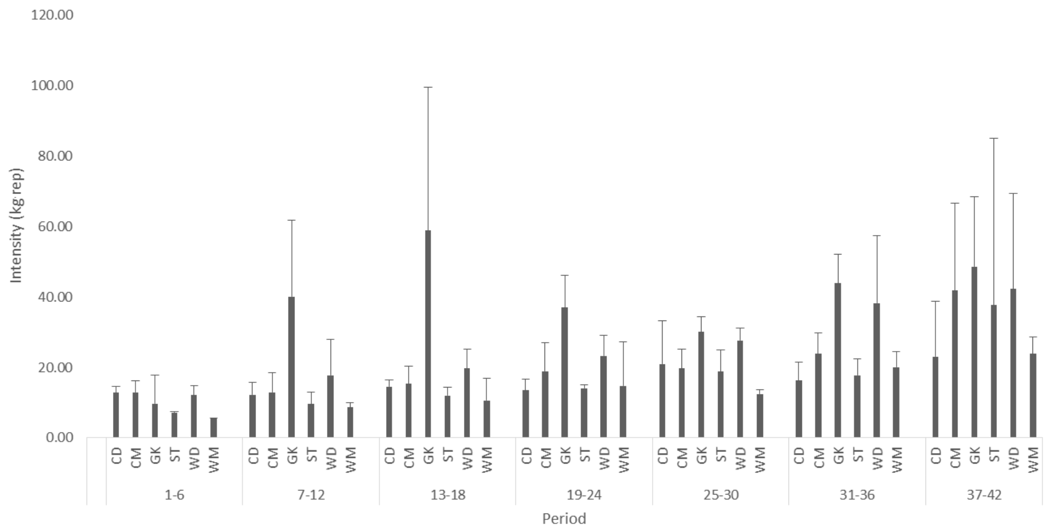


70
60
50
40
30
20
10
0
Volume (sets wk)
CD CM GK ST WD WM
1-6
7-12
13-18
19-24
25-30
31-36
37-42
Period

d)



e)



f)

Figure 4.1. Training load data represented across 6 separate, 6 week mesocycle periods during pre-season (week 1-6) and in-season phases. A) Frequency; b) total volume; c) lower body volume; d) upper body volume; e) additional volume; f) total intensity. CD = Central defenders; WD = Wide defenders; CM = Central midfielders; WM = Wide midfielders; ST = Strikers; GK = Goalkeepers.

4.3 Discussion

The aim of this study was to quantify the frequency of resistance training and analyse the training loads of an elite professional football team across a competitive season. Weekly resistance training frequency ranged from 1±1 to 2±1 sessions per week during the pre- and in-season phases. The lowest observed frequency of sessions was in weeks 7-12 (the first phase of the in-season). Significantly greater values for training frequency were observed during preseason (weeks 1-6) and the later phases of the in season (weeks 13-18 and 37-42). The variable nature of this resistance training loading pattern is likely a reflection of the training structure being influenced by external factors, such as the increased or decreased number of matches played during certain periods. This serves to highlight some of the difficulties associated with the implementation of strength training in elite football environments. Despite the general low level of frequency in resistance training there were occasions within the annual cycle when training frequency was increased, such as pre-season and certain periods of the in-season. This is likely due to a decreased number of matches during these times. These data illustrate that increases in training frequency are periodically possible during the in season and may suggest that alternative planning models may be useful. This insight may suggest that traditional strength training approaches to planning may not be appropriate in this setting. Strength and conditioning coaches may therefore need to employ more novel approaches to the delivery of training programmes in order to be effective in this environment.

Reduced training frequencies during the early in-season phase resulted in lower total training volume, lower body training volume and upper body training volume during the first phase of the in-season (weeks 7-12). Total volume, lower body volume and upper body volume were all greater during the later phases of the season. On examination of volume, whilst mean weekly training volume ranged from 18±16 to 30±24 sets$\cdot$wk^{-1}, lower body training volume however made up a relatively small proportion of total training volume (3±3 to 6±4sets$\cdot$wk). In the meta-analysis of Peterson (2004) it was demonstrated that strength gains are best elicited among competitive athletes who train at a mean 8-set per muscle group. These data demonstrate the added strength benefits that accompany higher training volumes than those seen in this study and may suggest that the training volumes observed in these elite football players may be insufficient to improve lower body strength and power during the season. Given that weekly volume is a product of training frequency and session volume, it may be necessary to not only increase the volume within each session to those levels suggested in the literature (Peterson., 2004) but to also increase training frequency. Again, this may further highlight the influence of external variables, such as match frequency, on the ability to optimally develop strength and power in elite football players.

Training intensity ranged from 15+13Kg per rep during pre-season to 48+39 kg per rep by the end of the season. This is in contrast to training frequency and volume variables, as the intensity of training demonstrated its lowest values during preseason (weeks 1-6) An observable trend for an increase in intensity was noted as significant increases in training intensity were observed in the latter phases of the season compared with pre and early season phases. These are the first data of this nature available from professional football players at this level. This makes it difficult to evaluate whether these levels of training may or may not be sufficient for increasing strength and power in this cohort. Nevertheless resistance training intensity could be considered a proxy measure of strength and the observed linear increase in intensity through the season could be accompanied by increasing strength levels of these players during the season. Whilst these data alone are insufficient to conclude that increasing intensity is representative of increasing strength performance in these athletes, these data indicate that athletes progressively and continuously lift heavier loads over the duration of a season. Future research would therefore seem required on the monitoring and interpretation of training intensity in elite football players.

No significant differences were observed between playing positions for session frequency, total training volume, upper body training volume, additional training volume or training intensity. Goalkeepers and Central Midfield players did, however, perform significantly greater lower body training volumes than all other positions with the exception of WD players. Whilst it is unclear in this case whether such differences were purposefully planned via structured training programmes, these data do potentially indicate that it is possible to increase lower body loading, if only in specific individual cases. Given the previously stated importance of game frequency on resistance training exposure, players who are not regularly selected to start matches may therefore have an opportunity to systematically increase resistance training loading. Additionally, the highly contrasting game demands of goalkeepers in comparison to outfield players (i.e., lower running loads) may allow for different training structures to be employed than those of other positions, thus also allowing for greater resistance training loading. Unfortunately data on the impact of game selection and game and training demands on resistance training loading was beyond the scope of this study though these would provide an interesting area of investigation to examine in future research.

This is the first study, to the author's knowledge, that has systematically observed and quantified resistance training loads employed by an elite professional football team across a competitive season. The data suggest that resistance training loading is limited during different periods of the season and is predominantly a consequence of low training frequency. Such findings have practical implications for the organising and planning of training schedules. Firstly, if similar training loads are repeated longitudinally, there is the potential for negative adaptations to occur and strength and power performance may therefore be affected in football players. Secondly, these data may highlight the need for individual and flexible training plans, to enable greater resistance training loading. It appears that, due to external factors, current guidelines developed in traditional periodisation models are difficult to apply directly to football. Future work should therefore aim to assess the efficacy of such low volume training programmes in elite football players and their influence on strength and power markers during the competitive season.

4.4 Practitioner Reflection

Whilst the resistance training loads observed in the present chapter only represent the practices of one club, the loads observed seem low and may suggest that the training practices of this elite football teams may not be optimal for enhancing strength and power. The observed trend for increased intensity over the season may be due to an increase in athlete strength level, as they appear to lift heavier loads as the season progresses. However, due to the methodological limitations associated with quantifying session intensity as discussed in the literature review we cannot confidently conclude this. Whilst there may be periods whereby players need to employ lower resistance training workloads due to high fixture demands, practitioners should aim to identify the correct times and methods to increase resistance training loading.

CHAPTER 5

Seasonal changes in lower body power assessed by pneumatic leg press in an elite professional football team

5.0 Introduction

Chapter 4 suggests that resistance training load completed during training are low during certain periods of the season in elite football players. This is predominantly a consequence of a low training frequency within a given micro-cycle. This is potentially due to a variety of factors that include a high prevalence of competitive fixtures, frequent injuries, demanding travel schedules or the lack of desire in professional players to perform resistance training. The completion of such low levels of resistance training may have practical implications for the performance of players in tasks that require high levels of neuromuscular function. Inappropriate levels of performance in such tasks may also increase the potential for injury. Evaluating the implications of such resistance training stimuli for the function of players therefore seems important.

Neuromuscular performance can be measured via numerous different modalities that will utilise different muscle actions (e.g. isokinetic, isometric, isotomic). Given that power is an important determinant of a number of physical qualities that are key to football match play (i.e., acceleration, jumping, cutting) it would seem pertinent to evaluate the lower body power out of players. In addition to the provision of baseline values for this population there is a potential for power tests to enable a better understanding of how lower body power output may change in professional football players across a season. Such information may provide a detailed evaluation of the physiological response to the training strategies currently used in elite level football. This will enable a critical evaluation of the resistance training procedures used within the club and provide a framework to optimise future prescription. In order to be practically viable in this setting, power tests need to be simple to perform and easy to implement and repeat, whilst also possessing a reasonable degree of accuracy and repeatability. To this end, the purpose of this study was to quantify the change in lower body power outputs of an elite professional football team across a competitive season.

5.1 Methods and Materials

In order to quantify the change in lower body power outputs of the individuals in an elite professional football team across a competitive season this study attempted to (a) record the gym based training completed by each player across the competition cycle and (b) monitor the individual lower body power outputs over the same one season period. Where possible these evaluations were designed to be completed within the usual activities completed within the gym-based training programmes of the players to minimise the practical and logistical issues associated with collecting this type of longitudinal tracking data.

5.1.1 Participants and power assessments

Data collection for the study was carried out on a daily basis throughout the 2013/2014 football season. Resistance training data was collected from 22 elite football players (mean ±SD: age 25 ± 5 years, body mass 81.5 ± 7.5 kg, height 1.8 ± 0.05) competing in the English Premier League. A total of 960 individual training observations were collected during the in-season competition phase with a median of 59 training sessions per player (range = 14 – 102). The full content of each training session in the gym was recorded and the data derived from the individual gym-based training loads that were completed were analysed. The content of each training session was planned by the team's strength and conditioning coaches in line with the physical goals for each player. In order to investigate the periodisation strategies employed throughout both the competitive season, the training load data was separated into 7 blocks of 6-8 weeks for analysis. This enabled the analysis of the pattern of resistance training loading included within a period of time usually associated with a mesocycle (Bompa & Haff 2009).

An assessment of an individual's lower body power output was also collected throughout the season. A total of 246 individual power output observations were collected during the entire phase of the investigation. The players lower body power output was assessed at the start of all resistance training sessions completed during this time period that were targeted at the lower body. No performance data was collected if a injury did not allow full function. The data derived from each individual assessment of lower body power was recorded for later analysis. Data collection for this study was carried out at the football club's training ground within the gym facility. All players were made aware of the purpose of the study and provided written consent. The study was approved by the University Ethics Committee of Liverpool John Moores University.

5.1.2 Training data collection

The activity associated with each player's resistance training activity during resistance training sessions were monitored and recorded manually by the investigator. A custom-built spreadsheet (Excel, Microsoft, Redmond, WA) was used to log individual player data. The sets and repetitions completed, as well as the external load lifted (kg) per set, was recorded in the spreadsheet on completion of the exercise. This information was obtained by the direct observation of the exercise by the investigator. Set volume (the total number of sets completed in a given exercise/training session) was selected for analysis as a measure of total volume completed by the player (based on data from Chapter 3). Given the absence of an agreed scientific method to measure and report the intensity of a resistance training session the average load (mean external load lifted per repetition per session) was chosen as an indicator of intensity as per chapter 4 of this thesis.

The exercises recorded were characterised into 3 sub types; upper body, lower body and additional exercises as per Chapter 4 of this thesis. Additional exercises are those that can be classified as targeting the core and proprioception. These categories were employed to enable the further interpretation of training loads and specific information on the stimulus delivered.

5.1.3 Power Output Assessment

The power output of the lower body was assessed using a pneumatic resistance leg press machine with software and digital display (Keiser Sports Health Equipment Inc., Fresno, Ca). For this assessment, each player performed 4 repetitions at a load of 200kg with each repetition being completed with maximal explosive intent. This load was selected by the investigator to represent an assessment of maximum lower body power output against a standardized external load. This choice provided the opportunity to obtain a functional performance measure that could safely and consistently be implemented at the beginning of any resistance training sessions. All power assessments were performed prior to the completion of any lower body resistance training session completed by the players. Lower body resistance training, and therefore the assessment of power, was always performed 3 days prior to a match (MD-3). Power assessment would also not be carried out in the 2 days preceding a match (MD+1 and MD+2). For this reason testing was not carried out in a uniform, weekly manor but rather on an individual basis, around match schedule, individual training exposure and injury occurrence.

The evaluation using the pneumatic leg press required each player to start in a seated position on a pneumatic leg press machine (Keiser Sports Health Equipment Inc, Fresno, CA). The player positioned both feet centrally on to the individual foot plates. The seat position was then selected to ensure the individual was positioned with a angle of knee flexion to 90 degrees. The seat position for each participant was then recorded to ensure the identical set up of the measurement tool in future assessments. The centre pin was removed from the machine to allow limbs to move unilaterally. All athletes worked at a standardised intensity of 200kg. This load was obtained using the "+" and "-"buttons attached to the safety handles. The lower body power assessment was initiated by extending the right leg and lifting the "stopper" with the right hand (this enables full range of movement to be achieved throughout each rep of the assessment). The player then performed 4 repetitions on the leg press with the right leg using maximum intent(Figure 5.1). The athlete was instructed to "push out as hard and as fast as possible" during all trials by the investigator. The maximum power output of the 4 repetitions was displayed on the screen (Figure 5.1) of the equipment then manually recorded in a custom-built spreadsheet (Excel, Microsoft, Redmond, WA) by the researcher for later analysis. The same process was then repeated by each player on the left limb.

A) B)

C) D)

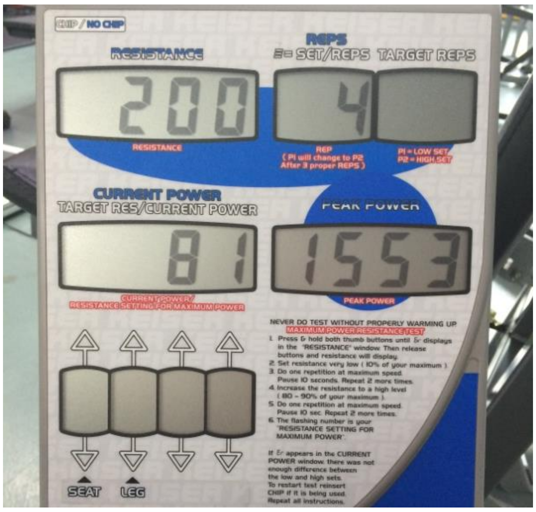


Figure 5.1. Leg press power test. A) Initial set up position, feet positioned centrally on to the individual foot plates, seat position was then selected to ensure the individual was positioned with a angle of knee flexion to 90 degrees, B) The assessment was initiated by extending the leg and lifting the "stopper" C) 4 repetitions were performed on the leg press using maximum intent, the athlete was instructed to "push out as hard and as fast as possible" during all trials D) The maximum power output of the 4 repetitions was displayed on the screen.

Due to its novelty the reliability of the approach was first examined before data collection was commenced. Seventeen male elite Premier League football players (Mean ± SD: age 25±4 years, height 180.2±6.5cm, body mass: 79±7.6kg) completed 2 separate assessment sessions. Players performed their initial assessment at least 5, and a maximum of 10 days, prior to re-testing. All players had prior experience of performing the leg press assessment completing a minimum of 3 previous trials. As a control measure players had not taken part in any competitive fixtures or performed any lower body resistance training in the 2 days prior to assessment. Data were analysed using calculation of standard error of measurement (SEM) and coefficient of variation (CV) between trials (Atkinson, 2003). Coefficient of variation demonstrated a test-retest value between trials of <6% (5.68%). These data would seem to suggest that the pneumatic leg press test can provides a repeatable method of assessing lower body power output in this population under these test conditions.

5.1.4 Statistical analysis

Following a visual inspection of both the mean and individual trends of power output change during the study period, data was analysed by means of linear mixed modelling analysis using the statistical software package R (Version 3.0.1). Mixed linear modelling was selected due to its ability to be applied to unbalanced designs, such as in the present study, due to players differing in terms of the number of assessments they were able to complete, as well as missing data from players (Cnaan et al. 1997). In the present study, mean baseline power output and effect of period (week number) were treated as categorical fixed effects. Random effects were associated with the individual players baseline power output and individual player by week power changes in order to assess individual differences. A descriptive analysis of training load data was also utilised.

5.2 Results

5.2.1 Seasonal Quantification of Resistance Training Loads

The training load data for the 6 separate 6-8 wk mesocycle periods are presented in Table 5.1. A descriptive analyses of the training load data showed that; the mean frequency of sessions completed remained steady between weeks 7-12, 13-18, 19-24, 25-30, 31-36 and 37-44 (number of sessions = 3±1). The total resistance training volume was lowest during weeks 19-24 and 25-30 (number of sets = 34±19 and 34±17 respectively), compared to weeks 37-44 which exhibited the highest total resistance training volumes (number of sets = 54±21). Lower body training volume also demonstrated the lowest values during weeks 7-12, 19-24 and 25-30 (number of sets = 8±4, 8±6 and 8±4 respectively). The highest lower body resistance training volumes were observed between weeks 13-18 (number of sets = 12±7). Upper body training volume was lower during weeks 7-12 and 19-24 (number of sets for both weeks = 20±14) with the greatest upper body training volumes observed in weeks 37-44 (number of sets = 29±18). Additional training volume was lowest during weeks 19-24 (number of sets = 3±4), the highest additional training volumes were observed between weeks 37-44 (10±12). The total training intensity was lowest during weeks 19-24 (give units as above19±5), compared to weeks 13-18 where the highest total training intensities were observed (27±11). Unlike in our previous chapter there was no observable trend for an increase in the intensity of training throughout the season.

Table 5.1. Training load data represented across 6 separate, 6-8 week mesocycle periods during the in-season phases. A) Frequency; b) total volume; c) lower body volume; d) upper body volume; e) additional volume; f) total intensity.

Week	Frequency ($d \cdot wk^{-1}$)	Total Volume ($sets \cdot wk^{-1}$)	Lower Body Volume ($sets \cdot wk^{-1}$)	Upper Body Volume ($sets \cdot wk^{-1}$)	Additional Volume ($sets \cdot wk^{-1}$)	Total Intensity ($kg \cdot rep^{-1}$)
7-12	2±1	35±16	8±4	20±14	5±9	22±10
13-18	2±1	38±23	12±7	22±20	4±6	27±11
19-24	2±1	34±19	8±6	20±14	3±4	19±5
25-30	2±1	34±17	8±4	22±14	4±6	22±7
31-36	2±1	39±17	9±5	23±11	8±10	20±9
37-44	3±1	54±21	11±6	29±18	10±12	26±11

5.2.2 The Seasonal Quantification of Peak Power Output

The lower body power outputs produced by the players ranged from 2200W to 4078W (mean ± SD3022±374W). A graphical representation of the weekly mean power output for the team can be seen in Figure 5.2. Power output showed a trend to increase linearly across the season.

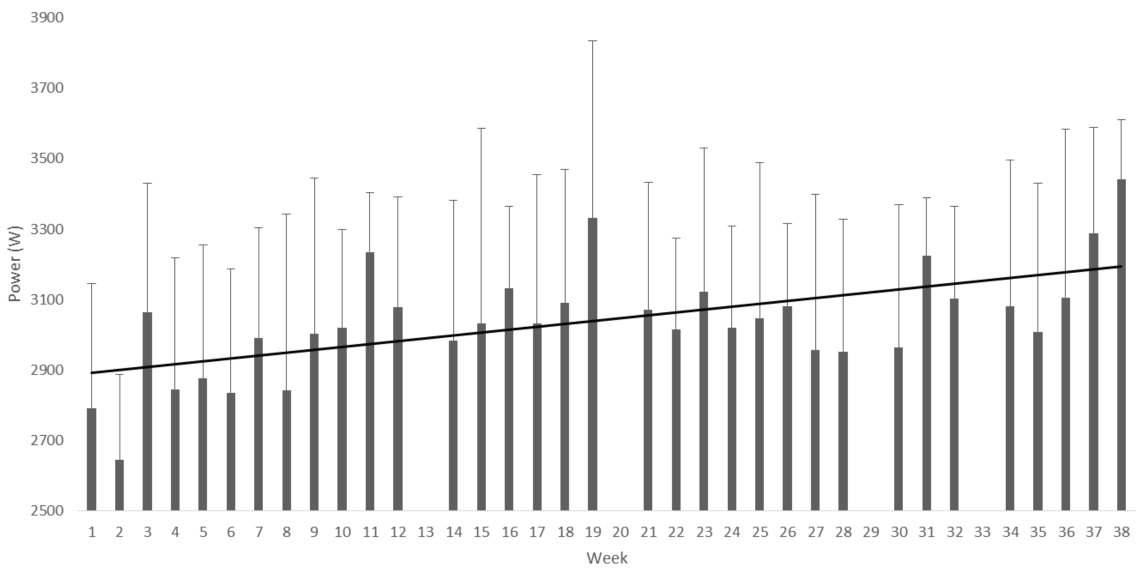
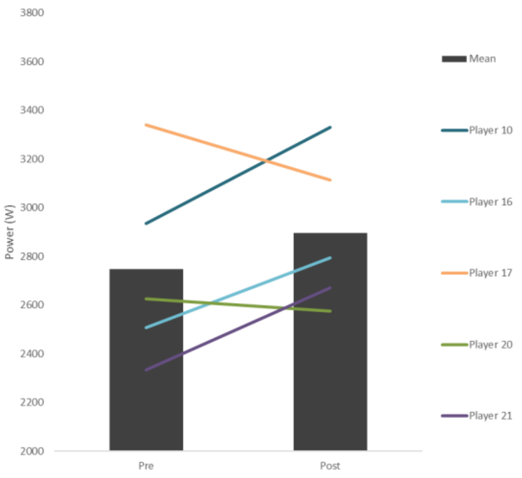


Figure 5.2. A graphical representation of the mean ± SD lower body power output on a week by week basis for all players during the 38 week in season period.

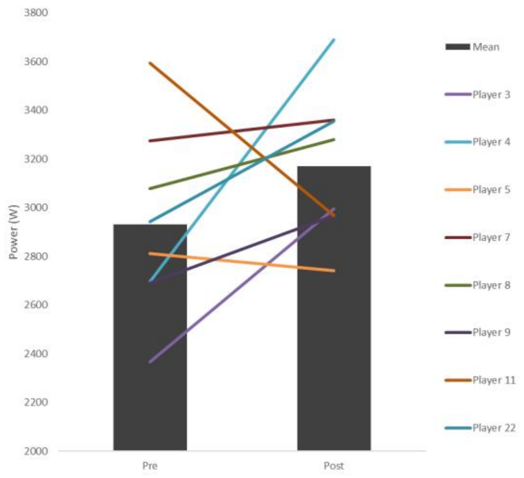
Linear mixed effects show there was a significant effect of week on lower body power output across the season (coefficient= 7.76W, p=0.0132). Specifically, when accounting for within player effects, lower body power output increased by a value of 7.76W per week during the season. Thus, at the end of the season (or after 38 weeks), the average increase was 7.76(W) x 38(weeks), = 295W. Consequently the lower body power output increased from an average of 2867W at baseline (the initial measurement obtained) to an average 3162W at the end of the season.

Although a linear increase in power output can be recognised (see Figure 5.2), this trend across the season was not observed in all players. This is supported by a further mixed model analysis of the random coefficient which shows individual weekly coefficients range from +39.9W to -18.13W per week. Figures 3 and 4 provide further illustrations of the individual nature of the training response within the sample. Figure 5.3 displays the pre and post season lower body power outputs for the sample as a whole (mean) and the individual responses for each player in the sample. Figure 5.4 presents a graphical representation of each individuals complete lower body power output profile across the 38 week in season period. Both figures 3 and 4 illustrate the large individual differences in power output observed over the course of the season. Despite a trend to increase over this period it can be seen that this trend is not evident in all players.

A)



B)



C)

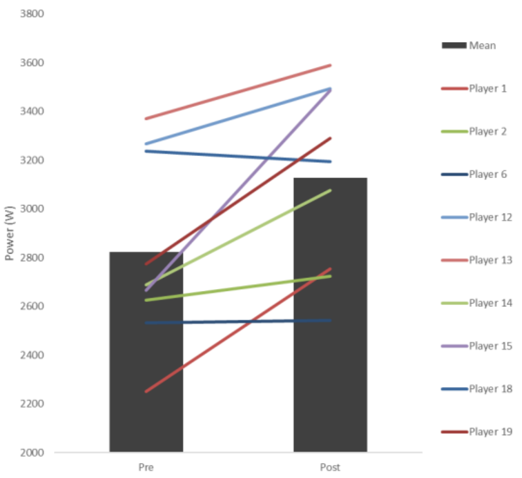


Figure 5.3. A graphical representation of the mean initial and final lower body power output measure (bar) and, the individual initial and final lower body power output (line) for players who A) completed 7-16 weeks of training, B) completed 17-28 weeks of training and C) completed 29-38 weeks of training.

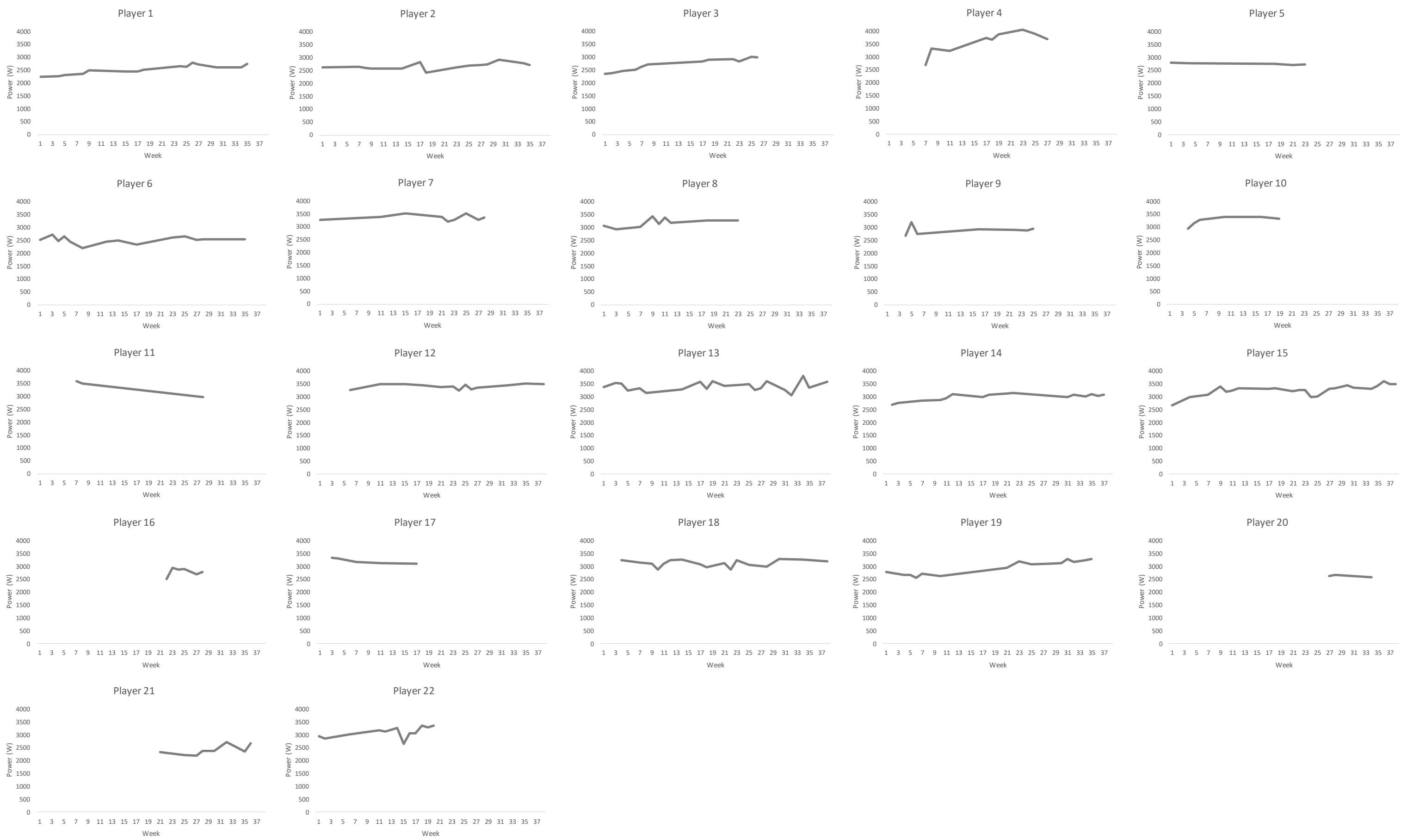


Figure 5.4. A graphical representation of individual lower body power output measures of all players during the 38 week in season period.

5.3 Discussion

The purpose of this study was to quantify both the resistance training stimulus and the change in lower body power outputs of an elite professional football team across a competitive season. The mean frequency of sessions completed was 3±1 session per week. The total resistance training volume ranged from 34±19 to 54±21 sets per week, of which 8±4 to 12±7 sets per week were performed for the lower body. Mean baseline lower body power output in our cohort was 2867±92W. There was a significant effect of week on power output, with a coefficient of 7.76, thereby suggesting that on average, power output increased by 7.76W each week during the season. Thus, at the end of the season (or after 38 weeks), according to this analysis the average increase in lower body power output was around 295W (7.76W x 38weeks). This would amount to a 10.3% increase over the course of a season for the average player. This value would not seem to exceed the CV of 5.68% (x2) that we observed in our repeatability assessment. We cannot therefore confidently conclude that the changes in power output observed across the season represent meaningful change for this group of players. However, the data did show large inter-individual varaiation with some showing large performance improvements. The individuality of training response indicates that individual approaches to training may be warranted. Furthermore we cannot therefore conclude that the training stimulus implemented during the course of this season was sufficient to increase power output in these players.

One reason for our findings may be due to the limitations associated with the power assessment methods. The assessment utilised in this study was designed to be practically viable, quick and easily implementable in the applied setting. Whilst these practical considerations were achieved there are a number of methodological limitations associated with this assessment. A standard load of 200kg was utilised across all assessments. Whilst this is consistent, it is not standardised relative to each athletes strength and power level. An implication of this is that, theoretically, athletes are being assessed at different points along their individual force velocity curves. Data may therefore represent different physical qualities in each athlete. Via the assessment of players 1RMs this could potentially be overcome and loads could be individualised to a standardised %1RM. However 1RM testing has its own limitations surrounding it also. A further limitation of this assessment method is related to the calibration of the equipment. The pneumatic leg press machine (Keiser Sports Health Equipment Inc, Fresno, CA) utilised for testing is not able to be calibrated daily by the practitioner, as a result calibration only took place when serviced by the Keiser Sport Health company at the beginning of the study and not prior to each testing session. There is obviously a trade-off therefore between the ease of data collection in this setting and the quality of the data collected. These limitations therefore need to be considered whilst interpreting data from this study.

Resistance training studies implemented during in-season in football are scarce, especially in elite players such as those included in this sample. Of the studies that do exist, to the authors knowledge, there is no strength or power data available in elite premier league football players, with only two studies evaluating adults football players over a full competitive season (Nunez., 2008;Koundourakis 2014). Whilst no comparative data is available in elite football players over a premier league season, data in lower competitive levels provides similar findings to the data here. Nunez (2008) examined the variation in jump variables, (as a marker of power output), over the duration of a season in semi-professional football players. These data indicated a linear increase in power output over the duration of a season, with these changes been seen as significant improvements between the beginning and end of season. The resistance training frequency reported in this study was 2 sessions per week . This is a lesser frequency than that observed in the Premier League football players included in the sample in this thesis, however on analysis of the training programme design it is clear a greater proportion of training in this study was targeted for the lower body. Whilst initial training status, as indicated by playing level, may be a contributing factor in the superior adaptations observed in these individuals, greater lower body training volume is likely the main factor responsible for the greater performance improvements that are observed in these individuals.

In a more recent study, Koundourakis (2014) studied 3 Greek professional football teams during a full competition season. Koundourakis (2014) reported significant improvements in neuromuscular performance, assessed via jump variables and sprint time, at the mid- and end-points of the season compared with baseline. These improvements were achieved using a resistance training frequency of 1 session per week, which is comparable to the frequencies observed in our sample. Despite being significant, the magnitude of improvement observed in jump assessments were, however, less than the percentage improvements observed in power output measures in the current study (<9.1% vs. 10.3% respectively). With the variation (CV) typically associated with counter movement jump assessments previously being reported as similar to the variation associated with the power assessment utilised in the current study (4.6% vs. 5.6% respectively) (Markvic et al., 2004), the data of Koundourakis, both in terms of magnitude of performance improvement and the measurement error associated with the assessmentstherefore appears highly comparable to the data of the current study. These data would suggest that performance improvements associated with training programmes employing a frequency of 1 session per week may be may be attributable to noise in the data rather than true physiological adaptation.

It is evident that our observations in mean power outputs across the season, is not the same in all players. The individual weekly coefficients of change in power output show large variations between participantspl. These individual ranges are from +39.9W to -18.13W per week. This wpuld suggest that some players are observed to improve their power performances while other players actually decrease from their baseline power output over the course of a competitive season. The available data on these individuals in this investigation makes it difficult to accurately pinpoint the exact reasons for this disparate change in power performance. One potential factor may be the varying exposure of individuals to resistance training, primarily as a consequence of their own individual approach to completing resistance training exposures and their involvement in competitive fixtures and injury. It is also possible that this may also highlight the highly individual responses to a set training stimulus though this may only become an important issue in those individuals who are regularly attend resistance training sessions. These data therefore further highlight the importance of both optimising training programme compliance and developing individual approaches to the prescription, monitoring and assessment of resistance training programmes in elite football players.

Our analysis combined with the other available literature may therefore suggest that power performance is at least maintained over the course of a full competitive season in elite football players. Combined with the training load data previously examined in this thesis it can be concluded that whilst one to two resistance training session per week may be sufficient to avoid in season de-training or minimally improve power performance in elite football players, a greater frequency or intensity of sessions may be necessary to obtain significant performance enhancements. Future work should therefore attempt to manipulate resistance training volume in elite players to evaluate the impact of changes in the resistance training programmes of elite football players. Whilst researching this in controlled, experimental investigations may be ideal, such approaches seem unrealistic in an elite high performance environment. The use of case study's may therefore seem an appropriate strategy for future investigations in this cohort.

5.4 Practitioner Reflections

Power output derived from leg press technology offers quick, practically applicable and reliable data regarding training adaptation and is a useful tool to monitor the longitudinal impact of training. Overall greater resistance training loading may be necessary to achieve improvements in lower body power performance over the duration of a season. Large individual variations in training adaptation however may suggest that whilst the current stimulus is sufficient in some players, others may need a greater stimulus to achieve similar improvements in lower body power performance. This further highlights the importance of monitoring and assessing training programmes regularly, and the requirement for an individual approach to planning, monitoring and assessing training plans.

CHAPTER 6

Case studies; Enhancing physical performance in premier league football players, individual approaches to safely increasing resistance training load during the in-season.

6.0 Introduction

The results of the previous studies in this thesis indicate that elite football players typically perform a frequency of 1-2$\cdot$d$^{-1}\cdot$wk^{-1} of resistance training, and that this training load is often insufficient to increase strength and power during a competitive season. Opportunities to increase resistance training exposure and loading during typical training schedules during the competitive period are limited due to a number of factors particularly the frequency of match play. As a result, it is particularly challenging for conditioning coaches in football to implement effective resistance training programmes to increase strength and power in-season.

Whilst it would be interesting to attempt to manipulate resistance training volume in all players in a controlled, experimental investigation such approaches are unrealistic in an elite high performance environment. Circumstances in which individual players cannot adhere to the normal training requirements of the squad, such as during periods of rehabilitation from injury, may however provide a unique opportunity for the manipulation of the resistance training prescription. Similar possibilities also surround specific cases where a systematic longitudinal development plan is required to underpin important aspects of a specific player(s) performance profile. The use of case studies would therefore seem an appropriate strategy for investigating and evaluating the impact of changes in the resistance training programmes of elite football players. In the current chapter, we provide two such case studies that outline and evaluate a structured approach to developing strength and power during the competitive season in elite football players. The aims of these case studies are to specifically investigate the potential effectiveness of approaches to implementing an increased training load in elite football players. These increased training loads are associated with the primary goal of positively influencing strength and power performance along with generating positive adaptations in body composition.

6.1 Case Study 1: Resistance training to enhance physical performance during rehabilitation from shoulder injury in a premier league football player.

6.1.1 Presentation of the athlete

The player in this case study is a professional football player, competing in the English Premier League (age: 23 yr; height: 1.68 m; mass: 63 kg). The player plays as a central midfielder, regularly playing for his club's 1st team. Having turned professional in 2007, aged 18, his achievements include representing Wales at senior international level, having also been previously named Wales's player of the year. Other representative achievements include playing for Team GB at the 2012 Summer Olympics. The player provided written consent to participate in the study, with the study being approved by the University Ethics Committee of Liverpool John Moores University.

Prior to the onset of this case study this player presented with chronic left sided shoulder instability. This occurred following initial injury in 2006 and re-injury following "Bankart" repair surgery in 2011. Having attempted to manage this injury non-operatively for two years it was decided, due to regular subluxation, that the player would undergo further surgery in the form of a "Laterjet" procedure in March 2013. This procedure took place at the commencement of this case study. It was estimated that the player would return to competition following 8-12 weeks of rehabilitation.

6.1.2 Overview of athlete assessment

The purpose of the present study was to determine the effectiveness of resistance training to enhance strength and power performance performance alongside body composition during a period of rehabilitation from injury. The study intervention commenced following two weeks of recovery following the "Laterjet" surgical procedure. During this initial two week recovery period the player performed no resistance training or pitch based conditioning sessions. Assessment data was collected prior to surgery to create a baseline for the player. Firstly the player was assessed for body composition via duel x-ray absorptiometry (DEXA) (QDR Series Discovery A, Hologic Inc., Bedford, MA). Secondly, lower body power output was assessed using a pneumatic resistance leg press machine with software and digital display (Keiser Sports Health Equipment Inc., Fresno, Ca). For this assessment, the player performed 4 repetitions at a load of 80kg, then a further 4 repetitions at a load of 160kg, each with maximal explosive intent. These loads were selected to represent an assessment of low-force/high-velocity power, and high-force/low-velocity power relative to the individual player's previously assessed strength level. Results of this initial athlete assessment are in Table 6.1. Assessments were repeated 8 weeks post surgery, i.e. following 6 weeks of resistance training. This was when the player was considered fully rehabilitated from injury and able to fully return to team training and match play.

Table 6.1. Initial athlete assessment

Descriptive	Output
Age (years)	23
Height (m)	1.68
Body Mass (kg)	63.0
Percent body fat (%)	9
Fat mass (kg)	5.4
Lean tissue mass (kg)	51.7
Peak power output @ 80kg (w)	1645 (Midfield average 1908±245 w)
Peak power output @ 160kg (w)	1866 (Midfield average 2429±384 w)

6.1.3 Resistance training programme design

The six week intervention consisted of three strength training sessions per week for the initial 3 weeks, followed by 2 sessions per week for the subsequent 3 weeks. The reduction to 2 sessions per week was due to an increased pitch-based training load during this phase of the rehabilitation process. Strength training sessions were performed on non consecutive days. Due to the injured site it was also not possible to undertake any upper body resistance training during this time. Additionally, lower body resistance training had to focus on exercises in which no load was going through the shoulder (i.e. no holding dumbbells, or resting barbells across the shoulders, as in a back squat). Each training session consisted of both single and double leg variations of a “leg press” exercise, “glute-ham raise” and “Yo-Yo leg curl” exercises.

Leg press exercises focused on improving functional performance through utilising triple extension movements of the lower limbs. This was to maximise movement specificity and therefore enhance transfer of training to on field performance (Santana, 2001). Repetitions in the leg press exercises ranged from 3-6 repetitions at an intensity of 60-80% of 1RM in order to enhance power output (Ratamess et al, 2009). These exercises were performed with maximal explosive intent in an attempt to further maximise the velocity specific gains of these exercises (Behm and Sale, 1993). In contrast glute-ham raise and YoYo leg curl exercises focused heavily on completing eccentric muscle actions around the knee and hip joints. These movements were included in order to both improve strength in these joints and reduce the risk of hamstring strain injury (Arnason et al, 2008). Exercises were performed with a 3 second eccentric muscle action for 6-8 repetitions in order maximise the hypertrophic response in the targeted muscles (Kraemer et al, 2004). Training volume (number of sets) for each exercise was 5 sets per exercise giving a total of 20 sets total per session. An example training session can be seen in Table 6.2.

Table 6.2. Example resistance training session.

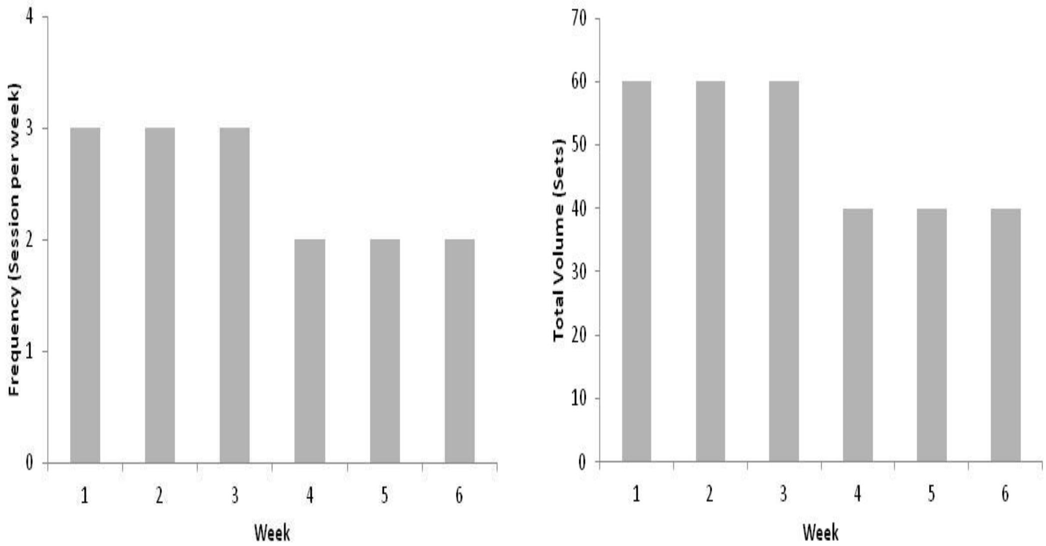
Exercise	Sets	Reps	Load (kg)
Single-Leg Leg-Press	5	3-6	180-280kg
Glute Ham Raise	5	6	Body Weight
Double-Leg Leg Press	5	3-6	180-280kg
YoYo-Flywheel Leg Curl	5	6	No load

6.1.4 Nutritional support for the training programme

To maximise the hypertrophic adaptation to resistance training, the player was advised to ingest protein (30-40 g) at each main meal (i.e. breakfast, lunch and dinner). In addition, the player also consumed a whey protein based supplement mid-morning, mid-afternoon and prior to sleep. As such, high quality protein was provided every 2-3 hours throughout the day in an attempt to maintain high rates of protein synthesis (Areta et al. 2013).

6.1.5 Outcome and overview of the resistance training intervention

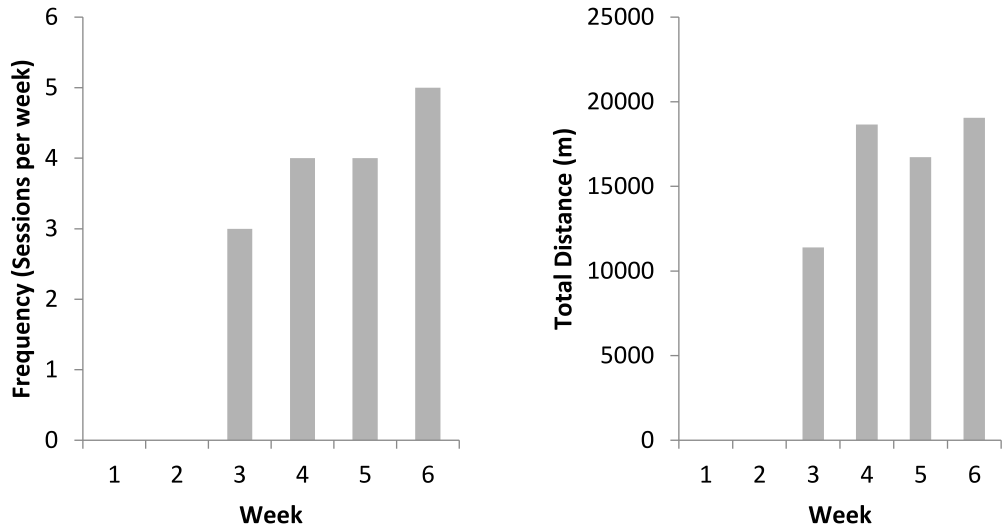
A summary of the completed resistance training volume can be seen in Figure 6.1. The player completed 60 sets per week over 3 sessions per week for the initial 3 weeks of the case study, followed by 40 sets per week over 2 sessions per week for the subsequent 3 weeks of the case study.



a b

Figure 6.1. Weekly resistance training data for a) frequency and b) volume (total sets), during the 6 week intervention.

A summary of completed pitch-based training volume can be seen in Figure 6.2. The frequency of pitch based training increased over the course of the intervention, from zero sessions in weeks 1 and 2, to a frequency of three sessions in week 3, four sessions per week in weeks 4 and 5 and five sessions per week in week 6. Training volume also followed a similar pattern to session frequency with the exception of a slight reduction in total distance between weeks 4 and 5 (18650m and 16730m, respectively).



a b

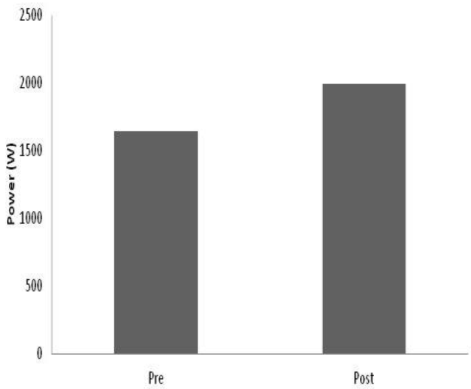
Figure 6.2. Weekly pitch-based training data for a) frequency and b) volume (total distance) during the 6 week intervention.

Changes in the player's body composition can be seen in Table 6.3. The total increase in body mass over the intervention week period equated to 5.4kg, of which 4.2 kg was accounted for through increases in lean mass and a 1.3 kg increase in fat mass. This resulted in a 1.3 % increase in overall body fat percentage.

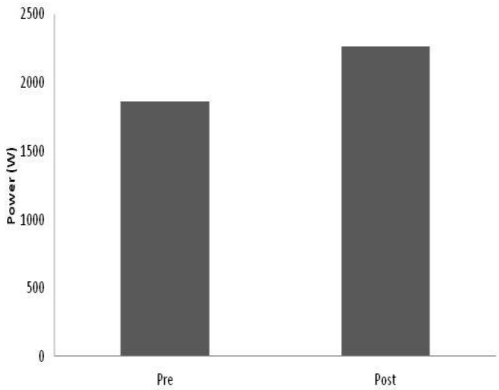
Table 6.3. Pre and Post intervention body composition

	Pre Injury	Post Intervention
Body Mass (kg)	63.0	68.4
Percent body fat	9	10.3
Fat mass (kg)	5.4	6.7
Lean tissue mass (kg)	51.7	55.9

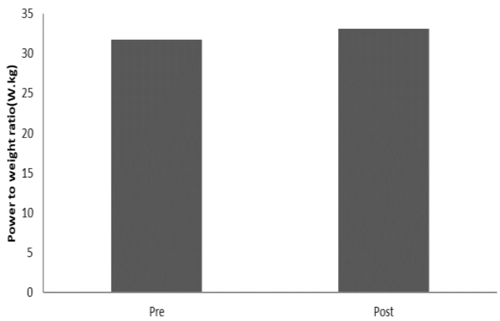
Changes in the player' power performance are illustrated in Figure 6.3. Peak power output increased by 21% at both 80 kg and 160 kg. This is in line with improvements in the literature for training programmes of this duration (Aagaard et al., 1996, Colliander and Tesch., 1990, Hakkinen et al., 1998). Despite the increases in body mass and body fat percentage, power to weight ratio also increased by 4.4 %.



a



b



c

Figure 6.3. Pre and post intervention power assessment. A) Peak power (W) at 80kg B) Peak power (W) at 160kg C) Peak power output relative to body mass (W·kg^{-1}).

6.2 Case study 2: Resistance training to enhance physical performance in a goalkeeper during a premier league football season

6.2.1 Presentation of the athlete

This player was a professional football player, competing in the English Premier League (age: 25 yr; height: 1.93 m; mass: 90.1 kg). The player plays as a goalkeeper, regularly playing for his club 1st team. Having turned professional in 2004, aged 16, his achievements include representing Belgium at senior international level, having also been previously named Belgian Goalkeeper of the year in 2010. Prior to the onset of this case study this player did not present with any current injuries. The player provided written consent to participate in the study, with the study being approved by the University Ethics Committee of Liverpool John Moores University.

6.2.2 Overview of athlete assessment

The purpose of the present study was to develop, monitor and evaluate a resistance training programme to enhance both strength and power performance parameters and positively influence body composition during a full competitive season. The study intervention commenced at the beginning of the 2013-14 season. During this period the player took full part in all pitch based conditioning sessions and the competitive fixture schedule. Assessment data was collected at the beginning, mid-point and end of the 2013-14 season. This season long intervention consisted of two phases of training. Phase 1 was 16 weeks in duration and represented the beginning to the mid-point of the season. During this phase the goal was to gradually and safely increase resistance training loading. This gradual approach was designed to avoid a performance decrement and reduce the injury risk which may be associated with a sudden increase in loading. Phase 2 was 20 weeks in duration and represented the mid-point to the end of the season. This phase represented a period of consistent high loading following the initial systematic increase in these variables.

The player was firstly assessed for body composition via duel x-ray absorptiometry (DEXA) (QDR Series Discovery A, Hologic Inc., Bedford, MA). Secondly, lower body power output was assessed using a pneumatic resistance leg press machine with software and digital display (Keiser Sports Health Equipment Inc., Fresno, Ca). For this assessment, the player performed 4 repetitions at a load of 200kg, each with maximal explosive intent. This load was selected to represent an assessment of high-force/low-velocity power relative to the player's individual strength level. Finally the players upper body strength was assessed via 6 repetition maximum assessments of the dumbell bench press and dumbell prone row. Results of this initial athlete assessment are shown in Table 6.4.

Table 6.4. Initial athlete assessment

Descriptive	Output
Age (years)	25
Height (m)	1.93
Body Mass (kg)	90.1
Percent body fat (%)	12.5
Fat mass (kg)	10.8
Lean tissue mass (kg)	71.8
Peak power output @ 200kg (w)	2666
Relative peak power (w/kg)	29.8
Dumbbell bench press 4RM (kg)	28
Dumbbell prone row 4RM (kg)	28

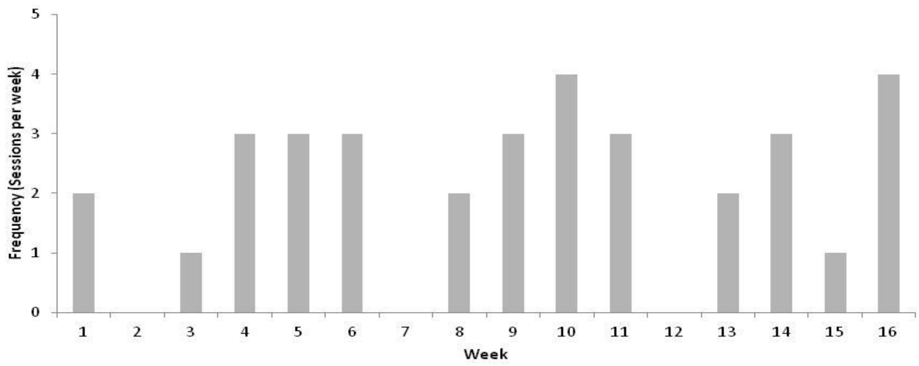
Results of initial body composition assessments suggest that fat mass and body fat % could be reduced to <10%. This would be targeted predominantly through nutritional strategies and supplemented by an increased resistance training volume. Improvements in peak power and relative peak power would also be beneficial, of which the later would be aided by reductions in fat mass.

6.2.3 Resistance training programme design

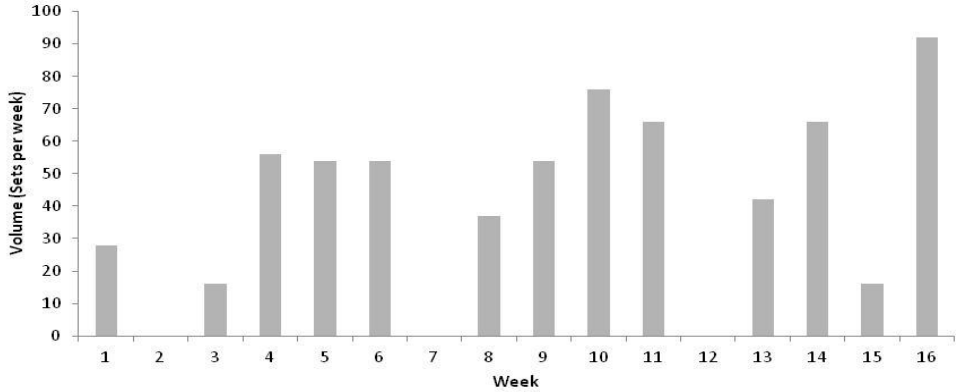
Whilst the frequency and nature of training are largely dictated by the playing schedule, the current training programme typically employed a frequency of 3 resistance training sessions per week. Strength training sessions were split into lower body and upper body focused training sessions. Lower body training was performed 3 days prior to a match whilst upper body sessions were performed 4 and 2 days prior to a match. The player would therefore typically perform 1 lower body and 2 upper body focused sessions per week.

6.2.4 Outcome and overview of the resistance training intervention – Mid season assessment

A summary of the completed resistance training volume during phase 1 of the training intervention can be seen in Figure 6.4. The player completed a mean weekly volume of 41±24 sets per week and a mean frequency of 2±1 sessions per week for the initial phase of the study. Figure 6.4 illustrates the variable nature of loading patterns of the exercise completed during this phase.



a)



b)

Figure 6.4. Weekly resistance training data for a) frequency and b) volume (total sets), during the phase 1 of the intervention.

Changes in the player's body composition and strength performance can be seen in Table 6.5. The total decrease in body mass over the initial intervention period was 4kg, of which 2.7kg was accounted for through decreases in fat mass and a further 0.9 kg by a decrease in lean mass. This resulted in an overall 2.7% decrease in body fat percentage.

Table 6.5. Pre and mid season body composition.

Descriptive	Pre Season	Mid Season
Body Mass (kg)	90.1	86.1
Percent body fat (%)	12.5	9.8
Fat mass (kg)	10.8	8.1
Lean tissue mass (kg)	71.8	70.9

Change in the player's power performance are illustrated in Figure 6.5. Peak power output increased by 25%, whilst power to weight ratio increased by 30%. The greater increase in power to weight ratio is due to the combined effect of an increase in power output and a decrease in body mass. Upper body pressing (Dumbell Bench press) and upper body pulling (Dumbell Prone pull) strength was also increased by 14% and 21% respectively.

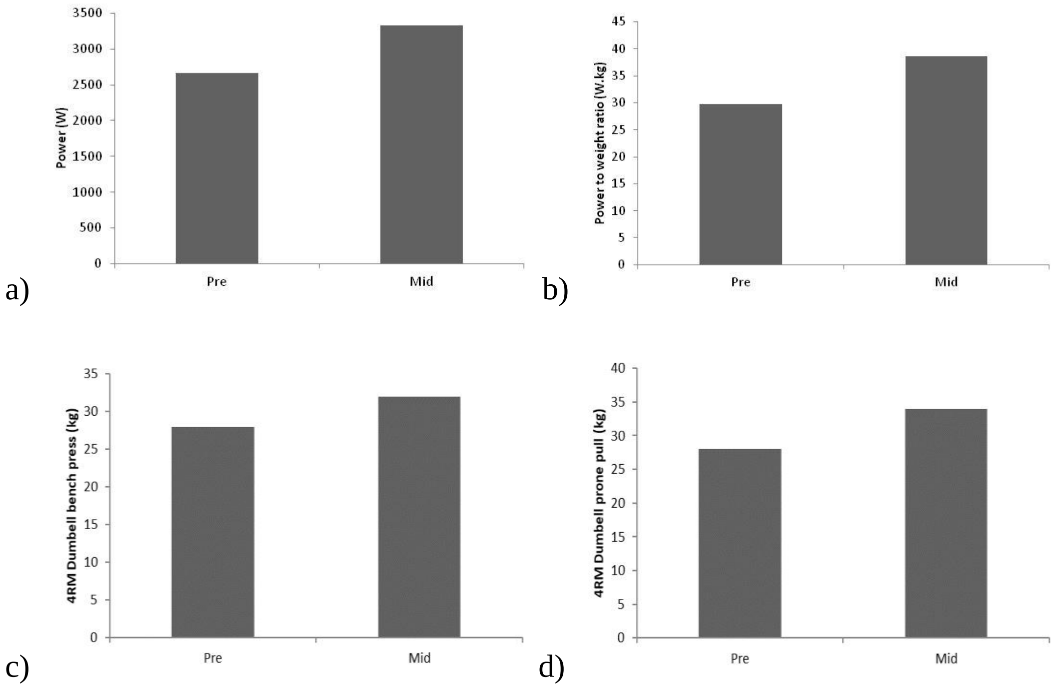
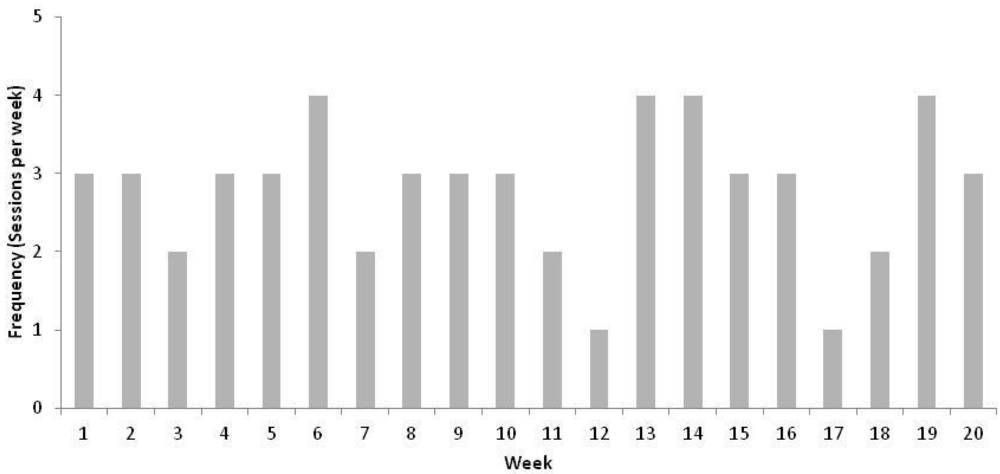


Figure 6.5. Pre and mid season strength and power assessment. A) Peak power (W) B) Peak power output relative to body mass (W·kg^{-1}) C) 4RM Dumbell bench press (kg) D) 4RM Dumbell prone pull (kg).

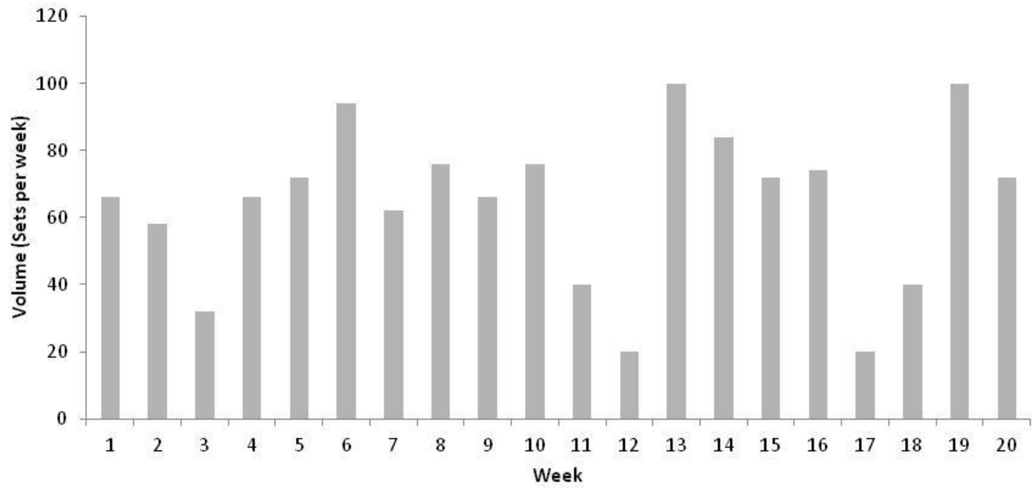
Training data illustrates the systematic increase in resistance training load over the initial phase of this intervention (Figure 6.4). Body composition assessments completed post training phase would suggest that fat mass and body fat % have been reduced to <10% as targeted. A goal for the subsequent phase of the training intervention would therefore be to maintain this level of body composition. The 0.9kg reduction in lean mass that occurred as a consequence of this training period was however an undesirable side effect of the intervention. An increase in lean mass was therefore targeted over the subsequent phase of the training intervention completed by this player. Beneficial improvements in peak power and relative peak power were also observed over the initial training phase of this study, despite the loss of lean muscle mass. Further increases in absolute peak power were targeted for the later training phase, this would ensure no decreases in power to weight ratio whilst lean mass, and therefore body mass were target for increase.

6.2.5 Outcome and overview of the resistance training intervention – End of season assessment

A summary of completed resistance training volume during phase 2 of the season can be seen in Figure 6.6. The player completed a greater mean weekly volume in the training completed in the later phase of the season compared to the initial training period (65±28 set per week vs. 41±24 sets per week in the initial phase of the season). A greater mean session frequency was also associated with the second training phase (3±1 vs. 2±1 session per week).



a)



b)

Figure 6.6. Weekly resistance training data for a) frequency and b) volume (total sets), during the phase 2 of the intervention.

Changes in the player's body composition and strength performance can be seen in Table 6.6. The total increase in body mass over the second phase of the intervention period was 1.2kg, of which 2.4kg was associated with increases in lean mass. A change in body mass over this phase also included a 1.2kg decrease in fat mass. This resulted in a 1.5% decrease in overall body fat percentage (9.8 to 8.3%).

Table 6.6. Mid and end season body composition.

Descriptive	Mid Season	End Season
Body Mass (kg)	86.1	87.3
Percent body fat (%)	9.8	8.3
Fat mass (kg)	8.1	6.9
Lean tissue mass (kg)	70.9	73.3

Change in the player’s power performance are illustrated in Figure 6.7. Peak power output increased by a further 9% from the values, observed mid-season whilst the power to weight ratio increased by a further 10%. Upper body pressing (Dmbell Bench press) and pulling (Dumbell Prone pull) strength also increased by a further 19% and 24% respectively compared to performance at baseline.

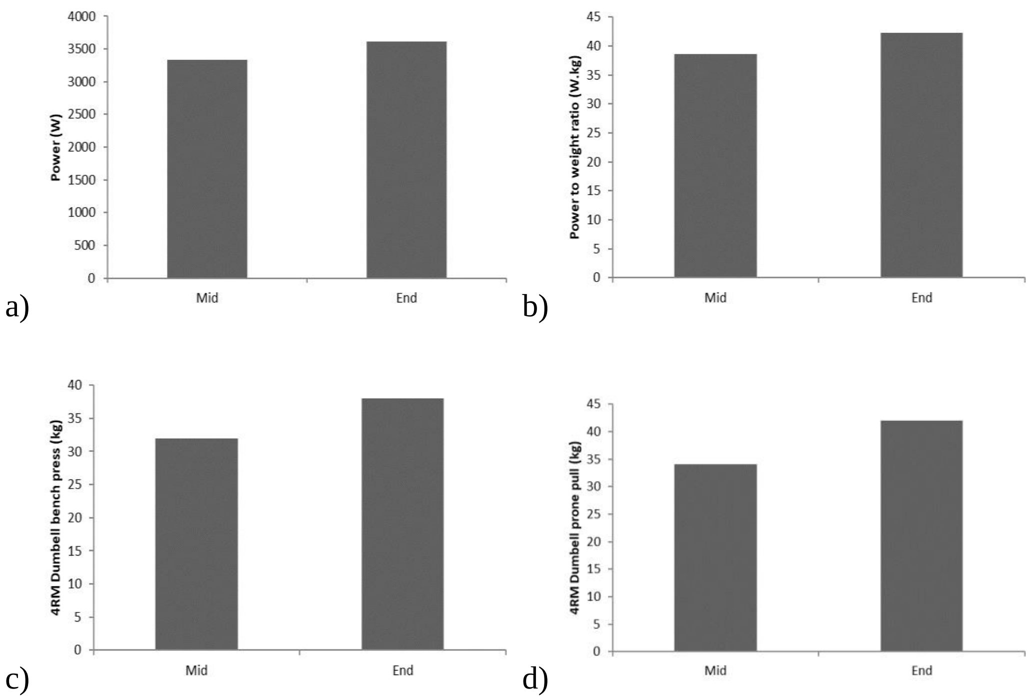


Figure 6.7. Mid and end season strength and power assessment. A) Peak power (W) B) Peak power output relative to body mass (W·kg^{-1}) C) 4RM Dumbell bench press (kg) D) 4RM Dumbell prone pull (kg).

6.3 Discussion of outcomes and practitioner reflections

An obvious challenge to conditioning coaches in football is to implement strength and power training interventions in-season when match frequency is high. This challenge has been discussed in Chapter 4. During these periods, opportunities to increase resistance training exposure and training load are limited. Here we present two examples where the training impulse has been systematically increased in players. Although it is difficult to compare the findings of these individual cases to broader outcomes associated with a larger number of individuals in a playing squad this data does seem to indicate that if resistance training programme variables are manipulated to increase training load it is possible to successfully increase physical performance parameters in elite level players. This would seem to be the case in both short, focused interventions and more long term, gradual approaches.

In the initial case study we present a relatively short period of increased resistance training loading associated with a period of rehabilitation from injury. The large increases in lower body power output (21%) and lean muscle mass (8%) illustrate that it is possible to increase performance when rapid short-term increases in resistance training load are completed. Whilst the observed increases in lean muscle mass in this case may support the notion that strength/power adaptations are largely associated with increases in muscle CSA, it is possible for muscular strength/power to develop without distinct changes in muscle morpolology (Gabriel et al., 2006). This shows that the respective mechanisms of adaptation in the neural and muscual systems are distinctly different (Hakkinen et al., 20003), performance improvements may therefore be underpinned via either neural or muscular adaptations, or often most likely, a combination of the two (Toigo and Boutelier 2006). The enhanced power production seen in this case, whilst associated with an increase in muscle mass in a relatively short period of time, is likely the consequence of both muscular and neural adaptations, such as motor unit recruitment, rate coding (frequency or rate of action potentials), synchronisation, and inter-muscular coordination (Cormie et al., 2011, Hakkinen et al., 1985, Aagaard et al., 2002).

The nature of adaptation observed in the initial case are somewhat in contrast to those seen in our second case. During our second intervention, it is noteworthy that the greatest increases in both absolute and relative lower body power output (25 and 30% respectively) were seen in the initial phase of the season, rather than during the second phase when resistance training loading was greatest. In contrast greater gains in lean muscle mass (3%) were however seen in the later phase of the training programme. Unlike the initial case this would support the notion that initial increases in test performance may be predominantly due to neural factors with muscular morphological adaptations accounting for longer term performance increases (Moritani et al., 1979). Whilst morphological adaptations are of great importance in the development of strength/power, it is clear that high volumes of resistance training are necessary to induce adaptations in muscle morphology. This is best highlighted in our second case study whereby the greatest adaptations in lean muscle mass were associated with the periods of greatest resistance training loading. This notion is supported in the literature by the work of Bogdanis et al (2011), who showed higher volume programmes supported greater increases in muscle mass in football players. This supports numerous other studies which suggest the magnitude of loading, is associated with differing physiological and performance adaptations (Aagaard et al., 1993, Trolle et al., 1992, and Los Arcos et al., 2014). Whilst high levels of resistance training loading may provide the best stimulus for morphological adaptations supporting strength/power performance, the associated fatigue, greater injury risk and acute performance decrements may make this level of loading difficult to attain in this setting.

From a practical perspective a further challenge to strength and conditioning coaches at this level is finding the balance between attaining the optimal training load to enhance physical performance whilst minimising the risk of injury. It is noteworthy that this initial case marked a sudden increase in training load above the players normal level. This was only possible due to the rehabilitation circumstances whereby match performance was no concern. However whilst periods of injury are common in this populations it is important to note that the nature of injury does not always allow this type and level of training to be performed. In cases where a player is still required to perform in match play on a regular basis a more gradual and systematic increase in training load would be necessary. As a result of these programming concerns we presented the second case, outlining a more gradual approach to increasing training load over a longer intervention period. The programme devised included a gradual increase in training load that was implemented over the initial phase of the season, and maintained at this increased level during the later phase of the season. Although no previous training data is available due to the player previously playing for a different club, the player subjectively reported that such levels of resistance training loading represented a substantial increase on the player's previous training approach.

Clearly there are many different approaches to manipulating resistance training load in order to positively benefit athletic performance. Ultimately it is the manipulation of the acute programme variables underpinning training load which determine the extent to which the neuromuscular system adapts and therefore positively influence strength and power performance. The data from the 2 case reports outlined within this study illustrate the need for individual approaches to manipulating these variables within elite sport. This is due to the vastly differing circumstances and demands placed upon a player.

The case study approach was adopted in this chapter to enable an insight into the context of each individual athlete and their training considerations and approaches in a setting whereby traditional group interventions were not plausible. The major criticism of the use of this method over a more traditional research design is that the data collected is not necessarily generalisable to the wider population. However, this approach provides a valuable method of assessing each individual case whilst, in this instance, giving the researcher and/or practitioner a greater insight into all the variables considered when manipulating resistance training loading in the elite football player. This therefore allows the insight into the real world application of these principles. We hope the data and methods outlined within this chapter demonstrate that with an individual approach it is possible to systematically increase resistance training loading of players and therefore positively and safely influence physical performance within the elite football setting.

CHAPTER 7

Synthesis

The purpose of the following chapter is to provide a broader conceptual and theoretical interpretation of the results obtained from the present thesis. Where possible the outcomes of the thesis will also be discussed from a practical perspective. An evaluation of the original aims and objectives will be conducted prior to reviewing the outcomes of the experimental studies in these contexts.

7.0 Evaluation of aims and objectives

The overall purpose of the present thesis was to gain a better understanding of resistance training practices in elite football.

In order to fulfil this aim the following objectives were completed;

1. To better understand practically applied methods of quantifying resistance training load.
    a. This was achieved through the comparison, assessment and evaluation of the available approaches during a 4 week training period in English Premier League footballers.
    b. Four available methods were compared. Our data illustrated discrepancies between methods and further analyses highlighted the specific limitations of each model.
    c. These data enabled a greater understanding of each methods limitations and therefore the ability to make a more informed decision when choosing the most appropriate method for any given environment.

2. To gain a greater understanding of the resistance training habits and training loads of elite professional football players.
    a. This was achieved through the quantification of the frequency of resistance training and further analysis of the resistance training loads of an elite professional football team across a competitive season.
    b. Such information provides detail of the training periodisation strategies currently used in elite level football, as well as enabling greater understanding of the factors which influence this, thus enabling

strength and conditioning coaches to optimise the resistance training prescription to players.

3. To understand the impact of current resistance training practices on physical performance in elite football.
    a. This was achieved via the analysis of changes in lower body power outputs across a competitive season.
    b. Whilst data shows on average minor increases over the course of a competitive season, large individual differences were also observed.
    c. Whilst such information provides some detail of the physiological response to training strategies currently used in elite level football, this data also illustrates the need for individual approaches to monitoring, assessing and programming resistance training in elite football.

4. To specifically implement individual approaches to increasing training load in elite football players with the primary goal of positively influencing both strength and power performance and body composition.
    a. This was achieved via the completion of 2 case studies. One case analysing a short acute period of increased resistance training loading during a period of rehabilitation. A further case study analysing a longitudinal (season long) approach to gradually increasing resistance training loading.
    b. Both cases demonstrated an ability to positively influence both strength and power performance and body composition with increased resistance training loading.

The individual studies conducted resulted in the fulfilment of these original aims.

7.1 General Discussion

To understand the findings of our research it is important to discuss these in terms of their broader contribution to the field of sports science and strength and conditioning from a theoretical, methodological and practical perspective. This general discussion will attempt to provide the broader implications of the findings of this thesis in these 3 areas. This will be based on both the objective data collected in this thesis and the researchers personal reflections on strength and conditioning practice at the club in question. Specific reference will be paid to the development of practical considerations for resistance training in football as these seem an important outcome of a thesis of this nature. The section will conclude by presenting some potential future research that would further support the understanding of resistance training in this population.

The aim of this thesis was "To evaluate the resistance training practices in an elite premier league football team". Our data in this thesis would seem to be confirmatory of many of the pre-existing theoretical ideas that exist within the applied strength and conditioning field. Firstly our data would indicate that appropriate resistance training prescription can lead to positive adaptations in elite footballers of advanced training age. Such adaptations do however require a careful consideration of the resistance training prescription that is completed. This can be evidenced by our data in the thesis (chapter 6) that illustrates that modifying the resistance training load beyond the levels that we observed in the majority of players in this specific population, but still within the guidelines widely published in the research literature, can be beneficial to performance outputs that are relevant to football performance. These summary statements are however based on some assumptions located within our methodological approach to collecting our data. The findings that support our ideas around the potential improvements in performance outcomes are based on a case study approach. Such approaches are inherently limited by the focus of the data collection and analysis on an individual rather than a sample of players. This will clearly impact on our ability to generalise from this data and to make assumptions around the suitability of such training programmes for others. These type of designs are however clearly important in such applied settings as they represent one of the only strategies that can be used to answer research questions in the "real world" environment of professional sport.

While it would seem theoretically appropriate to develop the resistance training programmes of these players to support their performance there are considerable practical challenges to doing this within elite football (see Chapter 4). Individual scientific observations and personal reflections during the duration of these studies has indicated that the ability to increase training load is often difficult due to a range of external factors that impact the players ability to complete increased resistance training loads. Most amongst these factors is a high frequency of match play, and the associated team training sessions to prepare for these games. The demands of these activities make the implementation of additional resistance training problematic.. Increases in training frequency are therefore often not always periodically possible during the in-season. Such factors, in this context, are not typically considered in the ideas that have informed traditional periodization models of resistance training. This may suggest that at a conceptual level we need to consider alternative planning models for resistance training practices that are used in elite football.

When resistance training is completed by players in this environment it is often completed against a background of concern for the short term, potentially negative consequences that can be associated with high load resistance training (e.g. soreness/stiffness). This is especially a mind set that is common in the technical coaching staff employed by clubs. For example different managerial regimes have imposed different restrictions on resistance training prescription. This has included not allowing resistance training for the lower body to be performed in the 2 days preceding a match for all players, or 2 days proceeding match play if the player had played 45minutes or more. Under such situations when there is a high prevalence of competitive fixtures it becomes almost impossible for any player to perform any lower body resistance training. Such ideas would seem to have some support from the available research. For example an increase in training load in general can negatively impact performance in the short term whilst also increasing the acute risk of injury (Killen, Gabbett and Jenkins, 2010). Other research would however suggest that such negative consequences are not common in individuals who have completed suitable levels of resistance training. This is a consequence of the adaptive responses that occur following resistance exercise. Such adaptations may however require exposure to resistance training sessions that is practically difficult to deliver to players in these environments. The perceived trade-off between possible short term negative consequences and potentially long term positive responses to training loading increases may therefore be an important driver of the resistance training programmes used in elite football. These factors highlight the challenges of the delivery of resistance training prescription in these environments for practitioners when key decision makers within the organisation dominate the overall schedule of the players.

The methodological contributions from this thesis can be located in the data that is associated with the measurement of both the resistance training stimulus and the assessment of power following chronic training exposure in the applied environment. These contributions from this thesis are especially pertinent for approaches to research in this area with elite athlete groups in football. Our data have provided us a greater insight into the potential methods of monitoring resistance training load in the resistance training practice associated with elite football. This information alongside reliable performance assessments have enabled the long term tracking of performance changes in this population. Whilst our data have enabled a greater understanding of each method and its application in this setting it has not provided significant advances towards a theoretical and methodological "gold standard" method of quantifying resistance training loads or the performance outcomes that accompany chronic training. Creating a "gold standard" approach to these issues from a monitoring of training perspective is problematic. This is predominantly due to the complex interaction of training variables that make up resistance training programmes. These include sets, repetitions, movement and contraction type, velocity of action, type of loading and form of resistance. Our comparison of applied methods of monitoring resistance training load has also allowed us to better understand the limitations associated with each method. For example we found volume load, a popular and widely utilised method of quantifying resistance training, to be unsuitable in elite football due to the quantity of bodyweight exercises utilised and the methods inability to quantify load in these instances. The understanding developed during this thesis through research projects such as in Chapter 3 has generated a positive impact on our ability to monitor resistance training programmes in the real world. For example, the methods utilised in this thesis have been utilised over a number of seasons at the premier league club in question to monitor and assess the long term performance changes of its players.

The intensity of the training stimulus is an important component of any resistance training programme (Tan et al, 1999; Bird et al, 2005; Ratamess and Triplett-McBride, 2002). The evaluation of training intensity is an area that remains problematic in the monitoring of resistance training especially in the applied setting. The accurate evaluation of training intensity would provide important information regarding the overall adaptive signal to the muscle as a consequence of the completed resistance training. The development of a simple method of quantifying resistance training intensity for use in the applied setting would therefore be of great benefit to the majority of practitioners, not just those working with elite footballers. The approach utilised in this thesis, to quantify intensity in a acute resistance training session (average load) was deemed the best method available at the time of data collection. This was predominantly a consequence of the limitations associated with other methods. For example, using a percentage of maximum load lifted (%RM) as a monitoring tool was impractical due to the inability to dedicate the time needed for the assessment of each individual players 1RM for all exercises performed. The combination of different exercises and exercise intensities within individual sessions for individual programmes would also make it problematic to produce a single intensity value per session if the %RM method was used. Average load was therefore deemed the most appropriate method due to its ability to provide a basis to monitor all of the different exercises, repetitions and loads utilised within a session. One major limitation of this method however, similar to the volume load method of volume calculation, is its inability to quantify bodyweight only exercises. Whilst this is a major limitation of this method, average load was still deemed the most suitable method available, as discussed in Chapter 4. Future research in the area of intensity measurement in resistance training would be highly beneficial.

The ability to assess performance change in a valid and reliable, yet practical and time efficient way is vital to enable the long term monitoring of the training process in elite populations. A variety of methods have previously been used in the literature to assess lower body power in athletes. These have included the countermovement jump (CMJ), 1RM testing using resistance training apparatus, isokinetic dynamometer assessment and performance tests such as the broad jump, T-Test, 10m acceleration and sprint velocity (Nuzzo et al., 2008, Peterson et al., 2006, McBride et al., 2009, Stone et al., 2004, Wilsoff et al., 2004, Enright et al., 2015). Irrespective of the theoretical potential of all of these evaluations to monitor changes in power are the associated difficulties in the implementation of these tests during a busy competitive and training schedule in elite football. The use of pneumatic resistance equipment in sports performance training has gained popularity in recent years due to its ease of use and safety when performing explosive actions. The potential of this type of equipment to provide live feedback on performance, as indicated by power output, provides a highly useful and time efficient way of monitoring power performance, both within sessions and longitudinally. Due to its now common use and therefore familiarity, testing with this equipment provided a reliable and highly time efficient way of collecting lower body power data during a football season. Our data in Chapter 5 supports this notion, with the coefficient of variation for this assessment demonstrating a test-retest value between trials of <6% (5.68%). Furthermore, practically this assessment method has been utilised far beyond the context of this thesis. It has been installed as a performance assessment at the club in question, routinely being performed prior to any lower body resistance training to provide longitudinal tracking information on power performance.

Whilst using pneumatic leg press machinery to assess power output provides valuable, yet easily accessible data on physical performance, power output alone does not provide detailed information relating to the specific adaptations to a training regimen. Whilst power output does relate to both strength and speed variables (Cronin and Hansen, 2005) and is highly associated with performance in sporting movements (Alexander, 1989; Anderson et al, 1991; Peterson et al, 2006), it would be beneficial to be able to assess the specific nature of the physiological processes that may or may not underpin adaptation in these populations in the future.

Aside from the contributions of a scientific nature this thesis also attempts to provide insight into the applied nature of sports science, specifically resistance training practice, in an elite football performance setting. Both the experience gained whilst studying this population in this setting and through the specific research studies that have been completed has allowed a greater practical understanding of the resistance training process to be gained. It is simple to draw the general conclusion from this thesis for the need for increased resistance training in this cohort. A key consideration in the potential strategies for such changes are the many practical difficulties associated with applying this increase in training load. While match and training demands are a large limiting factor, other external factors are often a bigger influence on decision making regarding the implementation of resistance training programmes in elite football. These include factors such as managerial opinion, the opinion of staff, the high level of focus on short term performance outcomes, cultural differences and the prior experience of individual players. In my experience players from different countries typically favour different training methods, for example, whilst British players may have more of an inclination towards traditional heavy resistance training, those from other European countries may be more motivated by what may be termed more "functional" exercises. Whilst it is apparent that external, personal and cultural factors hugely influence the implementation and/or ability to implement training plans in elite football there are a number of practical recommendations that can be made based on the experience of completing this thesis. These ideas are part of the basis for the development of further research questions that could be explored in other research projects following this thesis.

In order to impact and improve training habits in football, it is important that practitioners are able to derive useful information from this thesis that can be utilised in the applied setting. The following is a summary of key messages and practical recommendations to come from the studies which make up this thesis:

Key Findings and Practical Recommendations From This Thesis

What Do Elite Football Players Do?

Resistance training frequency (mean±SD) ranged from 1±1 to 2±1 sessions per week.

Resistance training volume (mean±SD) ranged from 18±16 to 30±24 sets per week.

Lower Body resistance training volume (mean±SD) ranged from only 3±3 to 6±4 sets per week.

This seems low and may not be optimal for performance enhancements?

Whats the Impact of this Training?

The power output of players ranged from 2200W to 4078W with a mean (±SD) value of 3022±374W.

When accounting for within player effects, power output increased 7.76W per week during the season.

Individual power output increases/decreases ranged from +39.9W to -18.13W per week.

This shows there are large individual differences in training adaptation. Some may need a greater stimulus to improve.

Why is it this way?

A high volume of match play and constant pressure to perform is likely the implementation of higher volume resistance training programmes.

Training is often completed against a background of concern for the short term, potentially negative consequences that can be associated with high load resistance training (e.g. soreness/stiffness).

The trade-off between potential short term negative consequences and potential long term positive responses to training loading increases may therefore be an important driver of the resistance training programmes used in elite football.

Monitor and Asses

It is important to monitor and assess programmes regularly.

The conflicting demands of the sport make this especially important to ensure to ensure no negative performance impact of additional training.

All methods of quantifying resistance training volume have their limitations, be aware of these when interpreting data.

Set volume offers a good, practical method of quantifying resistance training volume

Make the Most of Opportunities

The typically limited opportunity to perform resistance training increases the importance of maximising opportunities when they do arise.

Rehabilitation offers an unfortunate, yet valuable opportunity to increase resistance training loading.

Certain positions (i.e. goalkeepers) may have more scope to systematically increase loading without impacting performance in the short term.

Disguise load if necessary

Many players and managerial staff associate high load resistance training with bodybuilding and hypertrophy.

Whilst it is obviously important to educate people, sometimes it is also necessary to deliver a stimulus in a more disguised manner to alleviate these fears.

The utilisation of different exercise selections, contraction types, loading methods, movement speeds etc often enables the implementation of a desired stimulus without the negative opinions surrounding more traditional methods.

However, don't stray too far from your principles, overload is still essential.

Influence Others

Your ability to foster good working relationships and gain peoples trust is of the utmost importance.

Do not underestimate the influence of other peoples thoughts and opinions on your ability to perform your job.

The ability to implement resistance training programmes may rely on a multitude of factors. For example, player perception, managerial opinion, trust and culture. Degrees don't necessarily earn you this. It is therefore of high importance to be able to build and foster good relationships with people in order to gain the opportunity to educate and influence them.

7.2 Recommendations for future research

The studies completed within this thesis have provided novel information relating to the resistance training practices employed in an elite football club. In achieving the aims of the thesis, several issues and findings have provoked recommendations for future research. This section details those recommendations;

Development and analysis of an applied method to quantify resistance training intensity in elite football.

1. Data derived from study 1 enabled a greater understanding of four practical methods of quantifying resistance training loading. Whilst the understanding of each methods limitations enabled the ability to make a more informed decision when choosing the most appropriate method, methods regarding the intensity of resistance training were not assessed. Future work should aim to gather and evaluate available methods of quantifying resistance training intensity before they can be applied to the monitoring of football players.

The influence of match frequency on resistance training loading in elite football.

1. Data from study 2 in this thesis provides detail of the training periodisation strategies currently used in elite level football. Whilst these data provide a level of understanding of the factors which influence resistance training prescription, a greater level of understanding regarding the influence of match frequency on resistance training loading would enable strength and conditioning coaches to optimise the resistance training prescription to players further. Future work should aim to evaluate specifically the influence of match play frequency on resistance training exposure. This should also have special reference to players who have featured as substitutes or un-used substitutes to give the greater prospect to identify training opportunities.

The implementation and analysis of a progressive, resistance training regimen in outfield football players.

1. Data from study 4 demonstrated an ability to positively influence both strength and power performance and body composition with increased resistance training loading in a goalkeeper. Whilst this is valuable information it is clear

that the training and match demands of goalkeepers is far different from those of outfield players. Thus it would be beneficial to assess whether an increase in resistance training loading produces the same positive adaptations in outfield players as seen in a goalkeeper.

An analysis of the retention of strength adaptations in football players following an acute period of high resistance training loading.

1. Data from study 4 demonstrated an ability to positively influence both strength and power performance and body composition with an acute period of increased resistance training loading during a period of rehabilitation from injury.

References

Aagaard, P., Simonsen, E. B., Trolle, M., Bangsbo, J., & Klausen, K. (1996). Specificity of training velocity and training load on gains in isokinetic knee joint strength. Acta Physiologica Scandinavica, 156(2), 123-129.

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, S. P., Bojsen‐Møller, F., & Dyhre‐Poulsen, P. (2000). Antagonist muscle coactivation during isokinetic knee extension. Scandinavian journal of medicine & science in sports, 10(2), 58-67.

Aagaard, P., Andersen, J. L., Dyhre‐Poulsen, P., Leffers, A. M., Wagner, A., Magnusson, S. P., ... & Simonsen, E. B. (2001). A mechanism for increased contractile strength of human pennate muscle in response to strength training: changes in muscle architecture. The journal of physiology, 534(2), 613-623.

Aagaard, P., Simonsen, E. B., Andersen, J. L., Magnusson, P., & Dyhre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. Journal of applied physiology, 93(4), 1318-1326.

Aagaard, P., & Andersen, J. L. (2010). Effects of strength training on endurance capacity in top‐level endurance athletes. Scandinavian journal of medicine & science in sports, 20(s2), 39-47.

Abernethy, P., Wilson, G., & Logan, P. (1995). Strength and power assessment. Sports medicine, 19(6), 401-417.

Ahtiainen, J. P., Pakarinen, A., Alen, M., Kraemer, W. J., & Häkkinen, K. (2003). Muscle hypertrophy, hormonal adaptations and strength development during strength training in strength-trained and untrained men. European journal of applied physiology, 89(6), 555-563.

Andersen, J. L., Klitgaard, H., Bangsbo, J., & Saltin, B. (1994). Myosin heavy chain isoforms in single fibres from m. vastus lateralis of soccer players: effects of strength‐training. Acta Physiologica, 150(1), 21-26.

Arnason, A., Sigurdsson, S. B., Gudmundsson, A., Holme, I., Engebretsen, L., & Bahr, R. (2004). Risk factors for injuries in football. The American journal of sports medicine, 32(1 suppl), 5S-16S.

Arnason, A., Andersen, T. E., Holme, I., Engebretsen, L., & Bahr, R. (2008). Prevention of hamstring strains in elite soccer: an intervention study. Scandinavian journal of medicine & science in sports, 18(1), 40-48.

Atkinson, G., & Nevill, A. M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports medicine, 26(4), 217-238.

Atkinson, G. (2003). Does size matter for sports performance researchers?. Journal of sports sciences, 21(2), 73-74.

Augustsson, J., Esko, A., Thomeé, R., & Svantesson, U. (1998). Weight training of the thigh muscles using closed versus open kinetic chain exercises: a comparison of performance enhancement. Journal of Orthopaedic & Sports Physical Therapy, 27(1), 3-8.

Augustsson, J., & Thomee, R. (2000). Ability of closed and open kinetic chain tests of muscular strength to assess functional performance. Scandinavian journal of medicine & science in sports, 10(3), 164-168.

Bahr, R., & Holme, I. (2003). Risk factors for sports injuries—a methodological approach. British journal of sports medicine, 37(5), 384-392.

Bangsbo, J. (1994). Fitness training in football: a scientific approach. August Krogh Inst., University of Copenhagen.

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). The Yo-Yo intermittent recovery test. Sports medicine, 38(1), 37-51.

Baroni, B. M., Geremia, J. M., Rodrigues, R., Azevedo Franke, R., Karamanidis, K., & Vaz, M. A. (2013). Muscle architecture adaptations to knee extensor eccentric training: rectus femoris vs. vastus lateralis. Muscle & nerve, 48(4), 498-506.

Behm, D. G., & Sale, D. G. (1993). Intended rather than actual movement velocity determines velocity-specific training response. Journal of Applied Physiology, 74(1), 359-368.

Behm, D. G., & Sale, D. G. (1993). Velocity specificity of resistance training. Sports Medicine, 15(6), 374-388.

Benton, M. J., & Wagner, C. L. (2013). Effect of single-set resistance training on quality of life in COPD patients enrolled in pulmonary rehabilitation. Respiratory care, 58(3), 487-493.

Bird, S. P., Tarpenning, K. M., & Marino, F. E. (2005). Designing resistance training programmes to enhance muscular fitness. Sports medicine, 35(10), 841-851.

Blazevich, A. J., Gill, N. D., Bronks, R., & Newton, R. U. (2003). Training-specific muscle architecture adaptation after 5-wk training in athletes. Medicine and science in sports and exercise, 35(12), 2013-2022.

Blazevich, A. J., Cannavan, D., Coleman, D. R., & Horne, S. (2007). Influence of concentric and eccentric resistance training on architectural adaptation in human quadriceps muscles. Journal of Applied Physiology, 103(5), 1565-1575.

Bogdanis, G. C. (2009). Fatigue and training status. Human Muscle Fatigue, 164-204.

Bogdanis, G. C., Papaspyrou, A., Souglis, A. G., Theos, A., Sotiropoulos, A., & Maridaki, M. (2011). Effects of two different half-squat training programs on fatigue during repeated cycling sprints in soccer players. The Journal of Strength & Conditioning Research, 25(7), 1849-1856.

Bompa, T. O., & Haff, G. G. (2009). Periodization: Theory and methodology of training. Human Kinetics Publishers.

Bondarchuk, A. (1986). Periodization of sports training. Legkaya Atletika, 12, 8-9.

Bottinelli, R., Pellegrino, M. A., Canepari, M., Rossi, R., & Reggiani, C. (1999). Specific contributions of various muscle fibre types to human muscle performance: an in vitro study. Journal of Electromyography and Kinesiology, 9(2), 87-95.

Channell, B. T., & Barfield, J. P. (2008). Effect of Olympic and traditional resistance training on vertical jump improvement in high school boys. The Journal of Strength & Conditioning Research, 22(5), 1522-1527.

Christou, M., Smilios, I., Sotiropoulos, K., Volaklis, K., Pilianidis, T., & Tokmakidis, S. P. (2006). Effects of resistance training on the physical capacities of adolescent soccer players. The Journal of Strength & Conditioning Research, 20(4), 783-791.

Cnaan, A., Laird, N. M., & Slasor, P. (1997). Tutorial in biostatistics: Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. Stat Med, 16, 2349-2380.

Colliander, E. B., & Tesch, P. A. (1990). Effects of eccentric and concentric muscle actions in resistance training. Acta physiologica scandinavica, 140(1), 31-39.

Cometti, G., Maffiuletti, N. A., Pousson, M., Chatard, J. C., & Maffulli, N. (2001). Isokinetic strength and anaerobic power of elite, subelite and amateur French soccer players. International journal of sports medicine, 22(01), 45-51.

Cormie, P., McBride, J. M., & McCaulley, G. O. (2007). Validation of power measurement techniques in dynamic lower body resistance exercises. Journal of Applied Biomechanics, 23(2), 103.

Cormie, P., McCAULLEY, G. O., & McBRIDE, J. M. (2007). Power versus strength-power jump squat training: influence on the load-power relationship. Medicine and science in sports and exercise, 39(6), 996.

Cormie, P., McCaulley, G. O., Triplett, N. T., & McBride, J. M. (2007). Optimal loading for maximal power output during lower-body resistance exercises. Medicine and science in sports and exercise, 39(2), 340.

Cormie, P., McGuigan, M. R., & Newton, R. U. (2011). Developing maximal neuromuscular power. Sports medicine, 41(1), 17-38.

Cotte, T., & Chatard, J. C. (2011). Isokinetic strength and sprint times in English premier league football players. Biology of Sport, 28(2), 89.

Cracraft, J. D., & Petajan, J. H. (1977). Effect of muscle training on the pattern of firing of single motor units. American Journal of Physical Medicine & Rehabilitation, 56(4), 183-194.

Croix, M. B. D. S., Deighan, M. A., & Armstrong, N. (2003). Assessment and interpretation of isokinetic muscle strength during growth and maturation. Sports Medicine, 33(10), 727-743.

Cronin, J. B., & Hansen, K. T. (2005). Strength and power predictors of sports speed. The Journal of Strength & Conditioning Research, 19(2), 349-357.

Cutsem, M., Duchateau, J., & Hainaut, K. (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. The Journal of physiology, 513(1), 295-305.

Dempster, W. & Gaughan, R. (1967). Properties of body segments based on size and weight. American Journal of Anatomy, 120, 33-54.

Drinkwater, E. J., Lawton, T. W., Lindsell, R. P., Pyne, D. B., Hunt, P. H., & McKenna, M. J. (2005). Training leading to repetition failure enhances bench press strength gains in elite junior athletes. The Journal of Strength & Conditioning Research, 19(2), 382-388.

Drust, B., Reilly, T., & Cable, N. T. (2000). Physiological responses to laboratory-based soccer-specific intermittent and continuous exercise. Journal of Sports Sciences, 18(11), 885-892.

Duchateau, J., & Hainaut, K. (1998). Changes in single motor unit behaviour contribute to the increase in contraction speed after dynamic training in humans. The Journal of physiology, 513(1), 295-305.

Duclay, J., Martin, A., Duclay, A., Cometti, G., & Pousson, M. (2009). Behavior of fascicles and the myotendinous junction of human medial gastrocnemius following eccentric strength training. Muscle & nerve, 39(6), 819-827.

Ekstrand, J., Hägglund, M., & Waldén, M. (2009). Injury incidence and injury patterns in professional football: the UEFA injury study. British journal of sports medicine, bjsports60582.

Enoka, R. M. (1995). Morphological features and activation patterns of motor units. Journal of Clinical Neurophysiology, 12(6), 538-559.

Erskine, R. M., Jones, D. A., Williams, A. G., Stewart, C. E., & Degens, H. (2010). Inter-individual variability in the adaptation of human muscle specific tension to progressive resistance training. European journal of applied physiology, 110(6), 1117-1125.

Erskine, R. M., Jones, D. A., Williams, A. G., Stewart, C. E., & Degens, H. (2010). Resistance training increases in vivo quadriceps femoris muscle specific tension in young men. Acta physiologica, 199(1), 83-89.

Faigenbaum, A. D., & Myer, G. D. (2012). Exercise deficit disorder in youth: play now or pay later. Current sports medicine reports, 11(4), 196-200.

Faude, O., Koch, T., & Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. Journal of sports sciences, 30(7), 625-631.

Fleck, S. J., & Kraemer, W. J. (1988). Resistance Training: Basic Principles (Part 1 of 4). Physician and sportsmedicine, 16(3).

Folland, J. P., & Williams, A. G. (2007). Morphological and neurological contributions to increased strength. Sports medicine, 37(2), 145-168.

Fry, A. C., Allemeier, C. A., & Staron, R. S. (1994). Correlation between percentage fiber type area and myosin heavy chain content in human skeletal muscle. European journal of applied physiology and occupational physiology, 68(3), 246-251.

Fry, A. C., Smith, J. C., & Schilling, B. K. (2003). Effect of knee position on hip and knee torques during the barbell squat. The Journal of Strength & Conditioning Research, 17(4), 629-633.

Fry, A. C. (2004). The role of resistance exercise intensity on muscle fibre adaptations. Sports medicine, 34(10), 663-679.

Gabriel, D. A., Kamen, G., & Frost, G. (2006). Neural adaptations to resistive exercise. Sports Medicine, 36(2), 133-149.

Galvao, D. A., & Taaffe, D. R. (2004). Single-vs. multiple-set resistance training: recent developments in the controversy. The Journal of Strength & Conditioning Research, 18(3), 660-667.

Gleeson, N. P., & Mercer, T. H. (1996). The utility of isokinetic dynamometry in the assessment of human muscle function. Sports Medicine, 21(1), 18-34.

González-Badillo, J. J., Gorostiaga, E. M., Arellano, R., & Izquierdo, M. (2005). Moderate resistance training volume produces more favorable strength gains than high or low volumes during a short-term training cycle. The Journal of Strength & Conditioning Research, 19(3), 689-697.

Gorostiaga, E. M., Izquierdo, M., Ruesta, M., Iribarren, J., Gonzalez-Badillo, J. J., & Ibanez, J. (2004). Strength training effects on physical performance and serum hormones in young soccer players. European Journal of Applied Physiology, 91(5-6), 698-707.

Haff, G. G., Hobbs, R. T., Haff, E. E., Sands, W. A., Pierce, K. C., & Stone, M. H. (2008). Cluster training: A novel method for introducing training program variation. Strength & Conditioning Journal, 30(1), 67-76.

Hägglund, M., Waldén, M., Magnusson, H., Kristenson, K., Bengtsson, H., & Ekstrand, J. (2013). Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study. British journal of sports medicine, 47(12), 738-742.

Hainaut, K., Duchateau, J., & Desmedt, J. E. (1981). Differential effects of slow and fast motor units of different programs of brief daily muscle training in man. New developments in electromyography and clinical neurophysiology, 241-249.

Häkkinen, K., Alen, M., & Komi, P. V. (1985). Changes in isometric force‐ and relaxation‐time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. Acta physiologica scandinavica, 125(4), 573-585.

Häkkinen, K., Komi, P. V., Alén, M., & Kauhanen, H. (1987). EMG, muscle fibre and force production characteristics during a 1 year training period in elite weight-lifters. European journal of applied physiology and occupational physiology, 56(4), 419-427.

Häkkinen, K., Newton, R. U., Gordon, S. E., McCormick, M., Volek, J. S., Nindl, B. C., ... & Humphries, B. J. (1998). Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 53(6), B415-B423.

Häkkinen, K., Kraemer, W. J., Newton, R. U., & Alen, M. (2001). Changes in electromyographic activity, muscle fibre and force production characteristics during heavy resistance/power strength training in middle ‐ aged and older men and women. Acta Physiologica Scandinavica, 171(1), 51-62.

Häkkinen, K., Alen, M., Kraemer, W. J., Gorostiaga, E., Izquierdo, M., Rusko, H., ... & Romu, S. (2003). Neuromuscular adaptations during concurrent strength and endurance training versus strength training. European journal of applied physiology, 89(1), 42-52.

Hammami, M. A., Ben Abderrahmane, A., Nebigh, A., Le Moal, E., Ben Ounis, O., Tabka, Z., & Zouhal, H. (2013). Effects of a soccer season on anthropometric characteristics and physical fitness in elite young soccer players. Journal of sports sciences, 31(6), 589-596.

Henderson, G., Barnes, C. A., & Portas, M. D. (2010). Factors associated with increased propensity for hamstring injury in English Premier League soccer players. Journal of Science and Medicine in Sport, 13(4), 397-402.

Henneman, E., Somjen, G., & Carpenter, D. O. (1965). Excitability and inhibitibility of motoneurons of different sizes. Journal of neurophysiology, 28(3), 599-620.

Hopkins, W. G., Hawley, J. A., & Burke, L. M. (1999). Design and analysis of research on sport performance enhancement. Medicine and science in sports and exercise, 31(3), 472-485.

Hopkins, W. G. (2000). Measures of reliability in sports medicine and science. Sports medicine, 30(1), 1-15.

Hopkins, W. G. (2004). Bias in Bland-Altman but not regression validity analyses. Sportscience, 8(4), 42-46.

Hori, N., Newton, R. U., Andrews, W. A., Kawamori, N., McGuigan, M. R., & Nosaka, K. (2008). Does performance of hang power clean differentiate performance of jumping, sprinting, and changing of direction?. The Journal of Strength & Conditioning Research, 22(2), 412-418.

Hrysomallis, C. (2009). Hip adductors' strength, flexibility, and injury risk. The Journal of Strength & Conditioning Research, 23(5), 1514-1517.

Huijing, P. A. (1985). Architecture of the human gastrocnemius muscle and some functional consequences. Cells Tissues Organs, 123(2), 101-107.

Impellizzeri, F. M., Bizzini, M., Rampinini, E., Cereda, F., & Maffiuletti, N. A. (2008). Reliability of isokinetic strength imbalance ratios measured using the Cybex NORM dynamometer. Clinical physiology and functional imaging, 28(2), 113-119.

Iossifidou, A., Baltzopoulos, V., & Giakas, G. (2005). Isokinetic knee extension and vertical jumping: are they related?. Journal of sports sciences, 23(10), 1121-1127.

Jeong, T. S., Reilly, T., Morton, J., Bae, S. W., & Drust, B. (2011). Quantification of the physiological loading of one week of “pre-season” and one week of “in-season” training in professional soccer players. Journal of sports sciences, 29(11), 1161-1166.

Kamen, G., & Knight, C. A. (2004). Training-related adaptations in motor unit discharge rate in young and older adults. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 59(12), 1334-1338.

Kawakami, Y. A. S. U. O., Abe, T. A. K. A. S. H. I., & Fukunaga, T. E. T. S. U. O. (1993). Muscle-fiber pennation angles are greater in hypertrophied than in normal muscles. Journal of Applied Physiology, 74(6), 2740-2744.

Kawakami, Y., Abe, T., Kanehisa, H., & Fukunaga, T. (2006). Human skeletal muscle size and architecture: variability and interdependence. American Journal of Human Biology, 18(6), 845-848.

Kesidis, N., Metaxas, T. I., Vrabas, I. S., Stefanidis, P., Vamvakoudis, E., Christoulas, K., ... & Mandroukas, K. (2008). Myosin heavy chain isoform distribution in single fibres of bodybuilders. European journal of applied physiology, 103(5), 579-583.

Killen, N. M., Gabbett, T. J., & Jenkins, D. G. (2010). Training loads and incidence of injury during the preseason in professional rugby league players. The Journal of Strength & Conditioning Research, 24(8), 2079-2084.

Knight, C. A., & Kamen, G. (2008). Relationships between voluntary activation and motor unit firing rate during maximal voluntary contractions in young and older adults. European journal of applied physiology, 103(6), 625-630.

Koundourakis, N. E., Androulakis, N., Spyridaki, E. C., Castanas, E., Malliaraki, N., Tsatsanis, C., & Margioris, A. N. (2014). Effect of different seasonal strength training protocols on circulating androgen levels and performance parameters in professional soccer players. Hormones, 13(1), 578-83.

Kraemer, W. J., Deschenes, M. R., & Fleck, S. J. (1988). Physiological adaptations to resistance exercise. Sports medicine, 6(4), 246-256.

Kraemer, W. J., & Newton, R. U. (2000). Training for muscular power. Physical medicine and rehabilitation clinics of North America, 11(2), 341-68.

Kraemer, W. J., Ratamess, N., Fry, A. C., Triplett-McBride, T., Koziris, L. P., Bauer, J. A., ... & Fleck, S. J. (2000). Influence of resistance training volume and periodization on physiological and performance adaptations in collegiate women tennis players. The American Journal of Sports Medicine, 28(5), 626-633.

Kraemer, W. J., & Ratamess, N. A. (2004). Fundamentals of resistance training: progression and exercise prescription. Medicine and science in sports and exercise, 36(4), 674-688.

Krieger, J. W. (2009). Single versus multiple sets of resistance exercise: a meta-regression. The Journal of Strength & Conditioning Research, 23(6), 1890-1901.

Lambert, M. I., & Borresen, J. (2010). Measuring training load in sports. Int J Sports Physiol Perform, 5(3), 406-411.

Los Arcos, A., Yanci, J., Mendiguchia, J., Salinero, J. J., Brughelli, M., & Castagna, C. (2014). Short-term training effects of vertically and horizontally oriented exercises on neuromuscular performance in professional soccer players. Int J Sports Physiol Perform, 9(3), 480-8.

MacIntosh, B. R., & Holash, R. J. (2000). Power output and force-velocity properties of muscle. Biomechanics and biology of movement. Champaign (IL): Human Kinetics, 193-210.

Malliaras, P., Hogan, A., Nawrocki, A., Crossley, K., & Schache, A. (2009). Hip flexibility and strength measures: reliability and association with athletic groin pain. British journal of sports medicine, 43(10), 739-744.

Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. The Journal of Strength & Conditioning Research, 18(3), 551-555.

Marshall, P. W., Cashman, A., & Cheema, B. S. (2011). A randomized controlled trial for the effect of passive stretching on measures of hamstring extensibility, passive stiffness, strength, and stretch tolerance. Journal of Science and Medicine in Sport, 14(6), 535-540.

Marx, J. O., Ratamess, N. A., Nindl, B. C., Gotshalk, L. A., Volek, J. S., Dohi, K. E. I. I. C. H. I. R. O., ... & Hakkinen, K. E. I. J. O. (2001). Low-volume circuit versus high-volume periodized resistance training in women. Medicine and science in sports and exercise, 33(4), 635-643.

Matveyev, L. P. (1981). Fundamentals of sports training. English translation of the revised Russian version. Moscow: Progress.

McBride, J. M., Triplett-McBride, T., Davie, A. J., Abernethy, P. J., & Newton, R. U. (2003). Characteristics of titin in strength and power athletes. European journal of applied physiology, 88(6), 553-557.

McBride, J. M., McCaulley, G. O., & Cormie, P. (2008). Influence of preactivity and eccentric muscle activity on concentric performance during vertical jumping. The Journal of Strength & Conditioning Research, 22(3), 750-757.

McBride, J. M., Blow, D., Kirby, T. J., Haines, T. L., Dayne, A. M., & Triplett, N. T. (2009). Relationship between maximal squat strength and five, ten, and forty yard sprint times. The Journal of Strength & Conditioning Research, 23(6), 1633-1636.

Mellor, R., & Hodges, P. (2005). Motor unit synchronization between medial and lateral vasti muscles. Clinical neurophysiology, 116(7), 1585-1595.

Menzel, H. J., Chagas, M. H., Szmuchrowski, L. A., Araujo, S. R., de Andrade, A. G., & de Jesus-Moraleida, F. R. (2013). Analysis of lower limb asymmetries by isokinetic and vertical jump tests in soccer players. The Journal of Strength & Conditioning Research, 27(5), 1370-1377.

Milner-Brown, H. S., & Stein, R. B. (1975). The relation between the surface electromyogram and muscular force. The Journal of physiology, 246(3), 549.

Mjølsnes, R., Arnason, A., Raastad, T., & Bahr, R. (2004). A 10 ‐ week randomized trial comparing eccentric vs. concentric hamstring strength training in well ‐ trained soccer players. Scandinavian journal of medicine & science in sports, 14(5), 311-317.

Mohr, M., Krustrup, P., & Bangsbo, J. (2003). Match performance of high-standard soccer players with special reference to development of fatigue. Journal of sports sciences, 21(7), 519-528.

Moritani, T. (1979). Neural factors versus hypertrophy in the time course of muscle strength gain. American Journal of Physical Medicine & Rehabilitation, 58(3), 115-130.

Murtagh, C., Nulty, C., Vanrenterghem, J., O'Boyle, A., Morgans, R., Drust, B., & Erskine, R. (2017). The Neuromuscular Determinants of Unilateral Jump Performance in Soccer Players are Direction-Specific. International journal of sports physiology and performance, 1-28.

Newman, M. A., Tarpenning, K. M., & Marino, F. E. (2004). Relationships between isokinetic knee strength, single-sprint performance, and repeated-sprint ability in football players. The Journal of Strength & Conditioning Research, 18(4), 867-872.

Núñez, V. M., Da Silva-Grigoletto, M. E., Castillo, E. F., Poblador, M. S., & Lancho, J. L. (2008). Effects of training exercises for the development of strength and endurance in soccer. The Journal of Strength & Conditioning Research, 22(2), 518-524.

Nuzzo, J. L., McBride, J. M., Cormie, P., & McCaulley, G. O. (2008). Relationship between countermovement jump performance and multijoint isometric and dynamic tests of strength. The Journal of Strength & Conditioning Research, 22(3), 699-707.

Paavolainen, L., Häkkinen, K., Hämäläinen, I., Nummela, A., & Rusko, H. (1999). Explosive-strength training improves 5-km running time by improving running economy and muscle power. Journal of applied physiology, 86(5), 1527-1533.

Patten, C., Kamen, G., & Rowland, D. M. (2001). Adaptations in maximal motor unit discharge rate to strength training in young and older adults. Muscle & nerve, 24(4), 542-550.

Peterson, M. D., Rhea, M. R., & Alvar, B. A. (2004). Maximizing strength development in athletes: a meta-analysis to determine the dose-response relationship. The Journal of Strength & Conditioning Research, 18(2), 377-382.

Peterson, M. D., Alvar, B. A., & Rhea, M. R. (2006). The contribution of maximal force production to explosive movement among young collegiate athletes. The Journal of Strength & Conditioning Research, 20(4), 867-873.

Petersen, J., Thorborg, K., Nielsen, M. B., Budtz-Jørgensen, E., & Hölmich, P. (2011). Preventive effect of eccentric training on acute hamstring injuries in men's soccer a cluster-randomized controlled trial. The American journal of sports medicine, 39(11), 2296-2303.

Phillips, L. H. (2000). Sports injury incidence. British Journal of Sports Medicine, 34(2), 133-136.

Potier, T. G., Alexander, C. M., & Seynnes, O. R. (2009). Effects of eccentric strength training on biceps femoris muscle architecture and knee joint range of movement. European journal of applied physiology, 105(6), 939-944.

Rampinini, E., Coutts, A. J., Castagna, C., Sassi, R., & Impellizzeri, F. M. (2007). Variation in top level soccer match performance. International journal of sports medicine, 28(12), 1018-1024.

Reeves, N. D., Maganaris, C. N., & Narici, M. V. (2003). Effect of strength training on human patella tendon mechanical properties of older individuals. The Journal of physiology, 548(3), 971-981.

Reeves, N. D., Maganaris, C. N., Longo, S., & Narici, M. V. (2009). Differential adaptations to eccentric versus conventional resistance training in older humans. Experimental physiology, 94(7), 825-833.

Reilly, T. (2003). Science and soccer. Routledge.

Rhea, M. R., Ball, S. D., Phillips, W. T., & Burkett, L. N. (2002). A comparison of linear and daily undulating periodized programs with equated volume and intensity for strength. The Journal of strength & conditioning research, 16(2), 250-255.

Rhea, M. R., & Alderman, B. L. (2004). A meta-analysis of periodized versus nonperiodized strength and power training programs. Research quarterly for exercise and sport, 75(4), 413-422.

Robinson, J. M., Stone, M. H., Johnson, R. L., Penland, C. M., Warren, B. J., & Lewis, R. D. (1995). Effects of Different Weight Training Exercise/Rest Intervals on Strength, Power, and High Intensity Exercise Endurance. The Journal of Strength & Conditioning Research, 9(4), 216-221.

Rønnestad, B. R., Egeland, W., Kvamme, N. H., Refsnes, P. E., Kadi, F., & Raastad, T. (2007). Dissimilar effects of one-and three-set strength training on strength and muscle mass gains in upper and lower body in untrained subjects. The Journal of Strength & Conditioning Research, 21(1), 157-163.

Ronnestad, B. R., Kvamme, N. H., Sunde, A., & Raastad, T. (2008). Short-term effects of strength and plyometric training on sprint and jump performance in professional soccer players. The Journal of Strength & Conditioning Research, 22(3), 773-780.

Rønnestad, B. R., Nygaard, H., & Raastad, T. (2011). Physiological elevation of endogenous hormones results in superior strength training adaptation. European journal of applied physiology, 111(9), 2249-2259.

Sanborn, K. I. M., O'BRYANT, H. S., Hartman, M., Stone, M. E., Proulx, C., ... & Hruby, J. (2003). Maximum strength-power-performance relationships in collegiate throwers. The Journal of Strength & Conditioning Research, 17(4), 739-745.

Sander, A., Keiner, M., Wirth, K., & Schmidtbleicher, D. (2013). Influence of a 2-year strength training programme on power performance in elite youth soccer players. European journal of sport science, 13(5), 445-451.

Santana, J. C. (2001). Hamstrings of Steel: Preventing the Pull, Part II--Training the" Triple Threat". Strength & Conditioning Journal, 23(1), 18.

Saplinskas, J. S., Chobotas, M. A., & Yashchaninas, I. I. (1980). The time of completed motor acts and impulse activity of single motor units according to the training level and sport specialization of tested persons. Electromyography and clinical neurophysiology, 20(6), 529.

Scanlan, S. F., Favre, J., & Andriacchi, T. P. (2013). The relationship between peak knee extension at heel-strike of walking and the location of thickest femoral cartilage in ACL reconstructed and healthy contralateral knees. Journal of biomechanics, 46(5), 849-854.

Semmler, J. G. (2002). Motor unit synchronization and neuromuscular performance. Exercise and sport sciences reviews, 30(1), 8-14.

Semmler, J. G., & Nordstrom, M. A. (1998). Motor unit discharge and force tremor in skill-and strength-trained individuals. Experimental Brain Research, 119(1), 27-38.

Seynnes, O. R., de Boer, M., & Narici, M. V. (2007). Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. Journal of Applied Physiology, 102(1), 368-373.

Silva, J. R., Nassis, G. P., & Rebelo, A. (2015). Strength training in soccer with a specific focus on highly trained players. Sports medicine-open, 1(1), 17.

Simoneau, J. A., & Bouchard, C. (1995). Genetic determinism of fiber type proportion in human skeletal muscle. The FASEB Journal, 9(11), 1091-1095.

Stølen, T., Chamari, K., Castagna, C., & Wisløff, U. (2005). Physiology of soccer. Sports medicine, 35(6), 501-536.

Stone, M. H., Fleck, S. J., Triplett, N. T., & Kraemer, W. J. (1991). Health-and performance-related potential of resistance training. Sports Medicine, 11(4), 210-231.

Stone, M. H., Sands, W. A., Carlock, J. O. N., Callan, S. A. M., Dickie, D. E. S., Daigle, K., ... & HARTMAN, M. (2004). The importance of isometric maximum strength and peak rate-of-force development in sprint cycling. The Journal of Strength & Conditioning Research, 18(4), 878-884.

Strudwick, A., & Doran, T. R. D. (2002). Anthropometric and fitness profiles of elite players in two football codes. Journal of sports medicine and physical fitness, 42(2), 239.

Suetta, C., Andersen, J. L., Dalgas, U., Berget, J., Koskinen, S., Aagaard, P., ... & Kjaer, M. (2008). Resistance training induces qualitative changes in muscle morphology, muscle architecture, and muscle function in elderly postoperative patients. Journal of applied physiology, 105(1), 180-186.

Tan, B. (1999). Manipulating Resistance Training Program Variables to Optimize Maximum Strength in Men: A Review. The Journal of Strength & Conditioning Research, 13(3), 289-304.

Tihanyi, J., Apor, P., & Fekete, G. Y. (1982). Force-velocity-power characteristics and fiber composition in human knee extensor muscles. European journal of applied physiology and occupational physiology, 48(3), 331-343.

Timmins, R. G., Shield, A. J., Williams, M. D., Lorenzen, C., & Opar, D. A. (2016). Architectural adaptations of muscle to training and injury: a narrative review outlining the contributions by fascicle length, pennation angle and muscle thickness. British journal of sports medicine, bjsports-2015.

Toigo, M., & Boutellier, U. (2006). New fundamental resistance exercise determinants of molecular and cellular muscle adaptations. European journal of applied physiology, 97(6), 643-663.

Tran, Q. T., Docherty, D., & Behm, D. (2006). The effects of varying time under tension and volume load on acute neuromuscular responses. European journal of applied physiology, 98(4), 402-410.

Tschakert, G., & Hofmann, P. (2013). High-intensity intermittent exercise: methodological and physiological aspects. Int J Sports Physiol Perform, 8(6), 600-10.

Verkhoshansky, Y. V. (1985). Programming and organization of the training process, publishing house “Physical culture and sport”.

Wakahara, T., Fukutani, A., Kawakami, Y., & Yanai, T. (2013). Nonuniform muscle hypertrophy: its relation to muscle activation in training session. Medicine and science in sports and exercise, 45(11), 2158-2165.

Waldén, M., Hägglund, M., & Ekstrand, J. (2005). UEFA Champions League study: a prospective study of injuries in professional football during the 2001–2002 season. British journal of sports medicine, 39(8), 542-546.

Wernbom, M., Augustsson, J., & Thomeé, R. (2007). The influence of frequency, intensity, volume and mode of strength training on whole muscle cross-sectional area in humans. Sports medicine, 37(3), 225-264.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., & Hoff, J. (2004). Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. British journal of sports medicine, 38(3), 285-288.

Zehr, E. P., & Sale, D. G. (1994). Ballistic movement: muscle activation and neuromuscular adaptation. Canadian Journal of applied physiology, 19(4), 363-378.