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The impact of a periodised strength and conditioning programme on performance in elite under 18 academy football players

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The Impact of a Periodised Strength and Conditioning Programme on Performance in Elite Under 18 Academy Football Players

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ABSTRACT

Strength and Conditioning is rapidly growing and considered an essential part of athletic preparation, with the principal aims of improving performance and reducing injury risk in athletic performers. The current study aimed to measure the effect of a periodised 26 week in-season gym based Strength and Conditioning programme on performance improvement and injury risk in elite senior academy (Under 17 and Under 18) football players.

6 elite male football academy players (age 17.4±0.1 years; height 175.3±6.6 cm; body mass 66.2±5.0 kg) participated in the 26 week in-season gym based programme. Athletes were tested pre, week 11 and post for anthropometric measures and strength (predicted 1RM) for back squat, bench press and prone row. Performance measures of countermovement jump, 5, 15 and 30m sprints and T-Test agility scores were recorded pre and post. Measures of performance transfer from gym based improvements to the performance measures were calculated to assess the link between gym based training and sports performance. Functional Movement Screen scores were assessed pre and post, and injuries were recorded throughout the intervention period along with individual athlete exposure to training and matches.

Meaningful change was observed for mass and LBM coupled with reduction in body fat %. Small effect sizes were observed in relation to height at all time points (d≤0.1). Large effect sizes were calculated from pre to post in squat (74.9%, d=1.84), bench press (82%, d=1.78 and prone row (80%, d=1.86). CMJ performance improved 14% pre to post (d=1.10). Moderate effect sizes were noted in relation to improvement in sprint times pre to post over 5m (d=0.61), 15m (d=0.60) and 30m (d=0.52). The ratio of performance transfer from the improvements in squat performance to performances measures was 0.19 (CMJ), 0.09

(PP), 0.24 (AP), 0.05 (5m sprint), 0.03 (15m sprint) and 0.01 (30m sprint). Mean total scores in the Functional Movement Screen increased from pre (13.8 ± 1.2) to post (17.5 ± 0.9, $P<0.05$, 17.6% increase) and a 30% reduction in asymmetries within the squad were reported. Injury rate was calculated at 0.94 per 1000 hours of training exposure, estimated at 6.1 per 1000 hours of match play exposure and 1.6 per 1000 hours of total exposure.

The current investigation demonstrated that the application of Strength and Conditioning training to elite academy football players produced improvements in Functional Movement Screen scores and reported low levels of injury incidence and severity and therefore may be protective against injury risk. Large gains in gym based performance were recorded across the playing group, transfer however was only observed in improvements in countermovement jump performance. The poor transfer rate to sprint based performance, may suggest transfer of strength increases to complex movement patterns may require additional mechanisms.

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1. Introduction

Strength and Conditioning (S&C) is still considered a relatively young profession although the delivery of S&C is rapidly growing (Dorgo, 2009). However it is considered an essential part of athletic preparation, development and injury prevention underpinning successful performance (Pullo, 1992). While this is the case and some sports have embraced S&C over a long period, for example Rugby Union, with all top flight clubs employing dedicated S&C professionals; however this is not the situation for football. Anecdotal evidence from sports scientists and fitness coaches currently operating in the elite level of football outline that numerous 'top flight' clubs neither employ or dedicate time to gym based athletic preparation. The reasons for this are numerous and include high sports specific training volumes, matches and management and coaches' education in sports science and the disciplines under that umbrella.

1.1 Role of the S&C Coach

The National Strength and Conditioning Association (NSCA) researched responses from a national survey of S&C coaches to define the role of a modern S&C professional and concluded the following:

'Certified Strength and Conditioning Specialists (CSCS) are professionals who apply scientific knowledge to train athletes for the primary goal of improving their athletic performance. They conduct sports-specific testing sessions, design and implement safe and effective strength training programmes, and providing guidance regarding nutrition and injury prevention. Recognising that their area of expertise is separate and distinct, CSCSs consult with and refer athletes to other professionals when appropriate'. (Baechle, 1997; Dooman *et al.*, 1998).

It would appear, therefore, that the role and expertise of the S&C coach is multifaceted. Coaches are required to have a broad knowledge of sports science disciplines including biomechanics, sport psychology, exercise physiology, nutrition, testing and measurement of athletes, research methods and human anatomy (Dooman *et al*., 1998; Garhammer, 1998; Martinez, 2004; Massey, 2010). The coaches' knowledge base must also include specific scientific principles relating to the sports science field of S&C itself. This knowledge base should include program design variables, including the short and long term planning of the overall training program (periodisation) but also the structuring and organisation of individual exercise sessions to achieve specific goals e.g. exercise selection, exercise order, modes of training, volume of training and the load, repetition and rest scheme (Dooman *et al*., 1998; Martinez, 2004; Massey, 2010). Underpinning the short term session planning the coach must possess a broad repertoire of resistance training techniques and exercises, including competition weightlifting movements, e.g. clean and jerk and the snatch, know the proper form and spotting practices of these techniques and be able to teach them in progression to allow competency to be gained by the athlete (Dorgo, 2009; Durrell *et al*., 2003; Garhammer, 1988; Martinez, 2004; Massey, 2010). In conjunction with the weights room exercise knowledge base, the coach must also possess other techniques of athletic development such as plyometrics training in order to develop athletic characteristics of explosiveness (increased rate of force development) and power, speed and agility and cardiovascular fitness (Dorgo, 2009; Garhammer, 1998). Further to this, with a major aim of the S&C programme being the reduction of injuries, (Dorgo, 2009; Durrell *et al*., 2003; Garhammer, 1988; Martinez, 2004; Massey, 2010; Pullo, 1992) the S&C professional must gain an insight into the intrinsic and extrinsic causes of injury, the aetiology of injury, specific sites of injury risk relating to the demands of the sport and the injury rates for athletes competing at that level of the particular sport. Once this information has been collated strategies must be implemented to minimise their impact on the performer. Finally the S&C professional must gain a good knowledge of the specific demands of the sport and the individual athlete(s) they are working with (Dooman *et al*., 1998; Dorgo, 2009).

It would therefore appear that by incorporating all the knowledge strands of the S&C coach, the fundamental aim of the S&C programme and the S&C coach is to enhance the athletic performance and reduce injury risk of the individual or teams they are working with in a sporting context. This will include the training of sports specific energy systems, strength, power, speed, agility, mass (where appropriate) and lean body mass (LBM) and injury prevention (Durrell *et al*., 2003; Kontor, 1989).

1.2 Physiological Demands of Football

Football is a 90 minute game, during which elite level performers cover approximately 10km – 12km in non continuous running (Stlølen *et al*., 2005). The predominant energy system for football is aerobic metabolism with approximately 90% of the game spent performing aerobically but there is also a significant contribution via the anaerobic energy systems for activities such as repeated sprints, turns, jumps and kicking. The overall intensity of the game is close to anaerobic threshold (Stlølen *et al*., 2005) and approximately 7 minutes of the game is spent above lactate threshold. Since football is characterised as having an intermittent high intensity activity pattern, in addition to a good aerobic capacity, the ability to generate high levels of strength and power is an important capability. Explosive movements are required frequently with maximal 2-3second sprints required every ninety seconds. It has been reported that 96% of the sprints are shorter that 30m and 49% of sprints are shorter than 10m (Stlølen *et al*., 2005). In addition to this, players perform approximately 50 turns a game, each requiring forceful muscular contractions (Withers *et al*., 1982) as well as jumping, tackling, turning, holding off defenders and kicking (Bangsbo *et al*., 1991; Stlølen *et al*., 2005).

1.3 Fundamentals of S&C

With fundamental goals of a gym based S&C programme, in addition to injury risk reduction, being increases in strength, power and rate of force production an understanding of the mechanisms of how performance in these areas is increased is required. Force of muscular contraction is influenced by factors such as speed of lengthening or shortening, eccentric contribution from the stretch shortening cycle, number of motor units active at the same time and cross sectional area of the muscle (Behm and Sale, 1993). Considering these factors it is known that two mechanisms are available for increasing strength; muscular hypertrophy or neural adaptations (maximum strength training) (Hoff and Helgerud, 2004). Neural influences dominate the early onset of training in novice athletes, primarily including a reduction in inhibition to muscle tension via the Gogli tendon organs and an increase in neural drive in agonist muscles enhancing muscle recruitment, rate of pattern or discharge and firing rate (Baechle and Earle, 2008), although these mechanisms still dominate adaptations to strength training when the focus is maximal strength gains (Hoff and Helgerud, 2004). Hypertrophic gains resulting from resistance training primarily are attributable to an increase in cross sectional area to existing muscle fibres through increased rates of synthesis and a reduction in degradation of actin and myosin in the myofibrils and an increase in the number of myofibrils (Baechle and Earle, 2008). Through an application of sets and repetitions, stress can be applied to the musculoskeletal system to drive adaptation to meet the necessary training goal. Figure 1.1 outlines the repetition ranges required to drive adaptations of strength, power, hypertrophy (Baechle and Earle, 2008). Loads lifted in the repetition ranges would be expected to be a maximum load capable to that range, 5 repetitions are expected to equate to approximately 85% of 1RM and 10 repetitions would equate to approximately 75% of 1RM (Baechle and Earle, 2008). This %1RM-reptition relationship however is not consistent when working with a power emphasis, with lower percentage of 1RM of approximately 50% for the desired repetition range being appropriate (Siff, 2004).

Figure 1.1: The repetition maximum continuum (* The repetition ranges shown for power are not consistent with %1RM – repetition relationship) (Baechle and Earle, 2008)

An application of sufficient sets to generate adaptation is also necessary, for strength training 2-6 sets, power 3-5 sets, hypertrophy 3-6 sets and muscular endurance 2-3 sets (Baechle and Earle, 2008).

1.3.1 S&C in Football

Strength and power are important to football performance (Hoff and Helgerud, 2004; Stolen *et al*., 2005), so it is no surprise that strength and power have strong relationships with performance measures. Therefore increasing the maximum force of contraction of lower limb muscles associated with movement patterns such as sprinting, players have been shown to produce increases in sports specific field test involving those patterns, such as turning, jumping, accelerating and changing pace (Bangsbo *et al*., 1991; Wisløff *et al*., 2004; Chelly *et al*., 2010). The introduction of general conditioning resistance training to young players would assist with improving muscle mass, enhance bone and muscle strength, improve muscular endurance, develop core stability and reduce the incidence of soft tissue injury (Young, 2006; Garcia- Pallares *et al*., 2009). Musculoskeletal adaptations of this kind allow athletes to withstand the recurring mechanical stress experienced throughout the training and competition phases of their sport and therefore improves performance and reduces injury risk (Heidt *et al*., 2000; Marshall, 2005; Gamble, 2006).

It is recognised that a combination of both training stimulus for maximising hypertrophy and maximum strength, for increasing overall strength profiles of an athlete are required. There are however considerations when applying these to football. Players may not wish to focus on hypertrophy training as it will incorporate an increase in body mass that will require transporting during match play (Hoff and Helgerud, 2004), and therefore have a impact on aerobic fitness parameters. Although in youth players or players specifically identified by their coaches, hypertrophy may be an essential part of their development (Stolen *et al*., 2005). Further to this, the type of training associated with hypertrophy is high volume (8-12 reps, 60-85% 1RM) and exhausts the trained muscle, it is therefore only really appropriate in the off-season or early pre-season phases of a periodised plan for football (Chadd, 2010). In contrast the training stimulus for maximal strength that encourages neural adaptations such as increasing firing frequency of the motor neuron, increased synchronisation of firing and increased motor unit recruitment has a lower training volume, with rep ranges of between 3-5 (85-95% 1RM), and can be used to maintain/increase strength gains within season.

Despite an increase in maximal strength, increasing relative strength and therefore subsequently power (Hoff, 2005), a decrease in speed of contraction through hypertrophy and heavy resistance training could result in reduction of force production at high velocities of the force-velocity curve (Hoff and Helgerud, 2004), however this would be more pronounced in hypertrophy training than maximal strength training. As rate of force development is also essential in team sports play, it is also important to develop this aspect of training with specific exercises of low weight but high velocity of movement power training (Turner, 2009). It would therefore seem reasonable that throughout a periodised strength and conditioning plan that training programmes focus on different areas on the force-velocity curve and that the low loads involved in maximal strength and power training lend itself more to in season demands.

Studies have been conducted investigating the implementation of resistance training based S&C in football (Helgerud *et al*., 2002; Hoff & Helgerud , 2002; Ronnestad *et al*., 2008; Chelly *et al*., 2009), however all of these studies have been conducted during pre-season and only over short time frames of 6-8 weeks.

1.3.2 Periodisation

The S&C coach must engage in both short and long term planning, this must incorporate daily and weekly training plans with the corresponding short-term requirement of the athlete but also they must develop longer term plans ranging from weeks to an entire year, or in some cases even longer (Massey, 2010). Periodisation is the practice of structuring training to achieve performance results and incorporates dividing the long term plan into training phases (macrocycles, mesocycles and microcycles) (Siff, 2004; Issurin, 2008). The practice of periodisation stems from Selye's General Adaptation Syndrome (GAS) (1974), in which it was hypothesised that systems will adapt to stress in order to meet the demands of the stressors, by optimising this principle of overload and recovery with structured training programmes the neuromuscular system can adapt to improve performance (Rhea *et al*., 2002). GAS is split into distinct phases that include the 'alarm phase' when the system is exposed to new stress, and may experience a reduction in performance. This is followed by a 'resistance phase', where which training adaptations can occur and through recovery can lead to higher level of performance termed 'supercompensation' (Bompa and Hoff, 2009; Issurin, 2010). Periodisation has been demonstrated to produce greater gains in strength and body mass than non periodised training programmes (Stowers *et* al., 1983; Willoughby, 1993; Baker *et al*., 1994; Kraemer, 1997). A macrocycle is the largest division of the training model, and will typically be a whole year, but could equally be a smaller block of a few months, a season, or a 4 year cycle as utilised in many Olympic sports. A macrocycle will consist of multiple mesocycles, normally lasting a few weeks but potentially having duration of a few months. Each mesocycle will incorporate a general goal for that training period, for example general preparation. The mesocycle will be divided in to multiple microcycles, usually one week in duration focussing on the weekly and daily training variations (Bompa and Carrera, 2005; Siff, 2004; Baechle and Earle, 2008; Issurin, 2008; Bompa and Haff, 2009). Integrating and planning training about the competition schedule of an athlete to consider volumes of sports specific training and rest periods in the correct combination or sequence can create optimal athletic development within a given sport (Plisk and Stone, 2003; Chadd, 2010). The original forms of periodisation postulated were developed around a 4 year Olympic cycle aiming for annual training peaks for 1 or 2 major competitions and the Olympic Games every 4 years and contained preparatory, competitive and transition phases (Chad, 2010) and the development of these models was highly influenced by a few specific sports (weightlifting, track and field and swimming) (Verkhoshansky, 2006). The use of classic periodisation models has been utilised in team sports particularly in off-season and pre-season training blocks, with the in-season training programmes then based around maintaining the increase in strength and power gained in the out of competition phases (Hoffman *et al*., 1991; Chad, 2010). Unlike the sports, however, used in the development of classic linear periodisation models many team sports, such as football, have extended seasons in excess of 35 weeks (Gamble, 2006), multiple matches within a week and multiple peaks required e.g. important league fixtures, tournaments and cup fixtures and classic linear models may not suitable to provide multiple peaks and/or maintain peak performances within a season (Issurin, 2008). The demands of the modern day competition calendar and the perceived limitations of the classic linear model have led to researchers to develop additional strategies of periodisation, these include the Daily Undulating Model (DUM) (Fleck and Kraemer, 2007), Conjugate Sequencing System (CSS) (Verkhoshansky, 2006) and Concurrent Training (CT) (Gamble, 2006). Issurin (2010) however suggested that due to the complex nature of some of these proposed models, a modified traditional model may be still applicable to junior players, novice strength and conditioning athletes and low level athletes.

The CSS is focussed on developing one training characteristic during the accumulation phase of a mesocycle, while simultaneously undergoing maintenance type volumes of work for at least one, if not more other training characteristics. During the restitution phase, volume is decreased for the principal target of the phase and moderately increased for the other characteristics being maintained (Plisk and Stone, 2003). This method has been shown to provide athletes with a potent training stress, Fry *et al*., (2000) monitored the endocrine system and noticed following a period of CSS training and a subsequent taper showed significant increases in testosterone concentration levels from pre-training levels. Testosterone can influence protein synthesis in the muscle as well as acting on the neuromuscular system by increasing the amounts of neurotransmitters, therefore influencing both structural and neural adaptations to increase strength (Baechle and Earle, 2008). It is worth noting however due to the high volumes and multiple sessions required in implementing such a system, it places the athletes at risk of overtraining syndrome (Turner, 2011), and it is only considered suitable for advanced athletes who have access to large amounts of training time (Chad, 2010) and highly skilled S&C practitioners (Turner, 2011).

DUM refers to pronounced variation in training volumes and intensity within a training week, targeting a different percentage of repetition maximum and therefore having a new training stress for each session, for example 3 sessions per week would have exercises performed at 4-6RM, 12-15RM and 8-10RM in each separate session with a load that would elicit failure in the final set (Chadd, 2010). Rhea *et al*. (2002) assessed a 12 week linear periodised programme against a 12 week DUM matched for training volume and intensity targeted at increasing muscular strength. DUM was shown to give significantly greater gains in squat (55.78% compared to 28.78%) and bench press (25.61% compared to 14.37%)

performance. There are however limitations to the implementation of this model, with the principal of adaptation, overreaching and supercompensation, there is a reliance on the principal of alarm and subsequent resistance or fatigue to that stressor, in order to achieve positive adaptation. If the aim of targeting training is to always avoid fatigued energy systems we may not maximise potential stimulus for training (Chadd, 2010). Further to this Rhea *et al*. (2003) further compared DUM to a linear model matched for training volume targeted at increasing muscular endurance. The investigation found no significant difference in improvement in performance, with muscular endurance increasing 55.9% coupled with a 9.1% increase in 1RM for the linear model and a 54.5% increase in muscular endurance coupled with a 9.8% increase in 1RM utilising DUM. It would therefore appear that different models of periodisation may be better suited to meeting different resistance training goals. In addition to this, monitoring and adapting training loads for multiple sets, across multiple rep ranges within one week and to reach failure in the final set within a given rep range, across a squad of players may be difficult to manage in a real world squad environment, with players regularly being required to readjust loads due to residual fatigue from other training session.

CT involves training of multiple characteristics during any one training period and is widely used in-season in team sports due to the physical demands of the sport requiring the use of multiple characteristics at one time (Tan, 1999; Chad, 2010). Care must however be taken when implementing concurrent training in-season, to match the training phase to the energy system training that predominates sports team training during the competition phase. For example, training for aerobic power will require adaptation to increase the muscle oxidative capacity but in turn can reduce muscle protein synthesis (Bell, 1997), which would have a negative impact on strength gains if that were being sought concurrently. The concurrent training of some variables of performance is highly matched, for example strength and power, as strength is a precursor to power (Turner, 2011). The implementation of concurrent training can sometimes give the appearance of linear periodisation due to blocks of training being targeted for periods of time, although multiple characteristics of performance are being targeted at the same time, and illustrate how models can be adapted and integrated to meet the needs of the athletes the coach is working with (Chad, 2011).

The variables that can be manipulated across each training phase and in all of the above periodisation models to maximise adaptation include the number of reps per set, number of sets, exercises prescribed, number of exercises in a given training session, rest periods between sets and the number of training sessions per day and per week (Fleck, 1999).

1.3.3 Monitoring Resistance Training Volume

When administering a periodised training plan the ability to quantify training loads and volumes is considered important. The S&C professional will modulate training volume in order to manipulate training stressors and drive adaptation (Haff, 2010). One key aspect of monitoring athletic training demands is to estimate the amount of work the athlete undertakes during the resistance training component of their training plan (McBride *et al.*, 2009a). There is however currently no standard model for determining training volume within the literature and this is attributed to the complex variables that make up resistance training programmes (McBride *et al.*, 2009a).

Various methods have been proposed to determine training volume; Volume Load (VL) (VL (kg) = number of sets x number of repetitions x weight lifted (kg)) (Stone *et al.*, 1999; Bompa and Carrera, 2005; Haff, 2010), Maximum Dynamic Strength Volume Load (MDSVL) method (repetitions [no.] x [body - shank mass (kg) + external load (kg)]) (Peterson *et al*., 2010), Time Under Tension (TUT) (calculated from monitoring the time to perform the eccentric and concentric portions of and exercise) (Tran *et al*., 2006) and Total Work (TW) (TW (Nm) = Force (N) x displacement (m)) (McBride *et al*., 2002; Cormie *et al*., 2007; Haff, 2010). All of the methods outlined above have benefits and limitations associated with them and give different outputs for the amount of volume lifted. McBride et al. (2009a) assessed all 4 protocols across 3 specific training goals (hypertrophy, strength and power). The investigation utilised manipulation of reps, set and loads to target the specific training parameters required, however matched total training volume. Significant differences were shown between the calculated training volumes for hypertrophy, strength and power except when using TW method of calculating training volume, and concluded this would be the most valid determination of training volume. This view is echoed by other research (Garhammer, 1993; Cormie *et al*., 2007; Sato *et al*., 2009) however it is also accepted that due to the complex nature and cost of equipment, and increased time component required to monitor the displacement of the bar, that when delivering applied S&C it is implausible in a real world setting (McBride *et al*., 2009a; Haff, 2010). Rudimentary methods have been proposed to allow for the determination of displacement including estimation using tape measures, while this may seem acceptable for controlled compound movements such as bench press, research has illustrated that in power exercises such as a clean pull significant variation exists in displacement of the bar between repetitions of a set and therefore lead to inaccuracies in the training load calculated (Haff *et al*., 2003). Advancements in easy use accelerometers however mean this will become a realistic proposition in the future (McBride *et al*., 2009a; Sato *et al*., 2009; Haff, 2010). TUT and MDSVL are similarly not widely used in applied S&C by coaches due to equipment required and time consuming nature of their collection, TUT is also limited as it does not take in to account body mass displacement of the barbell, the external load or the actual force produced (McBride *et al*., 2009a). The measurement of VL, despite its limitations, is more widely used in the preparation of athletic populations (Stone *et al*., 1999; Rhea *et al*., 2002; Rhea *et al*., 2003; Stone *et al*., 2006; Haff, 2010), due to its simplicity in nature of collection and calculation (McBride et al., 2009a). McBride et al. (2009a) also concluded that the VL method resulted in reasonable estimate of work. Two main equations are proposed when quantifying VL one which utilises the absolute load lifted (VL (kg) = number of sets x number of repetitions x weight lifted (kg)) (Stone *et al*., 1999; Bompa and Carrera, 2005; Haff, 2010), and one which utilised the percentage of 1 RM the athlete is working at (Volume load (kg) = number of sets x number of repetitions x (1RM x %1RM)) (Bompa and Haff, 2009; Haff, 2010). While both of these equations are considered adequate in the calculation of VL, Haff (2010) recommends the use of the equation utilising %1RM in the planning process of programme design, and the calculation based on absolute load in the monitoring stages of the training programme. While utilising the %1RM method allows the S&C coach to predict and manipulate the VL based on the athlete's strength performance across those exercises, during the training period it does not take in to account the actual load lifted by the athlete, fatigue, progression and limited opportunities to reassess the athletes 1RM (progression by utilising rep ranges) can alter the total work done by the athlete and it is therefore considered vital that the actual load lifted is included in the VL equation (Tan, 1999; Haff, 2010).

In addition to the VL, some authors have reported the use of Volume Index (VI) (VI = Volume Load (kg)/Body Mass (kg)) as VL does not account for the athlete's body size (Haff, 2010).

The calculation of the VI will allow for easy comparison on progression between players within a squad and a more true representation of the work done in relation to the individual. Despite the potential limitations of calculating training load using this method training programmes should report the VL estimate as it is still a better illustration than only reporting the number of repetitions performed (Haff, 2010).

1.4 Testing Football Players

Despite aerobic fitness playing a large contribution to football performance (Stløen *et al*., 2005), due to the nature of the intervention in this study, no aerobic tests will be considered in the following review of testing procedures, which will focus mainly on strength and power measures and performance measures that reflect those characteristics in a field based environment.

1.4.1 Maximal Strength Testing (1RM)

Maximal strength is defined as the maximum force produced by the neuromuscular system during a maximal voluntary muscular contraction (Stløen *et al*., 2005). Methods for measuring maximal strength include the use of isokinetic testing (Leatt *et al*., 1987; Davis *et al*., 1992; Rahnama *et al.,* 2003; Croisier *et al.,* 2008; Greig, 2008) and free weight tests for example bench press and half squat tests (Wisløff *et al*., 1998; Wisløff *et al*., 2004).

Isokinetic tests do not reflect the movement patterns of the limbs involved during football as no natural movement is isokinetic (Stløen *et al*., 2005) and therefore these tests have limited value when predicting performance in dynamic sports (Hoff and Helgerud, 2004). The use of free weights through standardised movement patterns such as the squat will more accurately reflect the functional strength of the athlete (Wisløff *et al*., 1998; Hoff and

Helgerud, 2004). In addition to this, free weights are more readily available to sports teams than expensive isokinetic dynamometers (Stlølen *et al*., 2005). It is worth when examining 1RM testing scores for half squat the methods used, some practitioners have used a Smith machine, (McBride *et al*., 2002; Moore *et al*., 2005; Requena *et al*., 2009; Gonzalez-Rave *et al*., 2011) for additional safety. The Smith machine consists of a barbell that is fixed within steel rails, allowing only vertical movement. It is therefore likely that the Smith machine will not give a true functional measure of strength due to stabilisation and path of the bar is undertaken by the cage of the device (Cotterman *et al*., 2005). The use of free weights to determine measures of maximal strength however does present a greater risk of injury to players than use of isokinetic dynamometers where the tested muscle is isolated (Chapman *et al*., 1998; Svensson and Drust, 2005). In light of this many practitioners use multiple repetition maximum testing and prediction equations to evaluate 1RM to reduce injury risk (Baechle and Earle, 2008).

Various factors require considering when implementing multiple repetition maximum testing protocols as excessive warm up and testing sets may fatigue the athlete and affect the accuracy of the test (Baechle and Earle, 2008). Research has also highlighted that the closer to 1 repetition the athlete performs the test the more accurate the test will be with 10 repetitions seeming to be the uppermost limit for accuracy of testing using predictions equations (Brzycki, 1993; LeSuer *et al*., 1997; Chapman *et al*., 1998; Baechle and Earle, 2008). LeSeur *et al*. (1997) examined the accuracy of seven prediction equations in evaluating 1RM from multiple repetition testing in squat and bench press exercises and concluded that 1RM could be successfully predicted from lower than 10 reps to failure. In addition to this it was noted that Brzycki's prediction equation (Brzycki, 1993) predicted

1RM within 0.05% in a squat exercise. This study was however conducted in a group of untrained college students enrolled in a recreational weightlifting group and not elite level athletes.

Squat strength values for adult professional football players have been reported between 115-209kg for half squat (Hoff and Helgerud, 2002; White *et al*., 1988; Wisløff *et al*., 1998; Ronnestad *et al*., 2008) with elite youth team values observed at 105-142kg (MacMillan *et al*., 2005; Chelly *et al*., 2009).

1.4.2 Lower Body Power

Power is the production of as much force as possible in a given time and is heavily dependent on maximal strength (Stlølen *et al*., 2005). Improvements in maximal strength, improve relative strength and therefore in turn improve power (Verkoshansky, 2006). Lower body power production should ideally be measured using a force plate (Harmann *et al*., 1991) however as this equipment is not readily available, many practitioners use countermovement jump (CMJ) height to establish lower body power in athletic populations (Leatt *et al*., 1987; White *et al*., 1988; Garganta *et al*., 1992; Wisløff *et al*., 1998; Casajus, 2001; Hoff and Helgerud, 2002; MacMillan *et al*., 2005; Silvestre *et al*., 2006). When measuring lower body jump performance, it is common for practitioners to report jump height in (cm), however due to the impact of body mass on jump performance calculation of power output should also be included in the analysis of jump performance to measure lower body power utilising a suitable prediction equation (Harmann *et al*., 1991). Harmann *et al*. (1991) proposed a prediction equation for Peak Power (PP) and Average Power (AP) outputs during a CMJ, that predicted power output within 1% of those measured on a force plate in professional rugby league players (Cronin and Hansen, 2005).

CMJ performance has been noted in professional senior players between 34-63cm (White *et al*., 1988; Wisløff *et al*., 1998; Reilly *et al*., 2000; Casajus, 2001; Hoff and Helgerud, 2002; Strudwick *et al*., 2002; Silvestre *et al*., 2006; Ronnestad *et al*., 2008; Sporis *et al*., 2009) and between 34 -54cm in elite youth players (Leatt *et al*., 1987; Garganta *et al*., 1992; MacMillan *et al*., 2005; Chelly *et al*., 2009; Buchheit *et al*., 2010).

1.4.3 Sprint Performance

Speed is a very important component of football performance (Svensson and Drust, 2005). 96% of the sprints are shorter that 30m and 49% of sprints are shorter than 10m (Stlølen *et al*., 2005). Testing sprint capacity of football players should, therefore, involve distances of no more than 30m (Strudwick *et al*., 2002). Split times have been observed for 5m (Reilly *et al*., 2000), 10m (Reilly *et al*., 2000; Strudwick *et al*., 2002) and 15m (Reilly *et al*., 2000) in various studies.

Due to the nature of the activity directly relating to football performance, tests over the above distances have been demonstrated to have high levels of face validity, reliability and reproducibility (Mirkov *et al*., 2008). Where possible for reproducibility and accuracy of measurements photoelectric timing gates should be utilised (Stlølen et al., 2005; Svensson and Drust, 2005).

Sprint timings of 1.04-1.44s for 5m (Reilly *et al*., 2000; Sporis *et al*., 2009), between 1.75-2.44s for 10m (Reilly *et al*., 2000; Strudwick *et al*., 2002; Ronnestad *et al*., 2008; Sporis *et al*., 2009), 3.67s for 15m (Reilly *et al*., 2000) and 4.26-4.31s for 30m (Reilly *et al*., 2000; Strudwick *et al*., 2002; Taskin *et al*., 2008) have been observed in elite professional males and 1.92-1.96s for 10m and 4.57-4.70s for 30m in elite U15 males (Buchheit *et al*., 2010).

1.4.4 Agility Testing

Agility is defined as the ability to change to direction of the body rapidly, and combines strength, speed, balance and coordination (Svensson and Drust, 2005), and is therefore highly relevant to football performance. Agility has been suggested to be the best indicator of performance for football and has potential to provide the clearest differentiation between non-elite and elite players (Svensson and Drust, 2005) The application of an appropriate agility test can be dictated by the coach's desired outcome from the test or performance enhancement that has gone in to developing the test. It has therefore been proposed that some tests correlate with better with certain aspects of performance than others. For example the Illinois agility test has been illustrated to correlate well with velocity, whereas the 505 test correlates better with acceleration. The T-Test has been a valid predictor of agility performance with high reliability scores (Pauole *et al*., 2000) and it is a well accepted test of agility being simple to administer and requires minimal equipment and preparation (Sassi *et al*., 2009).

T-Test scores have been noted 9.21-12.8s for adult male athletes (Miller *et al*., 2006), however the author could find no published data for football players.

1.5 Performance Transfer

With the implementation of resistance training gym based exercise becoming increasingly utilised to develop strength and power for sports performance, the ability to maximise transfer of strength and power gains in the gym to performance gains in the field of play is considered a principal factor in a S&C programme (Young, 2006). Young (2006) proposed that transfer could be expressed as gain in performance/gain in trained exercise. Considering the significant relationships that have been shown between squat 1RM performance, jump and sprint tests in senior (Wisløff *et al*., 2004) and junior players (Chelly *et al*., 2010), and the high level of lower body involvement in the activities associated with football performance (Bangsbo *et al*., 1991; Stlølen *et al*., 2005), it would be relevant to associate the level of performance gains in sports specific tests to improvements in measures of lower limb function such as squat 1RM to ascertain the performance transfer.

1.5.1 Performance Transfer in Football

Training intervention studies in football have illustrated improvements in sprint performance over a number of distances and improvements in CMJ performance (Hoff and Helgerud, 2002; Helgerud *et al*., 2002; Ronnestad *et al*., 2008; Chelly *et al*., 2009) , following training protocols designed to improve lower leg strength and subsequently squat 1RM performance (see Table 1.1). Julien *et al*. (2008) observed improvements in agility performance after a 3 week strength training programme, although the magnitude of these changes was not clear.

Table 1.1: Percentage increase in performance of gym based squat measures and subsequent performance transfer measures in football related studies

			Performance Increase					
Author	**Subject Group**	**Training Duration**	**Squat 1RM**	**CMJ**	**5m Sprint**	**10m Sprint**	**20m Sprint**	**40m Sprint**
Helgerud *et al*. (2002)	Professional	8 weeks	34%	5%	-	3%	2%	-
Hoff & Helgerud (2002)	Professional	8 weeks	25%	-	-	5%	-	-
Ronnestad *et al*. (2008)	Professional	7 weeks	21%	5%	-	2%	-	1%
Chelly *et al*. (2009)	17 year old sub-elite	8 weeks	26%	7%	6%*	-	-	-

*Improvement in velocity (m/s). All other sprint values are improvements in performance time.

It is clear from the above that the application of gym based strength training aimed at improving 1RM performance in the squat, does transfer to performance measures, however the percentage of transfer is considerably less than gains seen in a gym based environment. It is also clear that the magnitude of transfer is greater in jump performance than sprint performance (Young, 2006). The superior rate of transfer from squat based performance to CMJ than sprint measures is to be expected. In strength training studies, it has been shown that increases in strength are dependent on the similarities between the training and testing exercise, due to the specificity of neuromuscular learning and coordination and reaction to speed of contraction stimulus (Almasbakk and Hoff, 1996; Stløen *et al*., 2005). CMJ directly incorporates movement patterns associated with the performance of a squat, high levels of specificity are therefore present therefore superior levels of transfer are subsequently observed in this test of performance. Sprinting performance however is a complex movement pattern involving unilateral contraction of hip flexors to propel motion (Young, 2006) and therefore the transfer of squat performance lacks specificity to the performance measure and reduced transfer rates are observed.

The S&C training age of study participants should also be examined when ascertaining the performance transfer ratio. The largest improvements to sprint and CMJ performance seen above (Chelly et al., 2009), subjects had no previous experience of S&C training and therefore as outlined earlier, general strength training may transfer better to performance than if undertaken in advanced athletes who may require greater specificity of training (Young, 2006). In addition to this the studies illustrated above were all undertaken in off or pre-season training periods, and the effect of competition schedule on performance transfer may have an impact on the magnitude of performance gain seen. Therefore although conditioning should provide a sound basis from which to develop more activity specific conditioning the extent to which it may transfer to aspects of performance, such as sprinting, in young talented football players is worthy of investigation, particularly during in-season where the demands of soccer performance could inhibit adaptation suited to increases of strength and power.

1.6 In-Season Variation in Performance Measures

When assessing the effectiveness of a strength and condition programme over an extended period during in-season, research based evidence in to the effects of prolonged competitive exposure has on performance variables may be required when interpreting results. Ispirlidis *et al*. (2008) demonstrated that it took between 96 to 120 hours (4 to 5 days) of rest, post match, to normalise blood markers of muscle damage (creatine kinase) and inflammation (uric acid) and to achieve pre-match values for maximal strength and 20m sprint performance, similar findings have also been reported for vertical jump performance (Andersson *et al*., 2008). It is therefore clear from current elite level training and playing demands that this rest period is rarely achieved. Consequently, if players are involved in multiple matches and daily training sessions throughout a week, it could be expected to reduce match-related physical performance, represented by distance covered, high-intensity work, sprint distance, and number of sprints during the second match (Dupont *et al*., 2010). Subsequently over a whole season one would anticipate reductions in performance measures such as sprint times and vertical jump performance due to fatigue (Ekstrand *et al*., 2004). Ekstrand *et al*. (2004) highlighted that 60% of the players who competed in more than 1 match per week prior to the commencement of the 2002 World Cup incurred injuries or underperformed. Dupont *et al*. (2010) assessed 32 elite professional players over 52 matches and noted no significant reduction in performance measures listed above betweens matches with a recovery time period of between 72 to 96 hours. While this may seem to contradict the earlier studies there may be multiple factors influencing the data in this study. As professional level footballers, there is likely to be an investment of time in the management of the recovery process through additional treatments, such a massage, pool recovery sessions and cold water emersion (Reilly and Ekblom, 2005), in addition to this tempo of the match, tactics, number of sprints and level of work have been illustrated to be affected by the current score line of the match in progress and therefore may not be a sufficient objective marker to determine fatigue within a playing group (Stlølen *et al*., 2005).

Further to this, gym based improvements gained in a pre-season training phase have been shown to diminish within season while performing maintenance loads of resistance training (Dos Remedios *et al*., 1995; Fleck and Kraemer, 1997; Schneider et al., 1998; Legg and Burnham, 1999; Baker, 2001). Pre-season strength gains have been illustrated to be maintained between 13-16 weeks of in-season performance (Dos Remedios *et al*., 1995; Fleck and Kraemer, 1997; Schneider et al., 1998; Baker, 2001), however Legg and Burnham (1999) observed reductions in strength of up to 25% over 10 weeks of competition.

Despite the range of results, which may be due to the variation in maintenance training prescribed in the studies, it is clear that even the longest period of maintenance illustrated above only covers half the normal team sports competitive season (Chadd, 2010). The literature therefore appears to suggest that over the in-season period measures of performance decrease, and require maintenance strategies to maintain them. Mechanisms proposed for this reduction in strength and power include reductions in muscle mass through the decrease in resistance training volume and increased volume of energy system training experienced through match practice and match play (Chadd, 2010). It would be reasonable to suggest that as sprint performance and jump height performance are closely linked to leg strength and power (Wisløff *et al*., 2004; Chelly *et al*., 2010), that actions that reduce strength and power outputs will equally adversely affect the outputs in a game situation or performance tests related to such aspects of game performance.

In light of the above a limited number of studies have looked at the effect of a whole seasons' performance on measures such as sprint times, jump performance, power output, body composition and aerobic fitness (Thomas and Reilly, 1979; Casajus, 2001; Ostojic, 2003; Kraemer *et al*., 2004, Silvestre *et al*., 2006; Cladwell and Peters, 2009; Magal *et al*., 2009; Carling and Orhant, 2010). The results presented in these studies paint an uncertain view of the effect of a competitive performance on performance measures and body composition.

Body composition may also change in season and this could affect performance tests. Casajus (2001), noted a significant decrease in the body fat % coupled with no change in body mass in professional players from Spanish La Liga and similar results were observed in studies involving elite professional players (Ostojic, 2003) and semi professional players (Cladwell and Peters, 2009). In contrast to this however various studies have reported no significant change in body fat % over the course of a season in National Collegiate Athletic Association (NCAA) Division I soccer players (Kraemer *et al*., 2004; Silvestre *et al*., 2006) and NCAA Division III players (Magal *et al*., 2009). Carling and Orhant (2010) reported a decrease in body fat % from pre-season to mid-season and an increase in body fat % from mid-season to post season tests in French Division I players. There may be a number of reasons why the picture is unclear, however a principal one may be the lack of integration or clarity within the analysis of data with regard to the amount of playing time subjects within the study have been exposed to. Only one study (Kraemer et al., 2004) analysed the subjects between starters and non starters and found body fat % showed no significant increase in starters but a significant increase in non starters over the course of a season. This is likely to have an impact on results presented, Magal *et al*. (2010) had a subject group of 12 players, it is therefore unlikely that all these players consistently played and trained throughout the whole season in what would be an estimated squad of 17 players.

The data presented with regard to performance measures such as sprint times and vertical jump performance is also unclear. No significant changes have been reported post season in jump test performance (Thomas and Reilly, 1979; Casajus, 2001; Silvestre *et al*., 2006; Cladwell and Peters, 2009) or sprint performance (Silvestre *et al*., 2006). Kraemer *et al*. (2004) reported significant reductions in vertical jump performance and 20 yard sprint time however, no significant reduction in 40 yard sprint time. Similarly Cladwell and Peters (2009) observed significant reduction in 15m sprint performance over the course of a season in some studies. Conversely however improvements in sprint performance were also reported over the course of a season. Magal *et al*., (2010) reported significantly improved 10m and 30m sprint times, however with no change in 40m sprints times, while Ostojic (2003) tested 50m sprint times and observed significantly improved times. In interpreting the patterns of results the evidence is unclear as to the effects of whole season competition schedule on performance measures, however, further analysis may illustrate reasons for differences. Of the two main studies that illustrated no changes in performance in both sprints and vertical jump, one highlighted an extensive S&C programme (Silvestre et al., 2006), while the further study illustrated increases LBM across the period indicating that some form of resistance training may have been present (Casajus, 2001). Despite Magal *et al*. (2009) showing improvements in short distance sprint performance, it is acknowledged that NCAA Division III is a lower level of playing standard for football, the players would have limited access to S&C and general conditioning and that speed improvements may be a function of low level fitness at end of pre-season (Casajus, 2001; Magal *et al*., 2009).

It would therefore seem apparent that the main aim of an S&C programme would be to maintain pre-season levels of performance throughout the season, with performance gains being a secondary priority due to the difficulty of programming for strength and power within a sustained period that has potential to be catabolic in nature.

1.7 Football Injury

As injury reduction is considered one of the major priorities in the introduction of an S&C programme to athletic populations, an injury audit process is considered relevant in the design and monitoring of such programmes. The injury audit can be considered a 4 stage process involving 1) the acquisition of data concerning the nature, extent, and severity of sports injuries, 2) understanding the risk factors associated involved in the injuries within that sport, 3) designing and implementing an intervention to impact on injury rates and 4) re-assess the rate, extent and severity of injuries to measure the effectiveness of the intervention and complete the cycle (Backx *et al*., 1991; Hägglund *et al*., 2005; Hawkins *et al*., 2001; Price *et al*., 2004).

Injury rates have been illustrated to have significant differences between male and female football (Inklaar, 1994; Schmidt-Olsen *et al*,. 1985; Junge *et al*., 2004a; Wong and Hong,

2005) and indoor (Futsal) (Junge and Dvorak, 2010) and outdoor football (Keller *et al.,* 1987). It is, therefore, the intention for the remainder of this literature review to only focus on outdoor football played by male participants.

Football has been shown to have high level of injury rates when compared to other participant sports (Hawkins and Fuller, 1998; 1999), and in Sweden football was identified as the 4th most likely of 17 sports to report an injury incident by visiting a physician (De Loes, 1988). In addition to this when compared to high risk industrial activities the overall risk was approximately 1000 times higher for professional football players (Hawkins *et al*., 2001; Hägglund *et al*., 2005). In light of the high injury rates seen in football, governing bodies for football such as FIFA (Federation of International Football Associations) and UEFA (Union of European Football Associations) (Hägglund *et al*., 2005, Ekstrand et al., 2011a) and National football associations (Hawkins *et al*., 2001) have expressed their concern about the load placed on a professional footballer and the translation of these loads into injuries. It has further been argued that under Health and Safety legislation the clubs as employers of players, have an obligation to reduce the injury risk where possible for players (Hawkins and Fuller, 1998; 1999). During two seasons (2003-2005) individual absences at an English division one soccer club from either training or a competitive game were documented on a comprehensive daily register (Parry and Drust, 2006). An absence was defined as the unavailability to train or play in a competitive game irrespective of reason. Reportable injuries accounted for 49% of first team match unavailability and 60% of training sessions missed indicating that the single biggest factor for a soccer player's absence is a soccer-related injury (Parry and Drust, 2006). This level of absence due to player injury has been shown to have a high level of financial implications for the clubs involved (Woods *et al*., 2002; Price *et al*., 2004). The projected financial loss due to injury for the 1999-2000 season was £74.7 million, as approximately 10% of a playing squad was unavailable for training each week due to injury (Hawkins et al., 2001). Further to the direct financial loss of paying players wages who were unavailable to 'work', additional costs would be incurred in the form of medical fees and increased insurance premiums (Woods *et al*., 2002). It could also be argued that poor league positions and poor cup runs due to absence of first choice players can attribute to the cost with lower gates figures, and reduced prize money (Woods et al., 2002).

In relation to academy football the cost is probably better considered from the point of view of athletic development (Price *et al*., 2004). For players to reach their athletic potential it is estimated to take 10 years or 10,000 hours of practice time (Ericsson *et al*., 1994), with players missing approximately 6% of the season through injury it is difficult to envisage them achieving the levels of practice required for expert skill acquisition (Price *et al*., 2004).

1.7.1 Defining and Monitoring of Injury

In order to understand and review the data relating to injury it is imperative that an understanding is gained of the methods and definitions utilised in the study of injury. One of the major criticisms of the epidemiological study of football injury is the inconsistencies between literature in defining injury and the various facets within and injury such as severity, exposure, training and reinjury and the methods and timeframe of collection within these definitions (Junge and Dvorak, 2000, Morgan *et al*., 2001; Junge *et al*., 2004b, Hägglund *et al*., 2005; Wong and Hong, 2005; Junge et al., 2006).

Within the literature there are multiple definitions of what is constituted an 'injury'. During any investigation into the incidence of injuries, the first step must be to define the term ‘injury’. Examining the literature relating to football it is clear that there is no agreement, even to the extent of whether the injury has to be sustained while the player is directly involved in football (Hägglund *et al*., 2005). Within some studies, only injuries for which an insurance claim was submitted have been recorded (Pritchett, 1981; De Loes, 1995), but in others the definition is limited to injuries in which the players received medical treatment at a hospital casualty department (Nilsson *et al*., 1978), this is classed as a ‘medical attention’ definition (Hägglund *et al*., 2005). If studies into sports injuries are undertaken using data collected through insurance files and medical attention reports, a large percentage of less serious or overuse injuries will be missed during the data collections and skew the data towards serious, predominately acute injuries (Junge and Dvorak, 2000; Hägglund *et al*., 2005). A ‘time-loss’ definition of injury has become more widely used in the most recent studies, however even with this shift in definition there is still large amount of inconsistency within this definition. Broadly defined a time-loss injury takes a player away from participation in training or competition within their sport, however within this definition a player was defined as injured if he was unable to participate in the next or at least one training session or game (Nielsen and Yde, 1989; Hawkins and Fuller, 1999; Walden *et al*., 2005; Hägglund *et al*., 2009; Dupont *et al*., 2010); missing training or matches for 24 hours following the injury occurrence (Drawer and Fuller, 2002; Froholdt *et al*., 2009), 48 hours following the injury occurrence (Hawkins *et al*., 2001; Price *et al*., 2004; Le Gall *et al*., 2006) or one week after the incident (Junge *et al*., 2000). The use of such definitions also has limitations; a player who trains daily has less chance of recovering before the next training session than does a player with training sessions twice a week, an injured player might participate in the training sessions or match play with substandard performance due to high importance of the match or pressure on selection (Junge and Dvorak, 2000). Finally studies have used the definition of any injury sustained during a football match or training session irrespective of any medical attention or time-loss (Junge *et* al., 2004a; Dvorak *et al*., 2007; Junge *et al*., 2009; Dvorak et al., 2011).

When using a time-loss definition of injury it is also necessary to define the severity of the injury and this is generally ranked according to the number of days away from full sport participation (Ekstrand and Gillquist, 1983b; Nielsen and Yde, 1989; Hawkins and Fuller, 1999; Hawkins *et al*., 2001). Full sport participation meant that players training but not taking part in full training were still classified as injured until signed off as fully fit by the clubs practitioners (Hägglund *et al*., 2005). Injury severity was initially categorised as slight (<3 days absence), minor (4–7 days), moderate (8–28 days), and major (>28 days) (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Drawer and Fuller, 2002; Woods *et al*., 2002;Price *et al*., 2004; Walden et al., 2005; Le Gall *et al*., 2006).

When expressing injury rates, numerous methods have also been employed. Studies have used a calculation of injury percentage, defined as the number of injured players divided by total number of players (Sullivan, et al., 1980; Yde and Neilsen, 1990; Hawkins *et al*., 2001; Junge et al., 2004a; Price *et al*., 2004). Professional players show a higher injury percentage than adolescent players, injury percentage is however considered less useful than injury rates based on other calculations, because the number of matches and training sessions varies widely, within players in a team, from one team to another, or even from one year to another (Wong and Hong, 2005). In addition to this, and more widely used, injury rate has been expressed as the risk of injury per exposure, and normally calculated per 1000 exposures calculated as follows: number of new injuries x 1000/total exposures. It has however been seen as per 100000 of exposures to be compared to industrial injury monitoring (Drawer and Fuller, 2002). The ambiguity within the literature here lies within the definition and calculation of exposure. Some authors have classified athlete-exposure as one athlete participating in one competition or one training session where they exposed to injury, no matter of the time parameters of that exposure (Junge *et al*., 2004a; Junge *et al*., 2006; Yard *et al*., 2008). For example, 3 training sessions involving 50 participants and 2 competitions involving 40 participants and would result in a total of 230 athlete exposures (Wong and Hong, 2005). Further to this some authors have utilised the method of expressing injury rate per 1000 hours of exposure, further divisions of classification are seen within this definition with authors expressing exposure as match hours (Hawkins and Fuller, 1998; Junge *et al*., 2004a, 2004b; 2004c; Dvorak et al., 2007; Junge and Dvorak, 2010), total exposure (the sum of all match and training hours) (Schmidt-Olsen *et al*., 1985) or expressing all three (match, training and total exposure) (Hawkins and Fuller, 1999; Junge *et al*., 2006; Le Gall *et al*., 2006; Froholdt *et al*., 2009; Hägglund et al., 2009; Dupont, 2010; Ekstrand *et al*., 2011a, 2011b). In calculating exposure related incidence, the amount of playing and training time for each individual player must be incorporated in to the data collection. Authors have recorded the individual each players times associated with training and competition (Walden *et al*., 2005; Parry and Drust, 2006; Dupont, 2010; Ekstrand *et al*., 2011a) but in other studies the exposure time has been estimated by multiplying the number of players by the hours of participation per week within training and matches often excluding such indices as match overtime (Hawkins and Fuller, 1999; Morgan *et al*., 2001; Junge *et al*., 2004a, 2004b; 2004c; Froholdt, *et al*., 2009; Junge and Dvorak, 2010; Dvorak *et al*., 2011; Ekstrand *et al*., 2011b). The nonattendance of players from training sessions or games and the removal of injury time exposure from calculations of injury rate, suggests that exposure time may have been overestimated and subsequently the incidence of injury has been underestimated (Junge and Dvorak, 2000). It would therefore appear that when calculating injury rate a preferred method would be to calculate individual player exposure hours to match and training play and rates should be expressed per 1000 hours of exposure based on the number of injuries received during the specific exposure total, not total injuries across the collection period. Overall total exposure and injury rate is also useful to compare across studies (Junge and Dvorak, 2000; Wong and Hong, 2005). It would also be pertinent to consider in the study of injury incidence the definition of training, football specific training should be included in any calculation of exposure, however at the more senior levels of football, coach led strength and conditioning sessions, pool recovery sessions and non soccer specific training sessions are regularly implemented and carry with them inherent risk and exposure time for these should be considered in the calculation of training exposure (Hägglund *et al*., 2005). Finally, the period of investigation needs to be considered when investigating the literature. Some authors have reported injuries during entire seasons (Backx *et al*., 1991; Morgan *et al*., 2001), multiple seasons (Hawkins and Fuller, 1998; Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Drawer and Fuller, 2002; Price *et al*., 2004; Le Gall *et al*., 2006; Hägglund *et al*., 2009; Dupont *et al*., 2010; Ekstrand *et al*., 2011a, 2011b), part of seasons (Froholdt *et al*.,2009) or during tournaments (Junge *et al*., 2004a, 2004b, 2004c; Dvorak *et al*., 2007; Dvorak *et al*., 2011). Due to injury rates being different for training and matches during different periods of the season (Hawkins and Fuller, 1999, Hawkins *et al*., 2001; Price *et al*., 2004), a predominance of tactical training, recovery sessions and more intense and frequent matches at tournaments (Froholdt *et al*., 2009; Hägglund *et al*., 2009) and the incidence of injuries during games is higher than during training (Junge and Dvorak, 2000), studies with different observation periods can be expected to yield different results.

With the above multiple definitions of many facets of injury monitoring, comparison between studies is very difficult and note should be made of the methods when comparing injury data (Morgan *et al*., 2001; Wong and Hong, 2005)

1.7.2 Football Injury Incidence and Prevalence Rates

The incidence of injuries amongst senior male professional soccer players across a season has been estimated to range between 27 and 35 per 1000 match hours (Hawkins and Fuller 1999; Morgan *et al.,* 2001; Walden et al., 2005). Injury rates for tournament play for senior males have been reported as significantly higher, with a range from 41 per 1000 match hours reported in the UEFA Championships (Hägglund *et al*., 2009) to 91 per 1000 match hours in 2002 World Cup (Junge *et al*., 2004b). The higher end of the injury rates discovered in tournament; 2006 World Cup, 68.7 per 1000 match hours (Dvorak *et al*., 2007), 1998 World Cup, 72.8 per 1000 match hours (Junge *et al*., 2004a), 2010 World Cup, 61.1 per 100 match hours (Dvorak *et al*., 2011) may be attributed to the authors including all injuries in the data irrespective of any time-loss from playing or training. In respect to age group football, injury rates have been demonstrated to be lower than those experienced in men's soccer. Le Gall *et al*. (2006) conducted a prospective study of injury over 10 years in French Academy football and found injury rates per 1000 match hours to be 9.5 (U14), 10.4 (U15) and 14.2 (U16). The trend for injury rates to increase as age increased was also observed in other studies in age group football (Junge *et al*., 2004c; Hägglund *et al*., 2009). Further to this, by the time senior academy age group level (U17 and U18 combined), as used in this study, is reached injury rates appear to mirror levels of those shown in senior male footballers, with a range being demonstrated per 1000 match hours of 27.9-37.2 (Hawkins and Fuller, 1999; Junge *et al*., 2004a; Junge *et al*., 2004c; Hägglund *et al*., 2009). Despite the variation in how time exposure is calculated there is conclusive evidence that more injuries are sustained per 1000 hours of exposure time during game situations when compared to training sessions (Hawkins and Fuller, 1999; Morgan *et al.,* 2001; Ekstrand *et al.,* 2004; Walden *et al.,* 2005; Wong and Hong*.,* 2005; Junge *et al*., 2006; Hägglund *et al*., 2009; Dupont *et al*., 2010; Dvorak *et al*., 2011). It has been reported that for senior players the injuries per 1000 hours of training time for senior soccer players was between 2.9 and 5.8 when measured across seasons (Hawkins and Fuller, 1999; Morgan *et al.,* 2001; Walden *et al.,* 2005; Hägglund *et al*., 2009; Dupont *et al*., 2010; Dvorak *et al*., 2011). These figures are again mirrored in senior academy level football with Hawkins and Fuller (1999) and Le Gall *et al*. (2006) observed injury rates per 1000 training hours to be 4.1 and 3.9 respectively. This suggests that the competitive nature of a game situation increases the risk of a player sustaining an injury and the level of competition brought about by the pressure of tournaments further increases injury likelihood. When injury rate across a season is expressed against total exposure the range observed is between 8.5-9.4 per 1000 hours of exposure for senior players and the senior academy age group (Hawkins and Fuller, 1999; Walden *et al.,* 2005; Dupont *et al*., 2010)

Interestingly many authors have also reported a trend for more injuries to be reported at the end of each half and later in a game (Hawkins and Fuller 1999; Hawkins *et al.,* 2001; Junge *et al.,* 2004, Yoon *et al.,* 2004; Woods *et al.,* 2004; Ekstrand *et al*., 2011), implying that fatigue may influence the occurrence of an injury. If fatigue is a major risk factor for injury within football, conditioning of players to resist muscular fatigue may reduce injury rates.

1.7.3 Injury Severity

Injury severity is dominated by injuries classed as slight and minor resulting in time-loss of <7days, ranging between 44-78% of all injuries recorded (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Hägglund *et al*., 2005; Le Gall *et al*., 2006; Dvorak *et al*., 2007; Froholdt *et al*., 2009; Hägglund *et al*., 2009; Dvorak *et al*., 2011). The predomination of these injuries appears to be regardless of factors associated with changes in injury rate, such as age (Hawkins and Fuller, 1999; Le Gall *et al*., 2006; Froholdt et al., 2009), training or match (Hawkins and Fuller, 1999) or data collection through a season (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Hägglund *et al*., 2005; Le Gall *et al*., 2006; Dvorak *et al*., 2007; Froholdt *et al*., 2009) or tournament (Hägglund *et al*., 2005; Dvorak *et al*., 2007; Hägglund *et al*., 2009; ; Dvorak *et al*., 2011). Hawkins and Fuller (1999), investigated injury over 3 years in senior academy and professional players in professional English clubs found injury the majority of injuries sustained to be <7 days in time-loss. It was observed that 54% match injuries, 51% training injuries in the professional players and 44% match injuries and 51% training injuries in the Academy players to be slight or minor.

1.7.4 Injury Location

It is well documented that the injury to the lower extremity dominates football injuries (Schmidt-Olsen *et al*., 1985; Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Junge *et al*., 2004a, 2004b, 2004c; Price *et al*., 2004; Walden *et al*., 2005; Wong and Hong, 2005; Le Gall *et al*., 2006; Dvorak *et al*., 2007; Froholdt *et al*., 2009; Dvorak *et al*., 2011, Ekstrand *et al*., 2011a, 2011b). When expressed as a percentage of total injuries it is reported that between 70-92% of soccer injuries in adult male players (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Walden *et al*., 2005; Wong and Hong, 2005;

Dvorak *et al*., 2011, Ekstrand *et al*., 2011a, 2011b) and between 71-90% of all injuries in youth soccer players (Schmidt-Olsen *et al*., 1985; Junge *et al*., 2004c; Price *et al*., 2004; Le Gall *et al*., 2006; Froholdt *et al*., 2009) occur at the lower extremity. The predominance of lower extremity injury in football is not surprising given the demands including running, shooting, turning, overuse from lower limb repetition, jumping and the focus of tackling towards the lower limb due to the proximity of the ball to this area (Hawkins and Fuller, 1999; Morgan *et al*., 2001; Wong and Hong, 2005). In addition to this there is evidence that the majority of injuries are observed in the dominant limb (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Price *et al*., 2004) and may be attributable to the dominant side being exposed to higher levels of use in jumping, kicking, tackling and controlling of the ball.

In regard to the specific injury location, there are some levels of ambiguity in the literature. The ankle has been considered a major injury site by many authors (Ekstrand and Gillquist, 1983a; Nielsen and Yde, 1989; Morgan *et al*., 2001; Junge *et al*., 2004a; 2004b), however there is also evidence to suggest the thigh is the main area of injury location (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Price *et al*., 2004; Le Gall *et al*., 2006). The knee and the groin are suggested to be the further areas prone to injury in the lower extremity (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Junge *et al*., 2004a; 2004b; Price *et al*., 2004; Le Gall *et al*., 2006). There is however more demonstrated consistency in the literature with regard to the type and mechanisms which dominate the injury sites, with thigh injuries consisting mainly of non-contact muscle strains (Hawkins and Fuller, 1999) whereas ankle injuries have a greater predication towards ligament strains brought about by contact (Hawkins and Fuller, 1999). Of all the muscle strains to the thigh there is a greater level of muscle injury to the posterior thigh and more specifically the hamstring muscle group than to the anterior thigh (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Price *et al*., 2004; Walden *et al*., 2005; Ekstrand *et al*., 2011a, 2011b). During a two season period (1997 – 1999) the single highest figure reported within 91 professional clubs for the location of an injury was the thigh; 23% of all injuries were reported in this location (Hawkins *et al.,* 2001). Of these thigh injuries, 81% were muscle strains, and 67% were in the hamstrings region (Hawkins *et al.,* 2001). There is a similar trend for the location of an injury within soccer youth academies, where 19% of all injuries occurred in the thigh; of these thigh injuries 79% were classified as strains and 57% of the strains in the thigh were reported to be in the hamstrings muscle group (Price *et al.,* 2004). It is worth noting that while contact injuries are very difficult to reduce injury rate for due to the external application of load to the complex array of risk factors already associated with football injury, non-contact injuries could be reduced by elements of conditioning.

1.8 Purpose of Functional Movement Screening

With injury incidence having been illustrated to impact on player development (Price *et al.,* 2004), squad continuity and team performance (Woods *et al.,* 2002) and a significant risk factor to further injury (Cook *et al*., 2006; Kiesel *et al*., 2009) a major goal of the rehabilitation and S&C professional has been to find methods of predicting athletes who are at risk of injury before it happens. Traditionally sports rehabilitation assessments have been focused on objective assessment of individual isolated specific joints and muscles coupled with sports performance measures and sports specific skills tests (Cook *et al*., 2006). The use of such assessment to ascertain an individual's readiness to perform, while useful, can be limited for several reasons. Athletes who perform well within a performance test or isolated movement pattern may do so in an inefficient manner utilising compensatory movement patterns in order to complete the task (Cook *et al*., 2006). The utilisation of compensatory movement patterns reinforces poor movement quality, in turn leading to poor biomechanics and efficiency, which leaves the athlete predisposed to potential micro- or macro-traumatic injury (Cook *et al*., 2006). In addition to this, previous injury is one purported explanation for the development of poor movement patterns (Lephart *et al*., 1997). Athletes who have suffered an injury may have a decrease in proprioceptive input, which may in turn result in alterations in mobility, asymmetric influences and stability, in due course leading to compensatory movement patterns, weakness, tightness or pain away from the injury site (Bullock-Saxton *et al*., 1994; Kiesel *et al*., 2009; Lephart *et al*., 1997; Nadler *et al*., 2002; Neely, 1998) and has recently been termed as 'regional interdependence' (Wainner *et al*., 2007). These programmed altered movement patterns lead to further mobility and stability imbalances, which are in themselves identified as risk factors for injury and therefore leaves the athlete exposed to injury risk (Keisel *et al*., 2007).

With these above limitations in mind, there has been a shift towards integrating a functional approach, incorporating the principles of proprioceptive neuromuscular Facilitation, (PNF), muscle synergy, and motor learning to athlete assessment to improve the accuracy of identifying at risk athletes (Cook *et al*., 2006; Minick *et al*., 2010; Pilsky *et al*., 2006). A tool that has been devised to assist this approach is the Functional Movement Screen™ (FMS™) (Cook *et al*., 2006) which should be integrated into pre-participation screening to establish who possesses, or lacks, the essential movements needed to participate in sports activities with a reduced injury risk. The FMS™ is comprised of 7 fundamental movement patterns that require a balance of mobility and stability but also include the incorporation of muscular strength flexibility, range of motion, coordination, balance and proprioception

(Kiesel *et al*., 2007; Okada *et al*., 2011). The 7 movement tests use a variety of positions and movements closely related to normal developmental growth and it is proposed that the fundamental movements tested in the FMS™, operate as the basis of more complex movement patterns used in regular daily and sport activities (Cook *et al*., 2006; Kiesel *et al*., 2007; Minick *et al*., 2010). The test comprises of the following movement patterns; the deep squat, the hurdle step, the in-line lunge, the shoulder mobility test, the active straight leg raise, the trunk stability push-up and the rotary stability test. During the administration of the test the athlete is required to complete the movement patterns that manipulate their body in to the extremes of mobility and stability. The movements also require the body to utilise its kinetic linking system in a proximal to distal sequence that is understood to produce efficient movement patterns (Okada *et al*., 2011). Such movement patterns allow the assessor to observe right and left side imbalances, mobility and stability weaknesses and compensatory patterns in the kinetic chain (Cook *et al*., 2006; Keisel *et al*., 2007).

The ease of administration and scoring of the FMS™ system has led to its increasing use by rehabilitation and S&C professionals (Kiesel *et al*., 2007, Minick *et al*., 2010) to fill the gap between the isolated movement assessments and assessments of movement patterns fundamental to sporting success. That said, there is a paucity of research relating to the FMS™ and this limited primarily to the sport of American football. Kiesel *et al*. (2007) conducted analysis over the course of a season relating injuries to pre-season FMS™ scores and concluded that athletes that scored a total score of <14 out of a possible 21 across the 7 tests were at an 11 fold increase of suffering a serious injury over a competitive season. A follow up study to this investigation also highlighted that any players that had any instance of asymmetry within the test were at a 2.3 time greater risk of becoming injured regardless of total score (Kiesel *et al*., 2008). Further to this Keisel et al. (2009) conducted a further study with American Football athletes in to the effect of an off season S&C programmes ability to positively affect FMS™ scores. Across the off season programme 52% of players were observed to take their overall total score above the earlier identified threshold of 14 for high injury risk, in addition to the 11% identified above the threshold prior to training. An 18% reduction in players demonstrating asymmetries was also observed post the training intervention. Keisel *et al*. (2009) also observed a poor overhead squat score had a high correlation with a poor overall score in the FMS™. Care must be taken however when applying the data obtained from the above studies in American Football to other sports, particularly football as utilised in this study. American Football has specific injury locations that are outside of the data outlined in football above, with high levels of injury occurring to the head/face, neck, torso and spine, in addition to lower limb injuries (Shankar *et al*., 2007)

Minick *et al*. (2010) assessed the interrator reliability of the screen across 2 novice and 2 expert raters, it was noted there was high interrator reliability across novice raters, expert raters and expert/novice raters. It would therefore appear from the research that the use of FMS™ is practical both in terms of identifying athletes at risk of injury and identify athletes that post intervention have increased their likelihood of staying injury free. It is also reproducible and comparable within and across studies. It is however worth noting that there are reported limitations to the FMS™. Kritz & Cronin (2008), highlight that no part of the assessment is directly linked to observation of static standing posture from which movements are instigated and this may be a fundamental behind all movement patterns. Frost *et al*. (2011) highlighted that while the FMS™ had demonstrated effectiveness in injury prediction, the current scoring system of 0-3 may not have sensitivity to detect changes in performance in the test or highlight the cause of the deficiencies in movement. In addition to this, care must be taken when analysing FMS™ screen to not utilise it as a performance indicator. No link has been established with poor performance and FMS™ scores, however it may be correct to suggest that poor movement may limit the athletes own potential to produce their maximum power outputs (Parchmann & McBride, 2011).

1.9 Rationale for S&C Programme

In light of the research above, and the requirements of the role of an S&C programme in football, practical considerations and rational for the programme have to be considered in the design and implementation of the training intervention. Of specific importance when working with elite performers, such as the subject group in this investigation, the coach's goals have to be considered in the planning stages of the programme. Despite the S&C programme commencing during in-season, the coach highlighted a specific requirement of the players to undergo hypertrophy for an increase in LBM. This implementation of hypertrophy training was in order to better facilitate the transition of senior academy players to senior football. As part of an academy remit is for the preparation of players for professional sport demands, the coaching team was prepared to forgo the possible impact of hypertrophy training on performance, in the early stages of the season. Hypertrophy training can be designed to impact on multiple muscle groups and can also be used as part of a general preparation phase of training to prepare the body for increased demands in later cycles, when training becomes more sport specific (Baechle and Earle, 2008)

The impact of this was to incorporate two types of periodisation within one season, a classic linear programme was followed in the early season to develop hypertrophy characteristics and basic strength though the prime movers for the sport (Hoffman *et al*., 1991). This was followed by periods of developing strength and power utilising CT (Gamble, 2006), other models of periodisation for team sports were not used due to the limited training age and time available for S&C in the subject group.

Despite general and specific conditioning programmes being demonstrated to have positive influence on injury prevention (Heidt *et al*., 2000; Young, 2006), the application of specific exercises to reduce injury risk in the sports should also be applied in a training intervention. As highlighted earlier, the posterior thigh (hamstring muscle group) is considered the area at highest risk of injury through non-contact mechanisms in football (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Price *et al*., 2004; Walden *et al*., 2005; Ekstrand *et al*., 2011a, 2011b). The programme therefore incorporated eccentrically loaded exercises targeted at the hamstring muscle group (Cleather and Brandon, 2007), these exercises included high load closed chain hip extension exercises such as the stiff leg deadlift (also known as the Romanian deadlift) and moderate load eccentric exercises based in rotation around the knee such as the Nordic hamstring extension (Brandon and Cleather, 2007). Further to this the knee was also highlighted as a high risk area for non-contact injury in football play (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Junge *et al*., 2004a; 2004b; Price et al., 2004; Le Gall *et al*., 2006). Gluteal control plays an important role in tracking of the knee and in absorbing and generating forces in unilateral sports specific situations such as decelerating, single leg landing and running (Brewer and Pettigrew, 2009). The inclusion of exercises to improve the motor pattern and recruitment of gluteus maximus and gluteus medius control particularly in the unilateral movement plane, such as single leg squats, were therefore incorporated (Brewer and Pettigrew, 2009).

Further to this the programme was structured to incorporate enhancement of performance, as previously highlighted the lower limb is the main focus of performance capability, such as jumping and sprinting and therefore the incorporation of leg concentrated exercises predominate the programme (Bangsbo *et al*., 1991; Stolen *et al*., 2005) and include specific exercises, for example squats and lunge patterns. It has also been highlighted that the S&C professional should look to develop throughout the course of the programme Olympic lifting technique through delivery of ancillary exercises and teaching progressions (Armitage-Johnson, 1994, Duba *et al*., 2007). The prioritisation of development of these exercise techniques for sports that involve high rate of force development, and triple extension movement patterns such as football, relate to the lifts having high levels of specificity to sports performance in terms of movement patterns, rate of force development, incorporation of coordination of triple extensions of the ankle, knee and hip and the ability to train the elastic properties of the muscle (Hoffman *et al*., 2004; Brewer, 2006; Waller and Townsend, 2007) and are particularly associated with the development of power (Waller and Townsend, 2007). Hoffman *et al*. (2004) observed greater increases in vertical jump performance and decreases in sprint times utilising Olympic lifts as opposed to traditional power lifting exercises.

2. Aims, Objectives and Hypotheses

The aims of this study were:

1. Examine the effect of an in-season gym based S&C programme on performance measures in elite academy footballers, and the ratio of performance transfer when related to gym based resistance training performance gains.

2. Examine any relationship present between performance measures and strength profiles of elite academy footballers.

3. Examine the effect of an in-season gym based S&C programme on screening measures designed to highlight injury risk in athletic populations.

4. Examine the effect of an in-season gym based S&C programme on injury rates, location and severity in elite academy footballers.

These aims were delivered by the completing the following objectives: -

1. An in-season gym based S&C programme will be designed, utilising evidence based research, and implemented to impact on the players performance profile and reduce injury risk, plus meet the requirements of the club coaching staff.

2. Measures of strength (1RM testing) and performance (5, 15 and 30m sprint, T-Test and CMJ) will be monitored through the implementation of the above S&C programme to ascertain if any performance gain has occurred during the intervention.

3. Anthropometric data (height (cm), body mass (kg) and skin fold measurements will be collected during the implementation of the S&C programme. The data will also be utilised to calculate body fat % and lean body mass.

4. Injury incidence, location, type, time-loss duration and player exposure time will be collected on an individual player basis, to calculate injury rates for the playing group in the intervention period.

5. FMS of all players will be tested pre and post the intervention period and used to examine if an S&C programme can have positive impacts on movement screening designed to highlight injury risk.

The hypotheses of this study were:

1. The introduction of an in-season periodised S&C programme will increase players' strength profiles.

2. The enhanced gym based strength profiles will translate to positive improvements in field based performance in sports specific tests.

3. The introduction of an in-season periodised S&C programme will reduce players' injury risk and injury occurrence of sports specific injuries.
4. The introduction of an in-season periodised S&C programme will produce observable improvement in FMS™ scores and a reduction in asymmetries present in the squad.

3. Methods

The study comprised of a 26 week S&C intervention within season. Measures of anthropometrics, FMS, 1RM, sprint times, agility times and CMJ were conducted pre and post the intervention.

3.1 Participants

Elite football academy players (n=6; age 17.4±0.1 years; height 175.3±6.6 cm; body mass 66.2±5.0 kg) undertook a 26 week (once or twice a week in-season) gym based S&C programme (see Table 3.1) (total of 39 sessions in the training period) designed to complement and enhance the players football specific training and match play. The group consisted of outfield players (4 midfielders and 2 defenders). Despite the academy under 18 squad numbering 16, there was a high attrition rate within the participants due to the demands of a professional football club working environment. Exclusion criteria were set that all players had to have completed a minimum of 85% of all prescribed S&C sessions and complete all pre and post testing measures. Within the squad players were regularly absent for a number of reasons, including 1st team involvement at matches and training, loan periods away from the club and being released or resigning from the contracts. All players had between 4 and 6 year's elite academy experience. In addition to the S&C intervention players participated in one or two competitive matches per week during the intervention (total 31 fixtures), in addition to 6 training sessions per week for a total of 9 hours. The players training was designed to improve components of game related fitness and technical and tactical skills. Prior to the intervention players had limited access to a leisure gym for weight training but had no experience of weight lifting for sports performance or a formal S&C training programme with qualified coaches. Due to the applied nature of this intervention and the elite nature of the subject group, no control group was used for this study.

The University's Research Ethics committee approved all procedures. The primary objective of this consultancy work was applying S&C to their Academy players and assisting in the monitoring and evaluation of the elite players in under 18 age group. The players are therefore assent to participating in the training and testing as part of their development plan set out by the football club and as stipulated in their contract. All players are only required to attend and participate in testing and sessions of S&C if passed fit by their physiotherapy and sports science staff at the club. Players are required to complete a daily health screen and fitness reporting sheet as part of their ongoing monitoring with the football club. The data within these sheets are monitored and evaluated by the clubs physiotherapy and sports science departments.

3.2 Training Intervention

The participants undertook a 26 week training programme of gym based weight training for sports performance. Prior to the commencement of the intervention, all the athletes were required to undertake a 3 week exercise and technique instruction period and be passed competent by the S&C coach before being allowed to complete the intervention. The programme was periodised in to the following blocks of training (see Table 3.1); a 4 week hypertrophy/muscular endurance mesocyle developing weightlifting technique including Olympic style lifting technique incorporating standard exercises to develop the snatch and the clean and jerk techniques (Duba *et al*., 2007) and compound movements such as squats, deadlifts and bench press (twice a week at 3 sets of 12 repetitions at 75% of 1RM, 60-90 seconds rest between sets) (see Appendix 1), followed by a 4 week basic strength mesocycle (twice a week at 3 sets of 12 repetitions at 85% of 1RM, 90-120 seconds rest between sets) (see Appendix 2). These periods of training were followed by a 2 week unloaded phase incorporating club directed active rest, participants were encouraged to have self led activities including recreational sport and light training away from football and the weights room. The athletes then completed 2 further mesocycles (one 4 week and one 5 week) of strength and power training (twice a week at 3 sets of 4 repetitions at 85% of 1RM; power exercises at 4 sets of 3 repetitions at 75% of 1RM, 120 seconds rest minimum between sets) (see Appendix 3), concluding with a 5 week mesocycle of maximum strength and power (twice a week at 3 sets of 2repetitions at 90-95% of 1RM; power exercises at 3 sets of 3 repetitions at 75% of 1RM, 120 to 300 seconds rest between sets) (see Appendix 4). Players were requested to maintain a lifting tempo of 21x for all non Olympic lifting based exercises, in which the downward phase of the movement was 2 seconds long, followed by a one second pause before an explosive upward phase of motion. All phases were progressively loaded using the 2-for-2 rule (Baechle and Earle, 2008), players were required to aim for 2 repetitions above their prescribed target during their final set, and if the player completed the additional repetitions the load was increased in the next training session. Throughout the S&C programme spotters were used in appropriate exercises and squad members were encouraged to give verbal encouragement throughout the session.

Training load was monitored by calculating volume load of each session throughout the 26 week period. Volume Load (VL) was calculated by multiplying the number of repetitions completed by the number of sets completed by the actual resistance lifted (Haff, 2010). Volume Load (kg) = number of sets x number of repetitions x weight lifted (kg)

Volume Index (VI) was calculated for each session by dividing the volume load by the body mass of the athlete (Haff, 2010):

Volume Index = Volume Load (kg)/Body Mass (kg)

VL and VI were then summated for each training week and the total mesocycle.

Table 3.1: Schematic overview of the 26 week periodised training plan for delivery of S&C to elite academy football players.

Month	Nov-09					Dec-09				Jan-10				Feb-10				Mar-10					Apr-10			
Date Wk/C	02	09	16	23	30	07	14	21	28	04	11	18	25	01	08	15	22	01	08	15	22	29	05	12	19	26
Wk	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Matches					2											2							2			
Testing																										
Training Phase	Hypert/Endur				Basic Strength				R		Strength + Power					R	Strength + Power				R	Max Strength + Power				
Training Type	General				PMFM				AR		Sports Specific					AR	Sports Specific				AR	Sports Specific				
Intensity	Moderate				High				Low		High					Low	High				Low	V High				
Volume	High				Moderate				Low		Low					Low	Low				Low	V Low				

Key – R = Rest, AR = Active Rest, PMFM = Prime Muscles for Movement, 2 = 2 matches during the week

3.3 Testing Procedures

Subjects underwent a battery of physical and performance measures which were conducted one week pre and post the intervention. In addition to this anthropometric data and one repetition maximum data was additionally collected in Week 11. All tests were conducted at the S&C facility at Coventry University or Coventry City Academy training facility, in the same order, utilising the same equipment and at the same time of day.

3.3.1 Anthropometrics

Height was measured using a Seca portable stadiometer (GMBH & Co., Hamburg, Germany) and body mass was recorded using Seca electronic scales (GMBH & Co., Hamburg, Germany).

Body fat percentage (BF%) was calculated using the sum of four skin folds (Durnin & Womersley, 1973). Skin folds were measured to the nearest millimetre using Harpenden skin fold callipers (Baty International, West Sussex, UK) at the bicep, tricep, subscapular and supra-iliac (see Figure 3.1). Intra-evaluator reliability for skin folds was measured via Technical Error of Measurement (TEM) with the anthropometrist having a mean TEM of 6.00% for the four skin folds measured and individual TEM of 6.12%, 6.32%, 6.17% and 5.40% for bicep, tricep, subscapular and supra-illiac respectively (Perini *et al*., 2005).

LBM was calculated:

Body Fat (kg) = Total Body Mass (kg) x (Body Fat %/100)

LBM (kg) = Total Body Mass (kg) - Body Fat (kg)

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Figure 3.1: Four skin fold sites a) bicep, b) tricep, c) subscapular and d) supra-illiac (Marfell-Jones, 1991)

3.3.2 Functional Movement Screening

All athletes were assessed through a functional movement screen (FMS™) (Cook *et al*., 2006) pre and post the intervention. FMS™ consisted of overhead squat (see Figure 3.2), in-line lunge (see Figure 3.3), hurdle step (see Figure 3.4), straight leg raise (see Figure 3.5), rotary stability (see Figure 3.6), trunk stability push up (see Figure 3.7) and shoulder mobility (see Figure 3.8). All FMS test positions were demonstrated and the athletes were allowed two practice attempts prior to test. FMS™ was scored a value of 0-3 for each of the seven tests (total of 21 points). A score of 3 was awarded if the athlete could perform the movement fully without any pain or limitations in range of motion. Scores were reduced if the athletes were unable to complete any of the test components or failed to complete the test in accordance with Cook et al. (2006). Five of the seven tests (in-line lunge, hurdle step, straight leg raise, rotary stability and shoulder mobility) also identified left/right asymmetries. Where asymmetries in movement were uncovered the lowest value was recorded towards the athletes FMS™ total score, and the asymmetry score noted. All tests pre and post were carried out by a single experienced rater in FMS™.

Functional Movement Screen : Deep Squat

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Figure 3.2: Description of the scoring criteria used for the overhead squat component of the FMS™ (Minick *et al.*, 2010).

Functional Movement Screen : In-Line Lunge

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Figure 3.3: Description of the scoring criteria used for the in-line lunge component of the FMS™ (Minick *et al.*, 2010).

Functional Movement Screen : Hurdle Step

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Figure 3.4: Description of the scoring criteria used for the hurdle step component of the FMS™ (Minick *et al.,* 2010).

Functional Movement Screen : Active Straight Leg Raise

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Figure 3.5: Description of the scoring criteria used for the active straight leg raise component of the FMS™ (Minick *et al.,* 2010).

Functional Movement Screen : Push Up

Figure 3.6: Description of the scoring criteria used for the trunk stability push up component of the FMS™ (Minick *et al*., 2010).

Functional Movement Screen : Rotary Stability

Figure 3.7: Description of the scoring criteria used for the rotary stability component of the FMS™ (Minick *et al*., 2010).

Functional Movement Screen : Shoulder Mobility

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Figure 3.8: Description of the scoring criteria used for the shoulder mobility component of the FMS™ (Minick *et al*., 2010).

3.3.3 One Repetition Maximum Prediction

Maximum strength measures were taken of bench press, back squat and supine row at three intervals throughout the intervention; one week prior, week 11 and one week post intervention. Subjects were required to warm up with one set of 15 repetitions of a low resistance followed by a 60s rest period, followed by 2 further warm up set of approximately 10 repetitions of a moderate resistance with a 120s rest period after each. The subject was then given a S&C coach estimated load close to 6 repetition maximum (6RM) and asked to perform 6 repetitions. If the subject was able to complete the repetitions, they were allowed 180s rest period before undertaking a further attempt with an increased load (Baechle and Earle, 2008).

One repetition maximum (1RM) was estimated from 6RM scores using Brzycki (1993) using the following equation (see Appendix 6):

1RM = Weight Lifted/(1.0278-(0.0278 x number of reps))

1RM in relation to the athlete's LBM ratio was then calculated (1RM/LBM) (McBride *et al*., 2009b).

3.3.4 Field Based Performance Tests

On a separate day the athletes were then required to undertake field based performance measures. Tests were completed following the players rest days on the same days of the week. All measures were undertaken on a 3G indoor football pitch.

Athletes were required to complete three 30m sprints with split times measured at 5m and 15m, 180s rest was given between repetitions. Athletes were then required to perform a T-Test (see Figure 3.9), each player had 6 attempts and were instructed to alternate between stepping left or right at the top of the T between each turn and were given 180s rest between each repetition. A left sided T-Test was classified as one that took you to the left direction, initially stepping off the right foot and right sided T-Test stepping off the left foot and moving right at the top of the stem of the T. Performance in the T-Test was analysed for Dominant Limb (DL) and Non Dominant Limb (NDL). All sprint measurements were taken using a SmartSpeed timing gate system (Fusion Sport, Queensland, Australia).

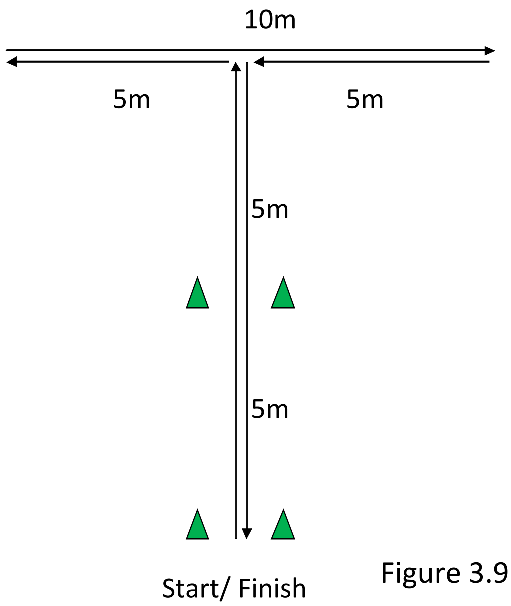

Figure 3.9: Schematic of the left side T-Test.

CMJ was measured using SmartSpeed Jump Matt system (Fusion Sport, Queensland, Australia). Athletes were given three attempts and the highest value retained. The jump matt system uses flight time to calculate jump height, as such all athletes were required to follow a set protocol. Athletes were required to start the jump in an upright position with hands placed on hips, this was followed by a downward movement to a self selected depth followed by leg drive in to flight phase, and were required to keep their legs straight during the flight phase of the jump (Chelly *et al*., 2009).

CMJ was analysed for PP and AP utilising the following equations (Harman *et al.,* 1991):

PP (W) = 61.9 x jump height (cm) + 36 x body mass (kg) + 1822

AP (W) = 21.3 x jump height (cm) + (23 x body mass (kg)-1393

For the field based tests the athlete's best score across the attempts was taken as the performance score. The athletes were habituated to undertaking all of the field based performance measures having completed similar testing protocols at least twice per year in the 4-6 years of playing academy football.

3.4 Performance Transfer

Performance transfer is expressed as a ratio of % increase in gym based lower limb performance (squat 1RM) and % increase in field based performance tests. This was calculated by dividing the change in the performance test by the change in the squat performance. A negative ratio would illustrate a decrease in the desired performance.

3.5 Injury Data

Injury data for the season were monitored and evaluated by the physiotherapist based at the football club. An injury was defined in accordance with the 'time-loss' category as an injury that occurred during a scheduled training session or match that caused absence from the next training session or match. A training session was defined as 'any coach directed physical activity carried out with the team' (Hägglund *et al.*, 2005). It would therefore be appropriate to consider in the calculation of exposure hours and collection of injury data, sessions such as recovery pool sessions and a strength session in the gym. Data was collected to include individual player exposure hours (in order to calculate injury rates per 1000 hours of exposure) (Hägglund *et al.*, 2005), contact and non-contact injury, injury severity by training days lost (slight 1-3 days lost, minor 4-7 days lost, moderate 8-28 days lost or major <28 days lost) (Hägglund *et al.*, 2005) and if the injury was new or a reinjury (defined as an injury to the same location and of the same type within two months of the previous injury) (Hägglund *et al.*, 2005). Injury rate was then calculated per 1000 hours of exposure using the following equation:

Injury Rate = No. of injuries x 1000/total hours of exposure (training, match or total)

3.6 Data Analysis

Effect size was calculated using Cohen's *d* for all pre and post anthropometric measures, performance measures and 1RM scores (*P* values for performance test and 1RM scores available for reference in Appendix 7.7). One way ANOVA (repeated measures) incorporating Bonferroni post hoc tests adjustment was used to analyse differences between squad players VL and VI across each training phase. Pre and post FMS scores were analysed using Wilcoxon Signed Ranks test. Pearson's Correlations were used to assess the degree of relationship between 1RM scores and 1RM/LBM and performance measures. A probability of $P<0.05$ was used to determine significance. All data were analysed using SPSS 17.0 statistical analysis software (SPSS inc. Chicago, Ill, USA).

4. Results

Player adherence to the training programme was high, with a group mean ± sd % attendance of 96 ± 6%. Three of the six participants (half of the group) had a 100% attendance record. The lowest adherence rate was 85% by one player.

4.1 Anthropometrics

Calculation of effect size for anthropometric characteristics showed meaningful change in mass pre to post (*d*=0.49), LBM pre to Week 11 (*d*=0.59) and pre to post (*d*=0.69) and BF% pre to Week 11 (*d*=0.89) and pre to post (*d*=0.82). Small effect sizes were observed in relation to height at all time points (*d*≤0.1), BF% week 11 to post (*d*=0.06) (see Table 4.1).

Table 4.1: Anthropometric data (mean ± SD) pre, Week 11 and post intervention.

	Height (cm)	**Mass (kg)**	**Body Fat (%)**	**LBM (kg)**
Pre	175.3 ± 6.6	66.2 ± 5.0	12.5 ± 1.7	57.9 ± 4.2
Week 11	175.5 ± 6.5	67.9 ± 4.7	11.1 ± 1.2	60.3 ± 3.9
Post	175.9 ± 6.1	68.7 ± 5.2	11.2 ± 1.3	61.0 ± 4.6
Overall % Change	0.3	3.8	10.4	5.4

4.1.1 Anthropometric Analysis of Individual Players

Across the 26 week intervention period 3 players (half the squad) showed increases in height (see Figure 4.1). Body mass had increased by week 11 in all 6 players however by post testing body mass had only further increased in 3 players from week 11. 1 player had maintained body mass from week 11 to post and two players had seen reduction in body mass from week 11 however had increased body mass from pre testing (see Figure 4.1). All 6 players reduced BF% from pre intervention testing to week 11, 4 players' further reduced

BF% from week 11 to post testing, 1 player increased BF% to pre testing levels and 1 player saw a small increase from week 11 to post intervention testing however with an overall reduction in BF% from pre testing levels (see Figure 4.2). Further to this all 6 players increased LBM from pre to post, however half of the squad measured a reduction in LBM from Week 11 to post testing (see Figure 4.2).

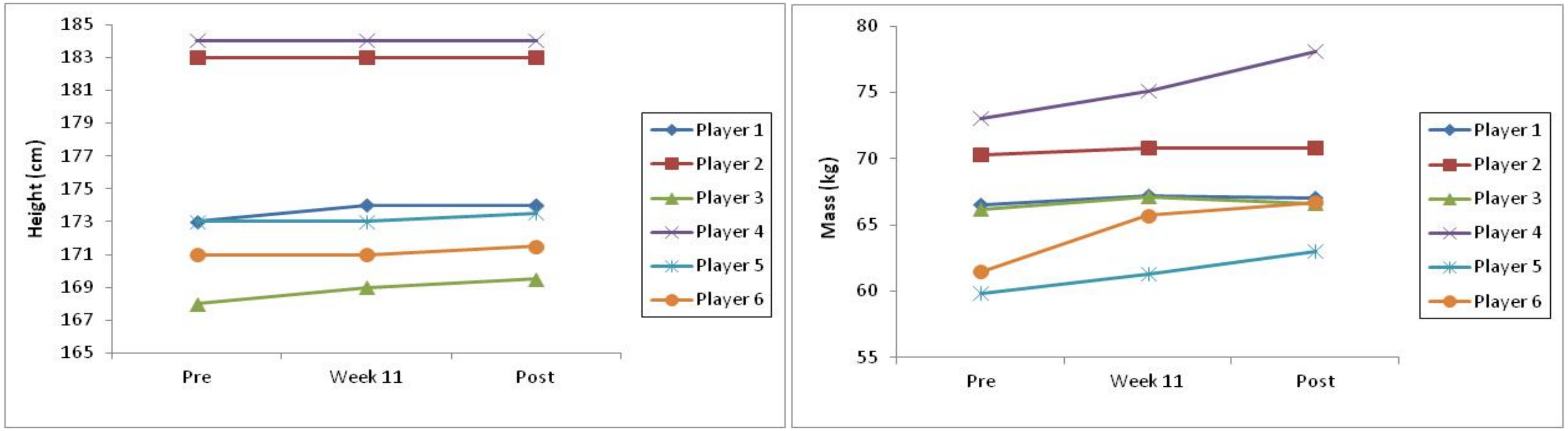

Figure 4.1: Height (cm) and Body Mass (kg) changes player by player at three points in the 26 week intervention.

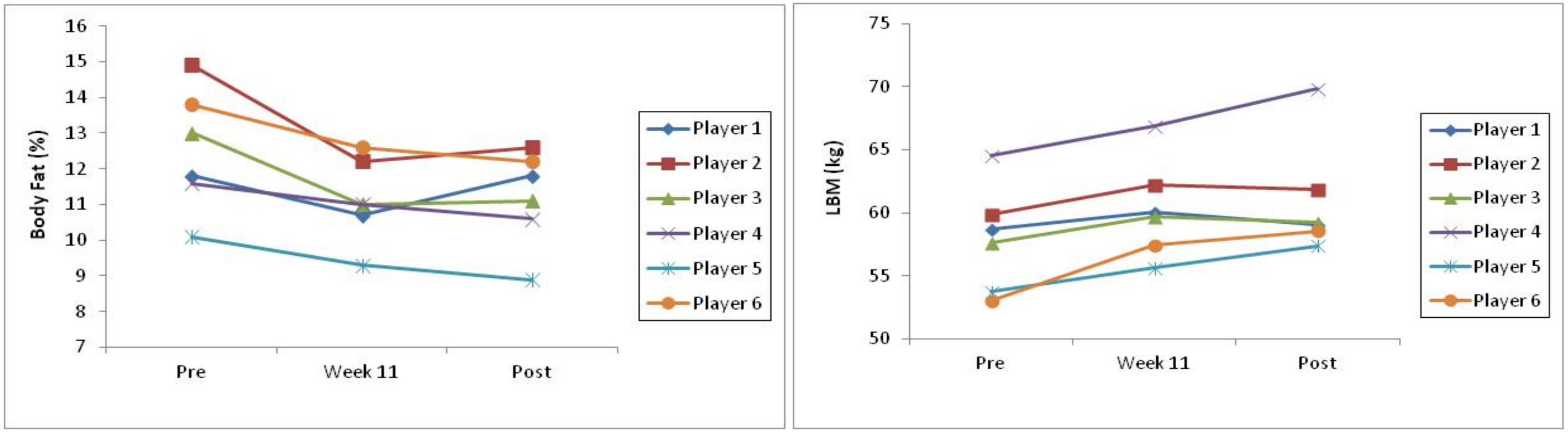

Figure 4.2: Body Fat (%) and LBM (kg) changes player by player at three points in the 26 week intervention.

4.2 Volume Load and Volume Index

Analysis of data between the 6 players within each training phase for VL and VI using Mauchly's test showed assumptions of sphericity had been violated ($P<0.05$) within all training phases, therefore degrees of freedom were corrected. Significant differences were observed between players' mean VL and VI within Muscular Endurance and Hypertrophy phase (VL, $P<0.001$, Greenhouse-Geisser; VI, $P<0.001$, Huynh-Feldt), Strength and Power One phase (VL, $P<0.01$, Greenhouse-Geisser; VI, $P<0.01$, Greenhouse-Geisser) and Max Strength and Power phase (VL, $P<0.001$, Greenhouse-Geisser; VI, $P<0.001$, Huynh-Feldt). No significant difference was observed between the mean VL and VI of each player for Basic Strength phase and Strength and Power Two phase (VL, $P>0.05$, Greenhouse-Geisser; VI, $P>0.05$, Greenhouse-Geisser)

Table 4.2 outlines peak minimum and mean ± SD data for VL and VI across each training phase in the 26 week period. Total weekly VL and VI across all training phases within the 26 week training intervention for individual players are represented in Figure 4.3.

Table 4.2: Total VL and VI by player and Mean ± SD VL and VI within all training phases

Subject	**Hypertrophy/Muscular Endurance**		**Basic Strength**		**Strength and Power One**		**Strength and Power Two**		**Max Strength and Power**	
	VL (kg)	**VI (kg)**	**VL (kg)**	**VI (kg)**	**VL (kg)**	**VI (kg)**	**VL (kg)**	**VI (kg)**	**VL (kg)**	**VI (kg)**
Player 1	62190	935	32394	487	34926	520	30692	457	21225	282
Player 2	80346	1344	46008	769	45149	737	41650	679	28293	390
Player 3	82290	1338	56694	922	46735	711	42854	652	29400	386
Player 4	94665	1297	65298	894	50678	675	46516	619	33227	381
Player 5	90741	1291	61799	879	48875	690	11018	156	29708	375
Player 6	85764	1296	58555	885	46922	699	32108	479	29221	384
Mean ± SD	86031± 5594*	1301± 38*	57373± 6567	865± 54	47163± 2283*	696± 26*	35815± 13046	532± 197	29541± 1995*	380± 10*

*Significant difference observed between players mean VL and VI (*P*<0.05)

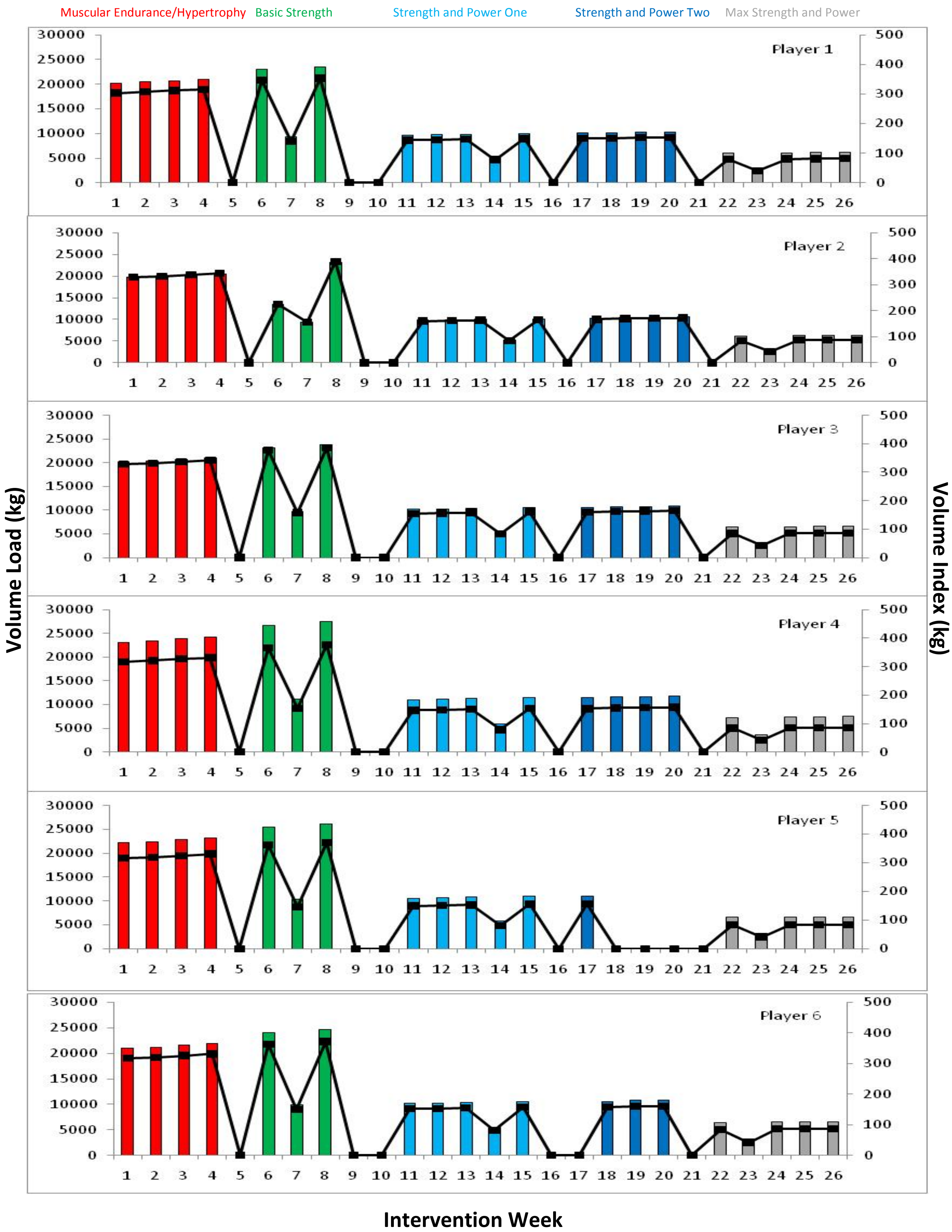

Figure 4.3: Weekly totals for Volume Load (Bar) and Volume Index (line) (kg) lifted in each training phase across the 26 week strength and conditioning training programme for each of the academy squad players.

4.3 Gym Performance Measures

Large effect sizes were calculated in weight lifted from pre to week 11, week 11 to post and from pre to post in squat (*d*=1.67, *d*=1.71, *d*=1.84 respectively), bench press (*d*=1.58, *d*=1.53, *d*=1.78 respectively) and prone row (*d*=1.78, *d*=1.71, *d*=1.86 respectively). In accord large effect sizes were also calculted in the 1RM/LBM ratio from pre to week 11, week 11 to post and from pre to post in squat (*d*=1.52, *d*=1.67, *d*=1.81 respectively), bench press (*d*=1.73, *d*=1.79, *d*=1.88 respectively) and prone row (*d*=1.77, *d*=1.79, *d*=1.88 respectively) (see Table 4.3).

Table 4.3: Mean ± SD 1RM (kg) and 1RM/LBM ratio for gym performance measures in Squat, Bench Press and Prone Row for Pre, Week 11 and Post training intervention.

		Pre	**Week 11**	**Post**	**% Change**
Squat	**1RM**	67.9 ± 5.6	88.3 ± 7.0	118.8 ± 9.7	75
	1RM/LBM	1.2 ± 0.1	1.5 ± 0.1	2.0 ± 0.2	67
Bench Press	**1RM**	47.5 ± 6.1	65.4 ± 7.1	86.7 ± 10.2	82
	1RM/LBM	0.8 ± 0.1	1.1 ± 0.1	1.4 ± 0.1	75
Prone Row	**1RM**	40.4 ± 2.5	55.4 ± 4.0	72.9 ± 5.6	80
	1RM/LBM	0.7 ± 0.0	0.9 ± 0.1	1.2 ± 0.1	71

4.3.1 Gym Performance Measure Analysis of Individual Players

All 6 squad players illustrated improvements in 1RM scores and 1RM/LBM ratios for squat (see Figure 4.4), bench press (see Figure 4.5) and prone row (see Figure 4.6), from pre to week 11, week 11 to post and pre to post. Similar trends in increase were observed in all players.

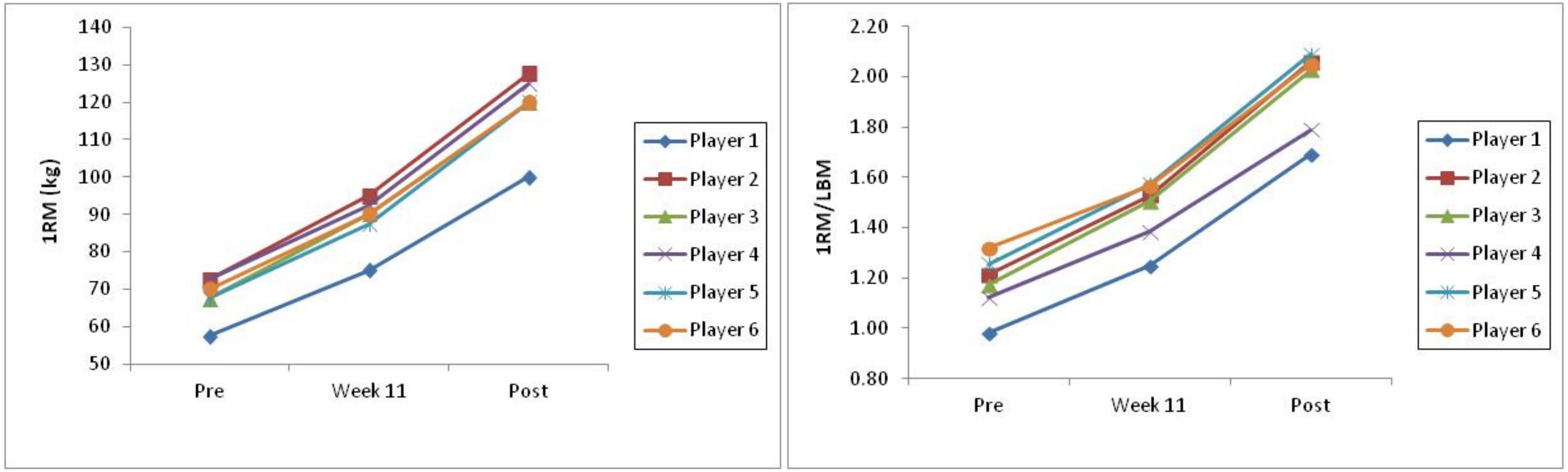

Figure 4.4: Squat 1RM and 1RM/LBM Ratio changes player by player across the 26 week intervention.

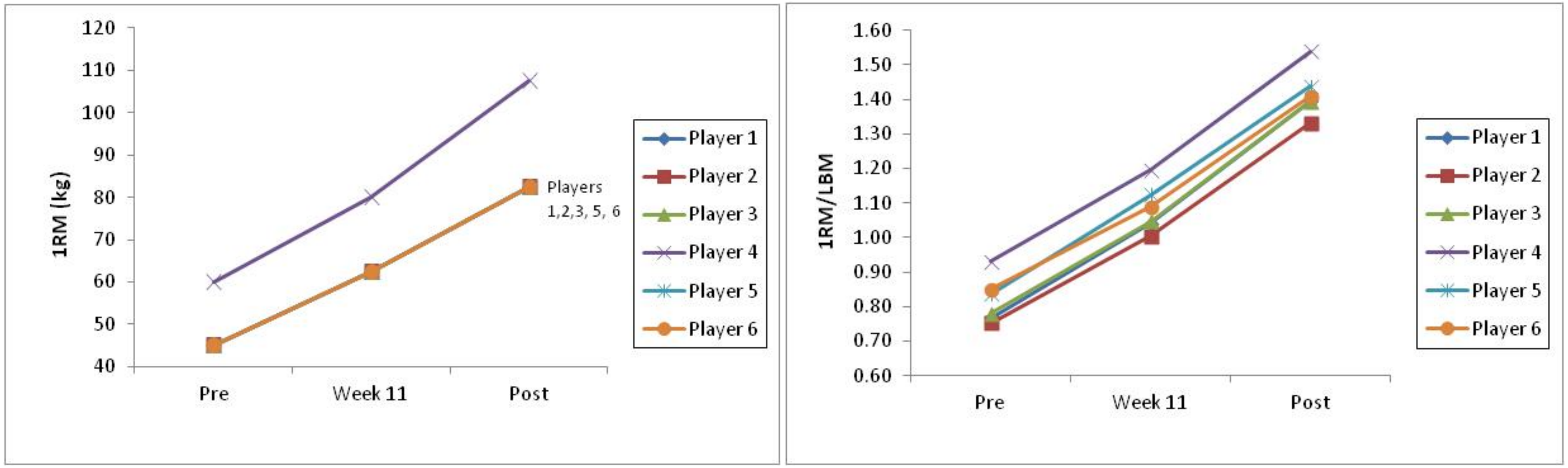

Figure 4.5: Bench Press 1RM and 1RM/LBM Ratio changes player by player across the 26 week intervention.

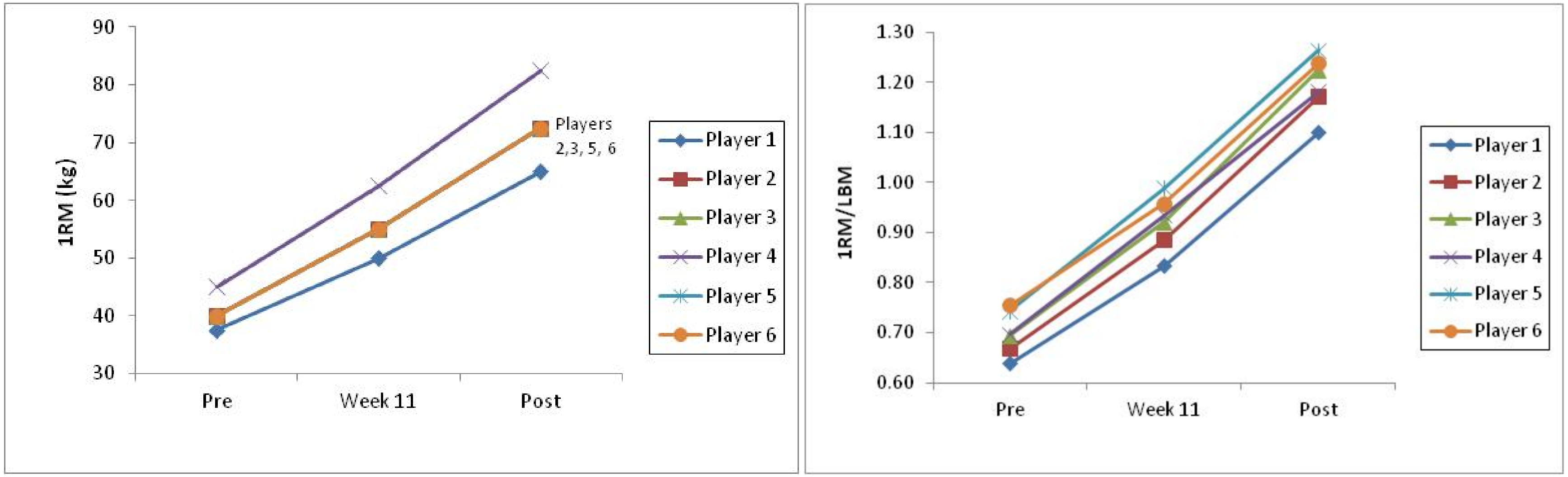

Figure 4.6: Prone Row 1RM and 1RM/LBM Ratio changes player by player across the 26 week intervention.

4.4 Performance Measures

4.4.1 CMJ

Mean ± SD CMJ performance improved from 42.7±4.0 to 48.8±5.6 cm (*d*=1.10) (see Figure 4.7). Commensurate with this, increases were observed in PP (pre = 6847±353, post = 7318±484 W; *d*=1.00) and AP (pre = 1039±165, post = 1227±215 W; *d*=0.91) (see Figure 4.8). Large effect sizes were observed for CMJ, PP and AP.

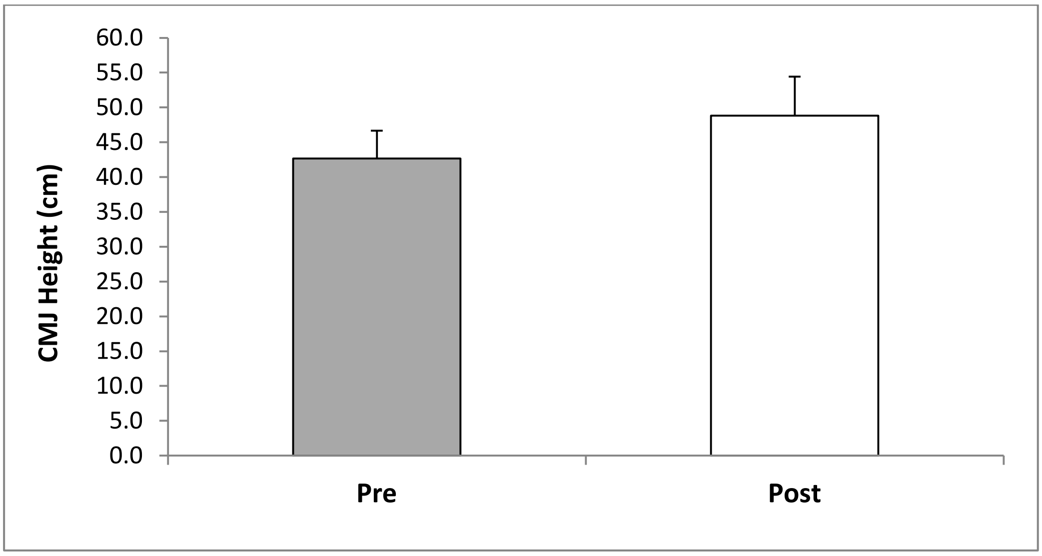

Figure 4.7: Mean ± SD counter movement jump heights (cm) pre and post training.

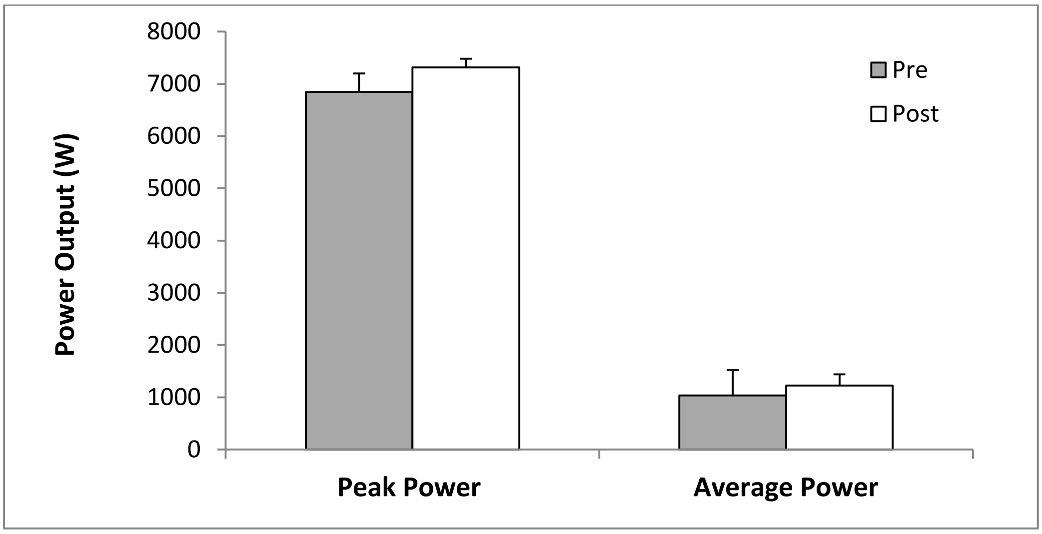

Figure 4.8: Mean ± SD peak power output (W) and average power output (W) from CMJ pre and post training.

4.4.2 Sprint Performance

An improvement in sprint performance coupled with a moderate effect size was observed pre to post in 5m (pre =1.20±0.07, post =1.16±0.06 s; *d*=0.61), 15m (pre =2.59±0.05, post = 2.53±0.14 s; *d*=0.60) and 30m (pre =4.44±0.08, post =4.39±0.08 s; *d*=0.52) (see Figure 4.9).

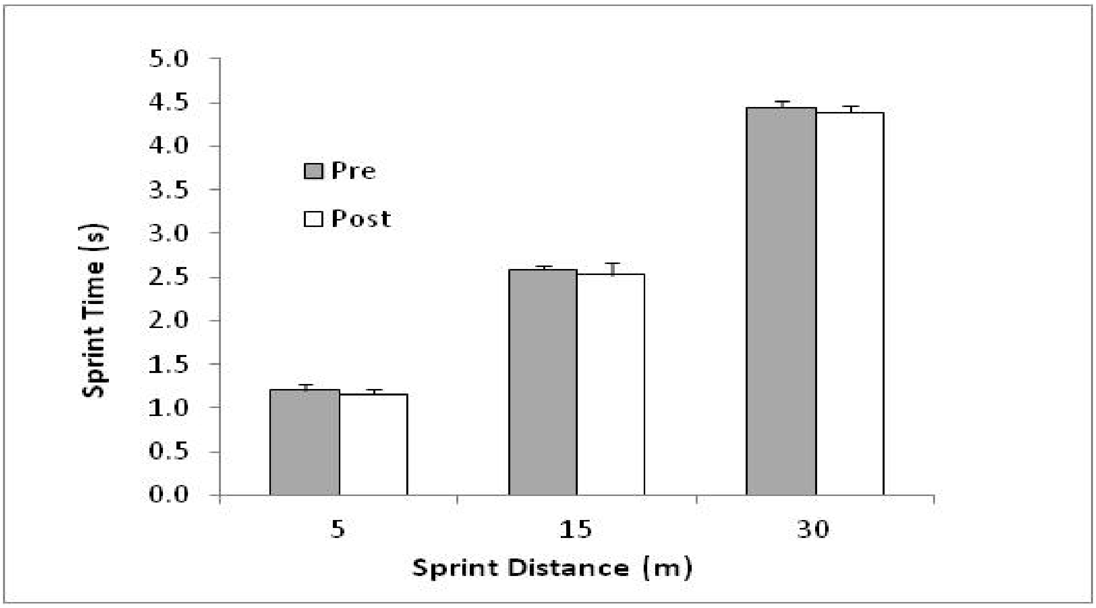

Figure 4.9: Mean ± SD sprint times (s) for 5, 15 and 30 meters pre and post training.

4.4.3 T-Test

T-Test data (see Table 4.4) was assessed between DL and NDL for differences between pre DL to post DL, pre NDL to post NDL, pre DL to pre NDL and post DL to post NDL. Moderate effect size was noted between DL and NDL pre intervention (*d*=0.65), a small effect size was however observed post intervention between DL and NDL (*d*=0.37). Pre to post an improvement in NDL T-Test performance and moderate effect size was observed (*d*=0.42), there was not an associated improvement in DL T-Test performance post intervention (*d*=0.08)

Table 4.4: Mean ± SD scores for Dominant Limb and Non Dominant Limb in the T-Test

	Dominant Limb	**Non Dominant Limb**
Pre	10.48 ± 0.40	10.67 ± 0.16
Post	10.44 ± 0.45	10.58 ± 0.29

4.4.4 Performance Measure Analysis of Individual Players

All 6 players produced increases in CMJ height from pre to post (see Figure 4.10) ranging from 7.3-23.9% (see Table 4.5). Corresponding to this increase in CMJ height all players with the training programme showed increase in PP (see Figure 4.11) and in AP (see Figure 4.12).

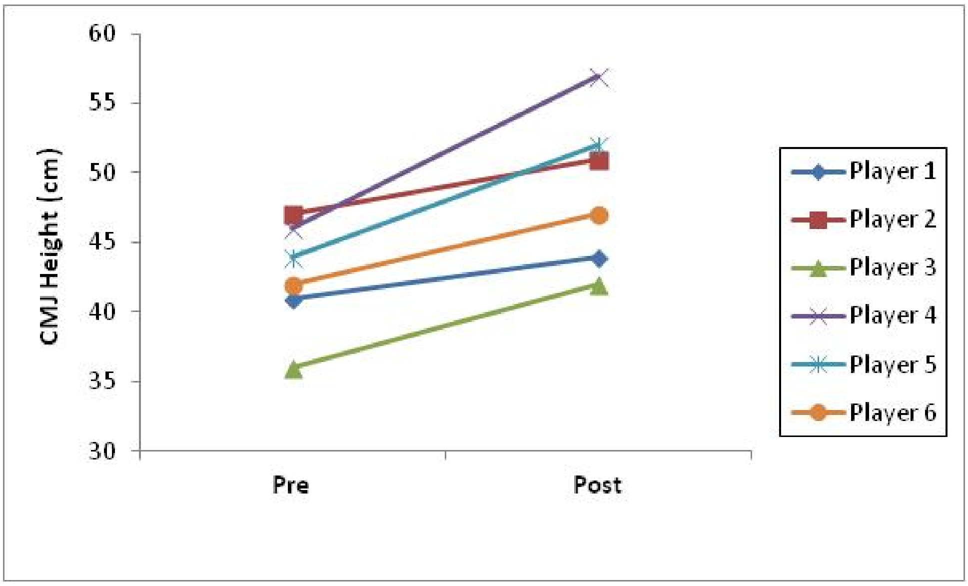

Figure 4.10: Pre and Post CMJ Height (cm) performance scores player by player across the 26 week intervention.

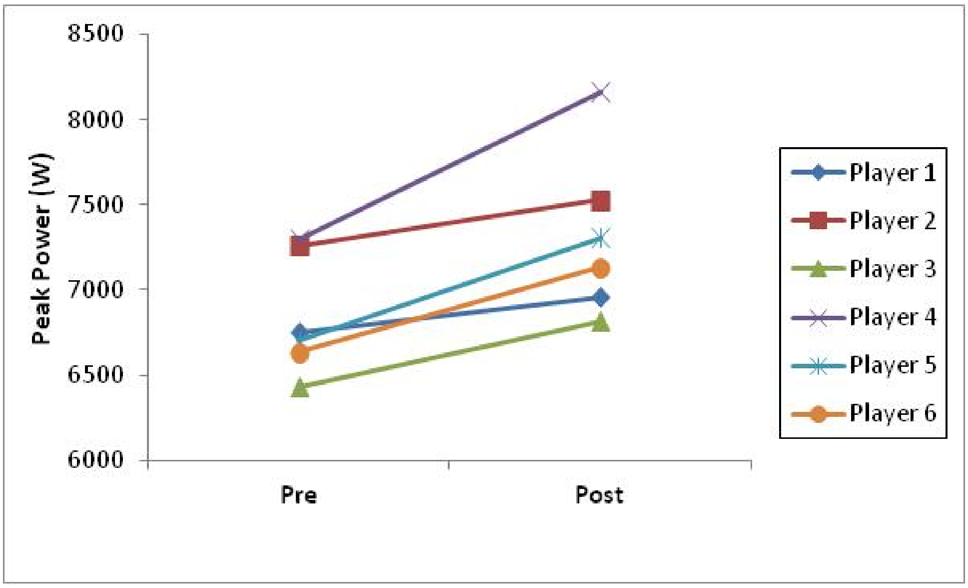

Figure 4.11: Pre and Post Peak Power (W) from CMJ performance scores player by player across the 26 week intervention.

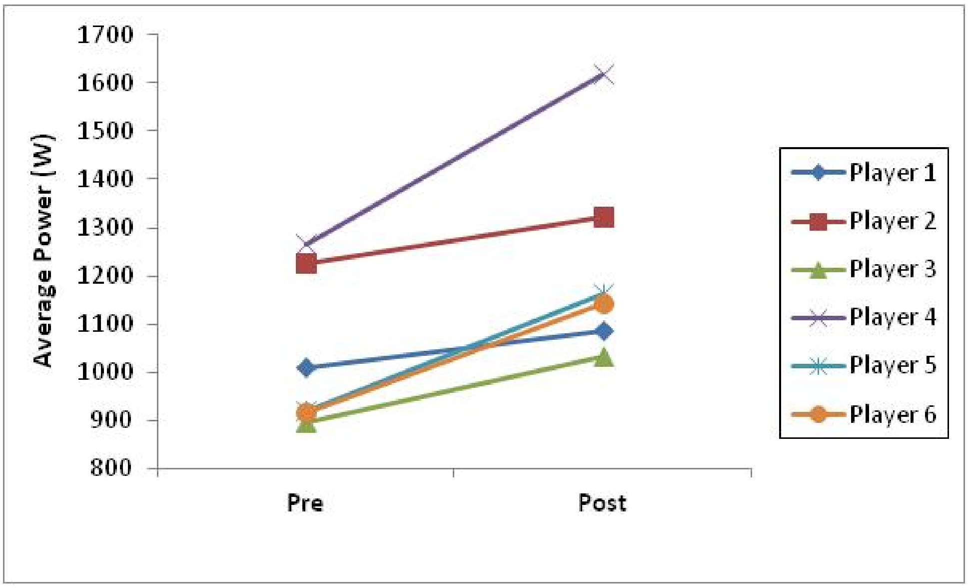

Figure 4.12: Pre and Post Average Power (W) from CMJ performance scores player by player across the 26 week intervention.

In relation to sprint performance within the squad of players only 2 of the 6 showed increases in 5m sprint performance (see Figure 4.12), 4 of the 6 players showed improvement in 15m sprint performance (see Figure 4.13) and 5 of the 6 players illustrated improvement in 30m sprint performance (see Figure 4.14).

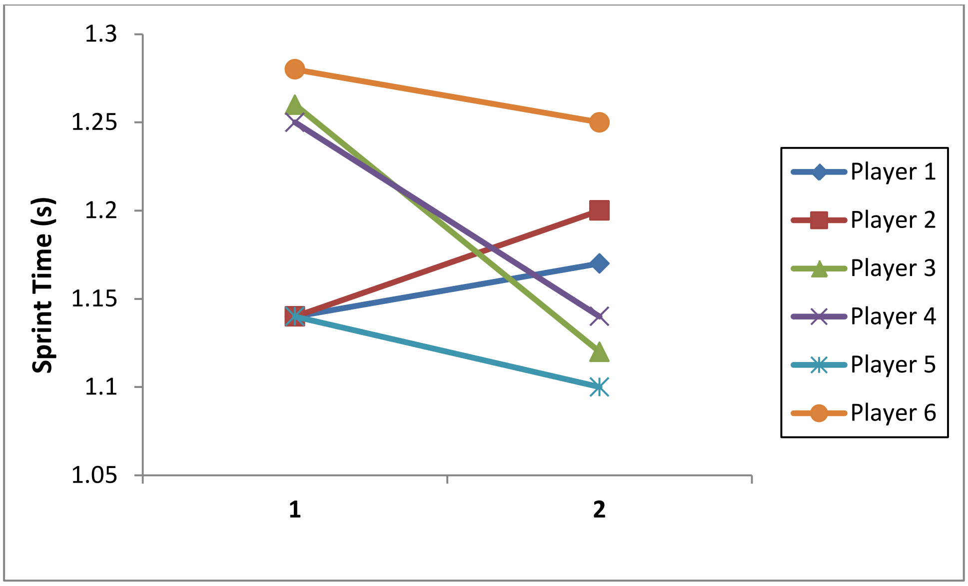

Figure 4.13: Pre and Post 5m sprint performance times (s) player by player across the 26 week intervention.

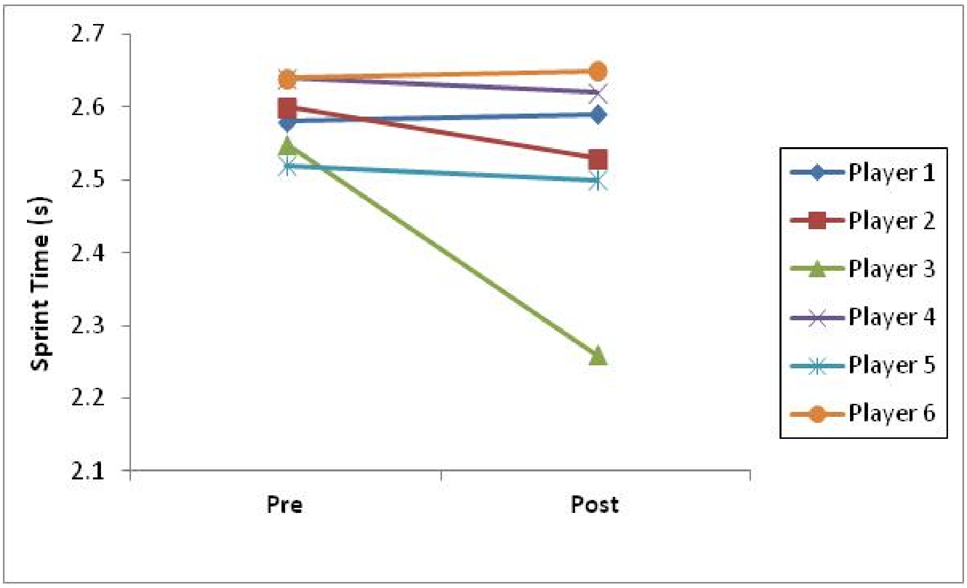

Figure 4.14: Pre and Post 15m sprint performance times (s) player by player across the 26 week intervention.

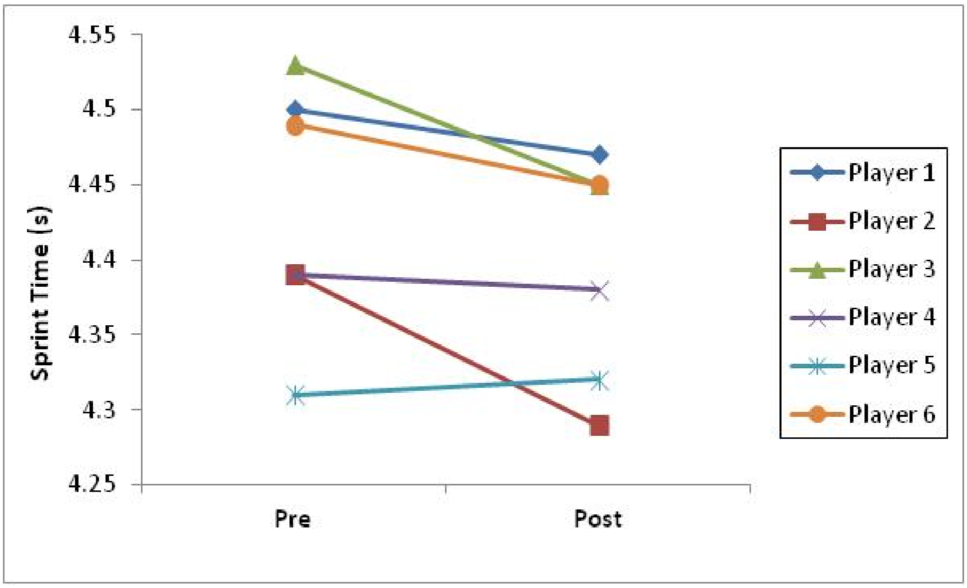

Figure 4.15: Pre and Post 30m sprint performance times (s) player by player across the 26 week intervention.

4.5 Performance Transfer

In relation to performance transfer, mean (± SD) strength gains in the lower limb 1RM scores were 74.9 ± 2.7% (measured through squat performance), in addition to this a 14.4 ± 6.34% increase in CMJ, PP increased by 6.9 ± 3.4%, and AP by 18.3±9.3%. A 3.44 ± 6.77 increase in 5m sprint time, a 2.47 ± 4.50% decrease in 15m sprint time and a 0.93 ± 0.94% decrease in 30m sprint time was also observed post training.

The ratio of performance transfer calculated against the 74.9% increase in squat performance was 0.19 (CMJ), 0.09 (PP), 0.24 (AP), 0.05 (5m sprint), 0.03 (15m sprint) and 0.01 (30m sprint).

No significant correlations were observed for % change in performance measures over the three sprint split times and CMJ in relation to % changes in lower limb 1RM score or lower limb 1RM/LBM or absolute changes in performance measure over the three split times and the absolute changes in 1RM score or lower limb 1RM/LBM (P>0.05).

4.5.1 Performance Transfer Analysis of Individual Players

Table 4.5 illustrates player by player analysis of % change in performance pre to post across all performance measures and the performance transfer ratio related to improvements in lower limb function (through 1RM squat performance). Only 1 player exhibited positive improvements and positive performance transfer across all measures. The lowest level of performance transfer appeared to occur within 5 m sprint performance, with poor levels of performance transfer being observed by all players in all the sprint tests distances.

Table 4.5: Percentage change and performance transfer ratio for all players across the field based performance measures related to percentage of improvement in lower limb strength gains.

Test	**Squat**		**CMJ**		**PP**		**AP**		**5m**		**15m**		**30m**	
Player	**% Change**	**Transfer Ratio**	**% Change**	**Transfer Ratio**	**% Change**	**Transfer Ratio**	**% Change**	**Transfer Ratio**	**% Change**	**Transfer Ratio**	**% Change**	**Transfer Ratio**	**% Change**	**Transfer Ratio**
P1	73.9	-	7.3	0.10	3.0	0.04	7.5	0.10	-2.6	0.04	0.4	-0.01	-0.7	0.01
P2	75.9	-	8.5	0.11	3.7	0.05	7.9	0.10	-5.0	0.07	-2.7	0.04	-2.3	0.03
P3	77.8	-	16.7	0.22	6.0	0.08	15.3	0.20	12.5	-0.16	-11.4	0.15	-1.8	0.02
P4	72.4	-	23.9	0.33	11.8	0.18	27.8	0.38	9.6	-0.13	-0.8	0.01	-0.2	0.00
P5	77.8	-	18.2	0.23	9.1	0.12	26.5	0.34	3.6	-0.05	-0.8	0.01	0.2	0.00
P6	71.4	-	11.9	0.17	7.5	0.11	24.7	0.35	2.4	-0.03	0.4	-0.01	-0.9	0.01
Mean	74.9		14.4	0.2	6.9	0.1	18.3	0.2	3.4	0.0	-2.5	0.0	-1.0	0.0
SD	2.7		6.3	0.1	3.3	0.1	9.3	0.1	6.8	0.1	4.5	0.1	0.9	0.0

4.6 Functional Movement Screening

Mean total scores increased from pre (13.8 ± 1.2) to post (17.5 ± 0.9, *P*<0.05, 17.6% increase). Significant differences pre and post were observed in overhead squat, in-line lunge and trunk stability push up (*P*<0.05). No significant differences were observed for straight leg raise, rotary stability and shoulder mobility (*P*>0.05) (see Table 4.6).

Table 4.6: Mean ± SD and % Change of Pre and Post FMS™ scores

	Overhead Squat	In-Line Lunge	Hurdle Step	Straight Leg Raise	Rotary Stability	Trunk Stability Push Up	Shoulder Mobility	Total
Pre	2.1±0.2	1.8±0.6	2.3±0.4	2.0±0.6	1.5±0.6	2.3±0.4	1.9±0.5	13.8±1.2
Post	2.8±0.3	2.5±0.5	2.8±0.3	2.2±0.4	2.0±0.0	2.8±0.3	2.4±0.4	17.5±0.9
% Change	23.3*	23.3*	16.7	6.7	16.7	16.7*	16.7	17.6*
Responders	5	5	4	1	3	5	3	6

*Statistically Significant *p*<0.05

Across the 5 tests that measure asymmetries in movement there were a 40% instance of asymmetries within the squad prior to the intervention, when upper body asymmetry was removed there was a 30% occurrence of asymmetry within the squad. Post the 26 week programme a 10% asymmetry occurrence rate was observed and an 8% occurrence rate when upper body asymmetries were removed. Despite asymmetries being observed in absolute scores on the FMS™ no significant difference was observed between the non dominant and dominant side of each test pre or post the intervention (*P*>0.05). Significant differences however were observed pre to post between scores in the non dominant side in-line lunge and dominant side in-line lunge (*P*<0.05). Table 4.7 outlines the instances of asymmetry per test pre and post the training period.

Table 4.7: Number of instance of asymmetry per FMS™ test pre and post the training intervention

	Number of Asymmetries	
FMS Test	**Pre**	**Post**
In-Line Lunge	2	0
Hurdle Step	3	0
Active Straight Leg Raise	1	1
Rotary stability	2	0
Shoulder Mobility	4	1

4.7 Injury

4.7.1 Exposure to Injury Risk

Table 4.8 outlines individual and mean ± SD player exposure to match play and training in minutes and the percentage of exposure against total exposure time available over the intervention period from playing and training. Total exposure hours for the players 1226.6 hours, 1063.5 hours exposure were related to training and 164.2 hours exposure related to match play.

4.7.2 Injury Incidence and Severity

During the 26 week training period within the playing group there were two instances of time-loss, non-contact, lower limb injury, both with a severity rating of slight, resulting in 3 training days lost and no missed matches (see table 4.8). One injury was a groin strain and categorised as acute, the other injury was inflammation to the Achilles tendon and classed as over use. When related to exposure, injury rate was calculated at 0.94 per 1000 hours of training exposure, estimated at 6.1 per 1000 hours of match play exposure and 1.6 per 1000 hours of total exposure. 1 injury occurred during training and one injury occurred during a match, neither injury was classified as a reinjury.

Table 4.8: individual and mean ± SD player exposure in minutes, percentage of exposure against total exposure time available and injury occurrence and days lost through injury over the 26 week intervention period.

	No of Sessions Trained	Total Minutes Trained	Training Attendance %	No of Games Played	Total Minutes Played	% of Potential Playing Time	Total Minutes Exposure	Injury Instance	Days Lost Through Injury
Player 1	141	11520	99	19.9	1788	69	13308	0	0
Player 2	104	8220	73	10.2	915	35	9135	0	0
Player 3	141	11520	99	19.1	1720	66	13240	1	1
Player 4	140	11790	98	22.5	2027	78	13817	0	0
Player 5	115	9360	81	21.4	1928	74	11288	1	2
Player 6	139	11400	98	16.4	1474	56	12874	0	0
Mean	130	10635	91	18.2	1642	63	12277	0.3	0.5
SD	16	1479	11	4.5	404	15	1765	1	1

4.8 Results Summary

Positive improvements were observed across all the players for gym performance measures. All players also showed increases in LBM and reductions in BF% from pre to post across the intervention period. In addition to this, a positive performance increase was also observed in CMJ performance and the associated variables of PP and AP. A moderate improvement in 5m, 15m and 30m sprint times were shown following the intervention. In addition to this a moderate effect size was observed pre to post for improvement in T-Test scores for NDL and a reduction in asymmetry of scores from DL to NDL was observed post intervention. Despite large positive gains in the strength profiles of the athletes performance transfer to tests of CMJ and sprint times were of a lower magnitude with complex movement patterns showing less performance transfer. Positive improvement was observed in FMS scores and a reduction in the instances in asymmetries observed across the players. Low rates of injury were also reported in the playing group during the 26 week intervention period.

5. Discussion

The aim of the study was to ascertain the effect of an in-season S&C programme on multiple facets of performance enhancement in elite academy footballers. The qualities to be enhanced incorporated strength, power and lean body mass gains. The impact of those strength gains on performance measures related to football, as well as the impact on injury parameters such as reducing injury rates and improving players' movement quality.

5.1 Anthropometric Variables

Anthropometric data (see Table 4.1) for the subject group, shows a similar mean height (pre 175.3 ± 6.6cm, post 175.9 ± 6.1cm) when compared to age matched elite academy players with a mean range of 175-179cm (Leatt *et* al., 1987; MacMillan *et* al., 2005; Stlølen *et al*., 2005). Mean body mass in elite U18 academy players has been observed at 69-71 kg (Leatt *et* al., 1987; MacMillan *et* al., 2005; Stlølen *et al*., 2005), the body mass of the athlete group pre-intervention was 66.2 ± 5.0kg. This supports the coach's decision to prioritise hypertrophy training in the early stages of the season, despite its potential for negative impact on performance from fatigue due to the high VL (see Table 4.2/Figure 4.3). Post intervention body mass was observed as 68.7 ± 5.2kg, this was coupled with a increase in LBM from 57.9 ± 4.2kg to 61.0 ± 4.6kg post intervention. The greatest magnitude of increase in LBM was observed at week 11 testing after the preceding mesocycle aimed at developing hypertrophy. No difference was observed in LBM from week 11 testing to post intervention testing, although an increase in LBM for the group was observed and a moderate effect size was reported pre to post for the intervention illustrating gains in the early phase of the season were maintained. While gains in LBM were not expected in players outside of the hypertrophy phase of training, 3 players demonstrated LBM gains during this period of the intervention however 2 of the 3 players showing increases in LBM during the post week 11 training also increased in height and therefore changes in LBM needed to be treated cautiously when related to a training stimulus (see Figure 4.1). 3 of the players showed small decreases in LBM from week 11 to post intervention (see Figure 4.2). The reduction in LBM could be attributed to detraining effect observed in other studies (Dos Remedios *et al*., 1995; Fleck and Kraemer, 1997; Schneider et al., 1998; Baker, 2001), who showed reductions in strength and power over 13-16 weeks, one of the proposed mechanisms for the reduction in strength and power outputs was a decrease in training volume, removing the stimulus for hypertrophic adaptation and an increase in energy system training which has been proposed to have catabolic nature (Chadd, 2010).

BF% decreased from pre intervention (12.5±1.7%) to week 11 (11.1±1.2%) and pre to post observed through large reported effect sizes. No difference was observed from week 11 to post intervention in BF%. BF% in-season in professional players of 8.6-11.5% has been observed (Casajus, 2001; Ostojic, 2003; Silvestre *et al*., 2006; Carling and Orhant, 2010). It would therefore appear that in early season, BF% reduced in line with results observed in other studies (Casajus, 2001; Ostojic, 2003), and BF% remained unchanged from week 11 to post intervention as observed in Kraemer *et al*. (2004), Silvestre *et al*. (2006) and Magal *et al*. (2009). An underlying reason for this variation may be due to the athletes' pre-season preparations prior to commencement of the S&C programme. The BF% of 12.5% measured is high when compared to the in-season BF% illustrated above, but is in-line with BF% observed by Ostojic (2003) in elite football players prior to commencement of pre-season training. The improvement of parameters of performance throughout in-season has been suggested to be based in low levels of fitness at the end of pre-season (Casajus, 2001; Magal *et al*., 2009) and therefore this may highlight a limited focus of pre-season work on body composition improvements. Individual analysis of players (see Figure 4.2) illustrates one player, showing a pattern of reduction in early season BF% and an increase in BF% in the later stages of a season observed by Carling and Orhant (2010), it was proposed that this finding could be explained by the tuning down of training intensity toward the end of the season, leading to a falling off in fitness measures. That this pattern was only observed in one player and as no difference was observed in overall playing and training time between players, it would appear other factors may contribute to this trend. Positional differences have been shown to impact workload, with midfield players covering more distance in a match than other players (Stlølen *et al*., 2005), contributing to positional differences in BF% response to in-season demands of football. No means of monitoring actual workload, for football based activities, such as GPS, was employed in this study, however a relationship may exist between this and athletes response to in-season demands. In addition to this, no record of player's calorie intake throughout the intervention period was taken and player diet was not controlled by a nutritionist, this could have a direct impact on the BF% response of team members to in-season demands.

5.2 Volume Load and Volume Index

Training volume (sets x repetitions) for the intervention period was prescribed. However the VL and subsequent VI were impacted upon by the amount of load per repetition each of the subject group could lift, which was related to the individual's strength profile. Significant differences were observed between players' mean weekly VL and VI in the Muscular Endurance/Hypertrophy, Strength and Power One and Max Strength and Power phases of the training programme. In all 3 training phases that illustrated significant differences in VL and VI a new training pattern of sets and repetitions was introduced to the athletes. The training phases that replicated set and repetitions prescriptions of the immediately preceding phase however did not show significant differences between the athletes. This pattern would suggest that some players within the subject group responded more positively to variations in training load than other members of the group.

The ability to tolerate changes in training volume, has been shown in more advanced athletes and allows for the administration of more complex methods of periodisation such as CSS (Plisk and Stone, 2003). While the performers in this study had no formal background in S&C training, it is recognised by the investigator that some of the subjects displayed techniques and body characteristics of recreational gym use based on aesthetic improvement. The muscles ability to generate force is dependent on many different factors of which the most common are initial position, speed of lengthening, speed of shortening, eccentric initial phase, types of muscle fibres, number of motor units active at the same time, cross sectional area of the muscle, impulse frequency and substrate available for exercising muscles (Behm and Sale, 1993). The athletes with a background in recreational gym work would possess improvements in many of the neural aspects illustrated above and have greater levels of motor control patterns and coordination in movement, which novice athletes do not possess during the initial neural training phase at onset of resistance training (Fleck, 1999; Baechle and Earle, 2008).

While no studies to the author's knowledge have published detailed VL and VI related to subject performance in a training intervention, there is a substantial agreement with Chadd (2010) that it provides greater insight to the progression and loading involved in applied interventions than demonstrated by the recording of just sets and reps completed in a programme.

5.3 Performance Measures and Performance Transfer

5.3.1 Resistance Training Performance

Large effect sizes were observed for pre to post for improvements in 1RM and 1RM/LBM measures squat, bench press and prone row (see Table 4.3). Due to the high levels of performance in football relating to lower limb action, the focus for subsequent discussion shall focus on performance in relation to the squat exercise. All players observed gains in squat performance of over 70% (see Table 4.5), with a mean squat performance increase of 74.9±2.7%. Post intervention squat values (118.8±9.7kg) were observed in the range for elite youth team football players of 105-142kg (MacMillan *et al*., 2005; Chelly *et al*., 2009) and at the lower end of the range (115-209kg) observed for senior professionals (Hoff and Helgerud, 2002; White *et al*., 1988; Wisløff *et al*., 1998; Ronnestad *et al*., 2008).

The magnitude of increase seen in squat improvement is considerably higher than observed in other training studies of between 21-34% (Hoff and Helgerud, 2002; Helgerud *et al*., 2002; Ronnestad *et al*., 2008; Chelly *et al*., 2009). A number of reasons may contribute to the discrepancy seen between the current study and previous research. The above studies were all undertaken over a 7-8 week training period, as opposed to the 26 week training period and therefore the magnitude of improvement would be anticipated to be greater in the current study. In addition to this, the athletes experience in relation to the exercise may impact upon pre intervention 1RM measurements. Helgerud *et al*. (2002) and Chelly *et al*. (2009) observed the largest increases in squat performance (34 and 26% respectively) of the studies above and used athletes with no experience of squatting. As discussed earlier, at the onset of an exercise programme, rapid increases in loads lifted are due to positive adaptation at a neural level as opposed to true gains in strength. These increased gains in performance, lend strength to the argument for use of increasing loads using methods such as the 2-for-2 rule (Baechle and Earle, 2008), with the athlete able to regulate load increases without having to wait for further testing of 1RM, which is difficult in the time constraints of a professional sport environment. If novice performers are subject to higher rate increases in load lifted due to the onset of training, it is highly likely that with novice S&C athletes, such as the ones used in this study, that pre test measures are not a true reflection of the athlete's strength and therefore would overestimate the magnitude of change in performance post testing. The use of multiple repetition testing and prediction of 1RM scores from prediction equations is seen as one method to combat this, as well as reduce injury risk (Baechle and Earle, 2008) and has been demonstrated to have high reliability (LeSeur *et al*., 1997). Additional methods of testing 1RM could be utilised to ascertain actual strength values, these would include a leg press machine or isokinetic testing, however the leg press removes the stabilisation of the body through the range of motion and control of the weight against gravity, much in the way seen with Smith machines and therefore lacks functionality as seen with isokinetic testing (Cotterman *et al*., 2005; Stløen *et al*., 2005). Thorstensson *et al*. (1976) (cited in Hoff and Helgerud, 2004), observed significant improvement in 1RM squat and maximal static strength, with no improvement represented in isokinetic knee extension, and therefore isokinetic measures may have narrow interest for use in predicting strength values for dynamic sport (Hoff and Helgerud, 2004). It is therefore clear that a trade off is required in the delivery of applied S&C when determining the mode of testing for strength and an understanding of the limitations and potential for measurement error is considered when interpreting results. The use of free weights through standardised movement patterns such as the squat will more accurately reflect the functional strength of the athlete (Wisløff *et al*., 1998; Hoff and Helgerud, 2004) and the availability of the required equipment makes it a preferred method for athlete assessment in an applied setting.

In relation to 1RM/LBM a ratio of 2.0 is considered a base standard for squat performance for professional football players (Hoff and Helgerud, 2004). Post intervention two of the players did not reach this parameter; one of the players had the greatest height and mass of the subject group, Hoff and Helgerud (2004) propose that the use of allometric scaling should be implemented when setting resistance training goals in relation to body mass of the players as larger individuals will be at a greater disadvantage than smaller individuals.

5.3.2 Performance Measures

It is considered important when measuring athletic performance that reliable measures are utilised to ensure reproducible test, with low variability in results, which enable accurate tracking of performance changes (Hopkins *et al*., 2001). Although no scope was available to undertake reliability studies in the performance measures utilised with this athletic population, the literature does support high levels of reliability in these tests with the current subject group. Hopkins *et al*. (2001) have reported coefficient of variation (CV) of approximately 0.9% for sprint running and CV for 10m and 20m sprint testing in male professional soccer players being measured and 2.3 and 1.2% respectively (Mirkov *et al*., 2008). Similar findings have been reported for CMJ measurement with CV of ~2.% (Hopkins *et al*., 2001; Jensen *et al*., 2011). In addition to this additional factors have been cited in decreasing variability of test-retest performance. The higher the training status of the athlete decreases the variability of results between tests and therefore increases the reliability of the measure, possibly due to the frequent exposure to competition, training and testing of a similar nature (Hopkins *et al*., 2001). Allowing athletes multiple attempts at a test and the sensitivity of the equipment, for example the use of timing gates over stopwatch for sprint time measurement, has also been suggested to reduce the CV between trials (Hopkins *et al*., 2001; Sporis *et al*., 2010). In light of the above, with the current subject group being highly trained, regularly exposed to systematic testing, having multiple attempts at each test in a session and the use of timing gates and jump mats for recording of data it can be considered that a high level of reliability is present in the current data.

All players demonstrated an improvement in CMJ and a commensurate improvement in PP and AP (see Table 4.5); mean improvement for the group in CMJ was 14.4% (42.7±4.0 to 48.8±5.6cm). Mean CMJ height for the players was in-line with CMJ heights of 34-54cm observed in other studies involving elite youth players (Leatt *et al*., 1987; Garganta *et al*., 1992; MacMillan *et al*., 2005; Chelly *et al*., 2009; Buchheit *et al*., 2010). The magnitude of improvement was however considerably greater than observed in other studies of between 5-9% (Hoff and Helgerud, 2002; Helgerud *et al*., 2002; Ronnestad *et al*., 2008; Chelly *et al*., 2009). This is not unexpected however as the above improvements in squat performance and duration of the training intervention far outweigh those in these studies.

Meaningful change, illustrated by moderate effect size improvements in sprint performance was in 5m, 15m and 30m sprint (see Figure 4.9). This is consistent with other studies that have seen a 1-3% improvement in sprint performance (Hoff and Helgerud, 2002; Helgerud *et al*., 2002; Ronnestad *et al*., 2008; Chelly *et al*., 2009) following strength training interventions, however all these were conducted during pre season training periods. When considering the possible implications for this outcome, multiple factors need to be assessed including performance transfer and seasonal variations in performance measures as outlined below.

Moderate effect sizes were also reported for improvements in NDL T-Test performance, coupled with no improvement in DL performance. There was however observed a reduction in the asymmetry of performance between NDL and DL at post testing. With asymmetry being an associated risk factor for injury (Keisel *et al*., 2008) this reduction in performance decrement between DL and NDL maybe an important improvement in performance through the season in reducing players injury risk.

5.3.3 Performance Transfer

Young (2006) proposed that transfer could be expressed as gain in performance/gain in trained exercise, giving a ratio of performance transfer. As the figure presented approaches 1.0 the magnitude of transfer could be suggested to be greater, with an ideal performance transfer measure being 1.0. To the investigators knowledge no other author has presented actual data on performance transfer using Young's equation for comparison. However calculation from data presented in the above mention training studies in football players would show performance transfer ratios of 0.08-0.2 for 10m sprints (Hoff and Helgerud, 2002; Helgerud *et al*., 2002; Ronnestad *et al*., 2008), 0.06 for 20m sprints (Helgerud *et al*., 2002), 0.05 for 40m sprints (Ronnestad *et al*., 2008) and 0.15-0.35 for CMJ (Helgerud *et al*., 2002; Ronnestad *et al*., 2008; Chelly *et al*., 2009). Only performance transfer for CMJ in the present study falls within a range observed in the above studies, no other detailed data in relation to football could be found to ascertain performance transfer ratio for 5, 15 and 30m sprints. It would be reasonable to suggest that for 10m and 40m performance transfer ratios are all above 0.05, a similar pattern would be expected at other distances within that range and are greater than the highest presented here of 0.03 in a 15m sprint. It is clear from the above data that all studies, including this one, illustrated a greater overall % increase in performance and subsequently an overall better ratio of transfer to performance in CMJ than any of the sprint measures. In strength training studies, it has been observed that measured increases in strength are dependent on the similarities between the training and testing exercise, due to the specificity of neuromuscular learning and coordination and reaction to speed of contraction stimulus (Almasbakk and Hoff, 1996; Stløplen *et al.*, 2005). With CMJ directly incorporating movement patterns associated with the performance of a squat and portions of the Olympic lifting techniques employed consistently throughout the training intervention, high levels of specificity are therefore present and it is not surprising greatest level of transfer is therefore seen in this test of performance.

No specific sprint training was imposed during the course of the S&C training programme, despite the use of lunge patterns and single leg work which may have been expected to improve the exercise specificity and subsequently improved the possibility of transfer. However sprinting performance is a complex movement pattern involving unilateral contraction of hip flexors to propel motion (Young, 2006) and a more integrated approach may be required to enhance performance transfer in athletes.

Therefore it can be seen from the above that the magnitude of performance transfer seen in this study and percentage improvements has been less than those seen in other studies. As all other studies have been conducted in off-season or pre-season, the effect of in-season competition and training schedules and measure of performance must be examined in relation to the current study. It is clear from current research that consistent match play and training brought about by in-season schedules has negative impact on strength profiles of players, sometimes even when coupled with resistance programmes aimed at maintenance (Dos Remedios *et al*., 1995; Fleck and Kraemer, 1997; Schneider et al., 1998; Legg and Burnham, 1999; Baker, 2001). Mechanisms for this include a reduction in LBM, as observed here and covered above, through removal of training stimulus for muscular hypertrophy and the catabolic nature of football match play and energy system training (Chadd, 2010). Monitoring of limb girths throughout the season may offer more in depth analysis relating to this as a proposed function for strength loss.

Previous studies have shown reductions in sprint and CMJ performance in football players over the course of a season (Kraemer et al., 2004; Cladwell and Peters, 2009). The current data set did not support this trend, and with improvement being observed in sprint performance, the application of strength training may have maintained performance levels despite in-season demands on athletes. This is consistent with other studies utilising S&C throughout the season with no change in sprint performance and vertical jump (Casjus, 2001; Silvestre et al., 2006).

No improvement in vertical jump that has been seen in the current literature. Despite in-season demands we have observed significant improvements in vertical jump performance, this may be attributable to the application of Olympic lifting techniques and derivatives of these lifts consistently throughout the 26 week intervention, the movement patterns and rate of force development in these lifts have high levels of specificity to jumping movement patterns and has been observed to illicit greater improvements in vertical jump performance than traditional power lifting exercises (Hoffman *et al*., 2004).

Playing proximity to testing may also have had an impact on post intervention performance tests, despite monthly minutes being calculated for exposure, no record of the distribution of those minutes in relation to subsequent testing was monitored, therefore players with a full 90 minutes performance immediately preceding post intervention testing may have a negative impact on performance measures. A full 96 to 120 hours of rest was hypothesised as necessary to return pre-match performance levels in 20m sprint and vertical jump performance (Andersson *et al*., 2008; Ispirlidis *et al*., 2008). While all players were in this window of recovery during post testing, player's individual response to recovery should be monitored and taken in to account to reduce the impacts of match and training fatigue on performance measures and ultimately it has been recommended to wait until all residual fatigue associated with training programmes has subsided before post test evaluation (Svensson and Drust, 2005). While the author accepts this, the applied nature of the intervention meant that almost immediately after the close of season, players are released from day to day commitments at football club and therefore only a small window of opportunity for retesting is available. It would appear in this situation, best practice would be to maintain as much consistency as possible with regard to training, playing and rest conditions at each scheduled battery of tests.

It is clear from the above that performance transfer from gym based gains to performance gains in football related performance measures are multi-factorial, and dependant on S&C experience of the athletes, time of training stimulus in relation to other sporting demands and the nature and quality of the periodised plan and specificity of the exercise selection. These parameters should be considered in the design and implementation of an S&C programme, particularly if over extended seasons, small gains in performance are required rather than simply maintenance of pre-season performance levels.

5.4 Injury

It is acknowledged by the author that caution should be observed when interpreting the following data set relating to injury due to the size of the subject group.

5.4.1 Injury Incidence, Severity and Location

Injury rates for the current study were calculated at 0.94 per 1000 hours of training exposure, 6.1 per 1000 hours of match exposure and 1.6 per 1000 hours of total exposure. Injuries amongst senior male professional soccer players across a season have been estimated to range between 27 and 35 per 1000 match hours (Hawkins and Fuller 1999; Morgan *et al.,* 2001; Walden et al., 2005). Senior academy age group level (U17 and U18 combined), as used in this study, injury rates appear to mirror levels of those shown in senior male footballers, with a range being demonstrated per 1000 match hours of 27.9-37.2 (Hawkins and Fuller, 1999; Junge *et al*., 2004a; Junge *et al*., 2004c; Hägglund *et al*., 2009). The current study demonstrates substantially lower injury rates for match play than those observed in the above studies. Further to this injury rates per 1000 training hours are also substantially less than those reported by other investigators of 2.9-5.8 during in-season (Hawkins and Fuller, 1999; Morgan *et al.,* 2001; Walden *et al.,* 2005; Hägglund *et al*., 2009; Dupont *et al*., 2010; Dvorak *et al*., 2011). These figures are again mirrored in senior academy level football with injury rates per 1000 training hours to be 3.9-4.1 (Hawkins and Fuller, 1999; Le Gall *et al*., 2006). Injury rate expressed against total exposure was also observed to be substantially less in the current study than observed in previous research. Injury rates per 1000 hours of exposure have been observed between 8.5-9.4 per 1000 hours of exposure for senior players and the senior academy age group (Hawkins and Fuller, 1999; Walden *et al.,* 2005; Dupont *et al*., 2010).

S&C training has shown reduction in injury rates in other studies in football (Heidt *et al*., 2000) and American Football (Keisel *et al*., 2007; Keisel *et al*., 2008). Heidt *et al*. (2000), observed significant reductions in injury rates following a 7 week S&C programme in 14-18 year old female football players, while it is appreciated that injury mechanism and associated risk factors for female football players are different to male football players due to the variation in joint laxity and anterior cruciate ligament geometry between male and female athletes (Quatman *et al.,* 2008). It would therefore appear that S&C training specifically designed to incorporate key exercises for a reduction in injury risk has a positive effect on injury reduction and may have contributed to the low injury rate seen in this study.

A number of considerations need to be taken in to account when examining the injury data in the current study, however when comparing it to other studies undertaken. The definition of a 'time-loss' injury was implemented in the current study as opposed to other available definitions, such as a 'medical attention' definition, for reasons outlined in the introduction. In further defining 'time-loss', the current study utilised a definition of 'players missing next training session or match', reported elsewhere (Nielsen and Yde, 1989; Hawkins and Fuller, 1999; Walden *et al*., 2005; Hägglund *et al*., 2009; Dupont *et al*., 2010). Numerous reports in age groups football have however utilised the definitions of 'missing training or matches for 24 hours following the injury occurrence' (Drawer and Fuller, 2002; Froholdt *et al*., 2009), '48 hours following the injury occurrence' (Hawkins *et al*., 2001; Price *et al*., 2004; Le Gall *et al*., 2006) 'or one week after the injury occurrence' (Junge *et al*., 2000). The justification for use of these definitions, in age group football, is that the players do not play or train every day as seen in professional senior players. In the current study however, as with most elite senior academy teams, the players do train every day, and on most days multiple times. In this context it would appear that utilising definitions used elsewhere in age group football would not be a true reflection of injury rate within this squad, in fact neither injury recorded during the intervention periods would have been reported utilising a 48 hour or one week time-loss definition. Further to this the current investigation utilised actual exposure time for players, recording actual player minutes in matches and training in-line with other research in this area (Walden *et al*., 2005; Parry and Drust, 2006; Dupont, 2010; Ekstrand *et al*., 2011a). Studies that have utilised estimations of exposure time and not included overtime periods (Hawkins and Fuller, 1999; Morgan *et al*., 2001; Junge *et al*., 2004a, 2004b; 2004c; Froholdt, *et al*., 2009; Junge and Dvorak, 2010; Dvorak *et al*., 2011; Ekstrand *et al*., 2011b) have potential to over and underestimate exposure time and subsequently have an impact on the reported injury rate. The method of counting 'athlete-exposures' for calculating injury rate (Junge *et al*., 2004a; Junge *et al*., 2006; Yard *et al*., 2008), also has a major limitation in that the role of fatigue has been documented as a risk factor for injury in football (Hawkins and Fuller 1999; Hawkins *et al.,* 2001; Junge *et al.,* 2004, Yoon *et al.,* 2004; Woods *et al.,* 2004; Ekstrand *et al*., 2011), with more injuries being be reported at the end of each half and later in a game an athlete's duration of involvement has a potentially crucial bearing on the calculation of the injury risk in the sport. The presentation of data relating to match, training and total exposure is considered the preferable method of analysis for sport injury risk (Hawkins and Fuller, 1999; Junge *et al*., 2006; Le Gall *et al*., 2006; Froholdt *et al*., 2009; Hägglund et al., 2009; Dupont, 2010; Ekstrand *et al*., 2011a, 2011b) as clear differences lie within the risk of exposure for training and match play. The higher incidence of injury reported in the literature for match play in relation to training is supported by the current investigation.

Other than the limitation of the small subject group acknowledged above, the duration of the collection period in the current study needs to be examined when relating its findings to the existing literature. Only Froholdt *et al*. (2009) have reported data on injury rates that do not coincide with a full season or whole competitions play. There are potential implications in terms of calculating injury rate from only part season data, depending on the portion of the season included in the sample. Injury rates for training have been observed as higher during pre-season as opposed to in-season (Hawkins and Fuller, 1999, Hawkins *et al*., 2001; Price *et al*., 2004), with potential reasons for this being a greater density, volume and intensity of training being conducted in this period as opposed to tactical game play, and high levels of competition for starting places during this period. The current study did not incorporate pre-season in its data collection period and therefore could underestimate the injury incidence rate for training.

All injuries recorded in this study were in the lower extremity. Lower extremity injury has been illustrated to dominate football injury due to the nature and demands of the sport (Schmidt-Olsen *et al*., 1985; Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Junge *et al*., 2004a, 2004b, 2004c; Price *et al*., 2004; Walden *et al*., 2005; Wong and Hong, 2005; Le Gall *et al*., 2006; Dvorak *et al*., 2007; Froholdt *et al*., 2009; Dvorak *et al*., 2011, Ekstrand *et al*., 2011a, 2011b) and this result was therefore in-line with previous literature. All of the injuries were classed as slight and therefore had a time-loss of <3 days and were non-contact injuries. While slight injuries were anticipated to dominate the injury incidences in this study based on current literature (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Hägglund *et al*., 2005; Le Gall *et al*., 2006; Dvorak *et al*., 2007; Froholdt *et al*., 2009; Hägglund *et al*., 2009; Dvorak *et al*., 2011) with up to 78% of injuries resulting in time-loss of <7days. However to have no injuries in the playing group with consistent exposure time of minor, moderate or major, was unexpected. A number of reasons may be proposed for this. Many of the injuries with higher classifications of severity were highlighted as contact or muscle rupture (Hawkins and Fuller, 1999; Hawkins *et al*., 2001). With regard to muscle rupture the dominant location was observed in the hamstring muscle group (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Price *et al*., 2004; Walden *et al*., 2005; Ekstrand *et al*., 2011a, 2011b). The hamstring muscle group was consistently exposed to eccentric exercise throughout the entire intervention and has been demonstrated as a mode of exercise to reduce the risk of injury in the hamstring (Cleather and Brandon, 2007). The lack of contact injuries may also been impacted upon by the implementation of an S&C programme, players with an increased strength profile as demonstrated here, may possess enhanced ability to resist external forces acting upon them in dynamic sporting situations and therefore reduce the risk of contact related injury.

While there are multiple risk factors, both internal and external, when considering injury incidence, the occurrence of a groin strain in the current study, also highlighted as a high risk area of injury in football (Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Junge *et al*., 2004a; 2004b; Price *et al*., 2004; Le Gall *et al*., 2006), may highlight a limitation in the current training programme. No exercise in the current study was specifically targeted at injury prevention at the groin. The inclusion of exercises, such as lateral lunges, in subsequent training programmes could assist in reduce injury in this region.

5.4.2 Functional Movement Screening

Positive changes in the entire playing group were apparent in FMS™ scores over the 6 month intervention with mean group score improving from 13.8±1.2 to 17.5±0.9 (see Table 4.6). All players were also reported scores of >14. No other study has observed the changes in FMS™ scores over the course of a season, or following the implementation of an S&C intervention at any level of football. Keisel *et al*. (2007) proposed that athletes receiving a total FMS™ score of <14 were at an 11 fold increase of suffering injury. It would therefore suggest that the implementation of the S&C programme had a positive impact on injury risk in the current subject group. Keisel *et al*. (2009) implemented an S&C intervention in American Football players, to ascertain its effectiveness in improving FMS™ scores and reported 52% of players with scores lower than the threshold improved scores above 14. It is of interest though that this figure is only 52% when, unlike this intervention, players in this study were given specific individual exercises to improve the aspects of the FMS™ test where they performed poorly. This may indicate issues with player adherence to the programme. In the current investigation players improved in two of the three tests relating to the lower body function (overhead squat, in-line lunge), where the majority of football injuries occur (Schmidt-Olsen *et al*., 1985; Hawkins and Fuller, 1999; Hawkins *et al*., 2001; Morgan *et al*., 2001; Junge *et al*., 2004a, 2004b, 2004c; Price *et al*., 2004; Walden *et al*., 2005; Wong and Hong, 2005; Le Gall *et al*., 2006; Dvorak *et al*., 2007; Froholdt *et al*., 2009; Dvorak *et al*., 2011, Ekstrand *et al*., 2011a, 2011b). The value of <14 proposed for increase of injury risk, should also be applied with caution when looking at football players, Keisel *et al*. (2007) conducted the research on American Football players, which has particular risk factors and injury rates and injury locations that are outside of the data outlined in football, with high levels of injury being observed to the head/face, neck, torso and spine, in addition to lower limb injuries (Shankar *et al*., 2007) and high injury rates of over 40 injuries per 1000 athlete exposures to competition (Shankar *et al*., 2007).

Although no specific exercises were administered directly to improve FMS™ scores, instruction and development of squat techniques including front squat and overhead squat for strength training and Olympic lift development was undertaken in all phases of the training programme, it is therefore not surprising that the overhead squat performance in the FMS™ test improved pre to post. Similarly poor performance in the in-line lunge is often considered representative of poor gluteal activation (Brewer and Pettigrew, 2009), the application of squats, single leg squats and lunge patterns improves gluteal activation (Brewer and Pettigrew, 2009) and would have direct correspondence to improved in-line lunge performance. Players were observed to maintain active straight leg scores through the intervention, demonstrating that hamstring length was maintained throughout the competitive season. Football training and match play has been demonstrated to reduce hamstring range of motion and subsequently increase the risk of injury to the posterior thigh (Engebretsen *et al*., 2010). It would therefore appear that the systematic application of eccentric exercise, aimed at improving hamstring health, maintains range of motion in addition to improving the functional strength of the hamstring muscle group. Further to the above, the application of an S&C intervention appeared to have a positive influence on the measurable asymmetries within the subject group, with a 30% reduction in asymmetries observed. The current study also looked at improvements in asymmetries relating directly to the demands of the sport and focussed on asymmetries presented in the lower limb. A 22% reduction in lower limb asymmetries was reported and significant improvements were observed in the reduction in asymmetry of the in-line lunge. The underlying mechanisms for adaption in this specific exercise are outlined above. No studies currently have reported the effect of S&C training on FMS™ asymmetry scores in football at any playing level, or looked at portions of the FMS™, in relation to their specificity to the athletes sporting requirements. Keisel *et al*. (2008) proposed that any player reporting any asymmetry irrespective of overall FMS™ score was at a 2.3 times greater risk of injury than players without asymmetry, it would therefore appear that through the reduction of asymmetries in S&C training featuring unilateral movements, injury risk is reduced in players.

FMS™ application, while for the reasons outlined above is an important tool in the assessment of athletic movement and injury risk, may have limitations when assessing injury risk during athletic performance. The current study and existing literature has outlined the low rate of transfer of improvements in athletes gym based strength profiles to sprint based performance and jump performance, with more complex movement patterns reducing the rate of transfer. It would therefore appear logical that the coordination of movement patterns in a gym based environment will potentially breakdown during a dynamic sport environment. If this is the case, a movement screen to assess athletes risk of injury should incorporate more dynamic movement for example single leg landing control or walking lunge patterns in addition to the basic movement screen outlined in the FMS™.

When assessing the results of the current study it is important to consider the reliability for repeated measures using FMS™. Although it was not within the scope of this study to run reliability studies on the use of FMS™, previous studies have outlined good inter-rater (Minick *et al*., 2010; Shultz *et al*., 2011; Smith *et al*., 2012) and intra-rater reliability (Shultz *et al*., 2011; Gribble *et al*., 2012; Smith *et al*., 2012) in both novice and expert raters. The high levels of test-retest reliability shown by the FMS™ have been attributed to the ease of scoring system utilised to assess movement dysfunction (Minick *et al*., 2010; Shultz *et al*., 2011; Gribble *et al*., 2012). Shultz *et al*. (2011) also stipulated that for best reliability of comparison between measures the same practitioner should be used for all measurements conducted on a subject, while Gribble *et al*. (2012) showed experienced practitioners, such as used in this study, had higher levels of intra-rater reliability compared to novice practitioners. It can therefore be considered that in the present study, where a single experienced FMS™ practitioner conducted all test pre and post intervention that high levels of test-retest reliability will be present.

5.4.3. Injury Summary

With the present study reporting lower injury incidence rates, low levels of contact injury and severe injuries coupled with improved FMS™ scores and reduced incidence of asymmetries present in the playing group, there is evidence to suggest that the inclusion of a S&C programme has had a positive effect on injury risk in the group of players in this study. If the true cost of injury in developing players is time-loss as proposed by Price *et al*. (2004), the implementation of an S&C programme to academy players may be instrumental in maximising their ability to meet the demands of professional performance but also giving players sufficient times to develop the skill base for attaining elite level.

5.5 Limitations of Study and Future Directions for Research

The current project sits at the applied end of the research continuum outlined by Drust *et al*. (2007) and while this gives the project high levels of external validity it compromises the study in terms of internal validity and therefore impacts on the inferences that can be drawn from the data collected. Two major limitations with regard to the current research project are the small sample size and lack of control group with which to reference against.

Due to the applied nature of the work, and the elite nature of the subject group and their demanding playing and training schedules and the transient nature of players to and from the team from senior squad call ups and leaving the club, maintaining members of the subject group was challenging, of the squad of 17 players only 6 completed the threshold of 85% attendance at the S&C sessions and completed all testing components. Similar obstacles have been reported in similar research with Casajus (2001), reported only approximately 50% of his initial study group of professional male footballers were able to be presented in the results.

It is also unrealistic in a squad of this nature to secure an equivalent level of player in a control group. Managers of elite performers would not wish the squad to be broken down for the administration of a season long intervention on performance enhancement, and with potential for lucrative football contracts available at the end of an Academy scheme it would potentially be unethical to do so. In addition to this, it is unlikely that a team of similar standing would allow it players to be periodically tested with the potential benefit of an intervention being delivered to potential rivals. No control groups have been used in similar interventions involving elite level performers (Keisel *et al*., 2007; Keisel *et al*., 2008).

In addition to this, further time for the testing of the field based performance measure mid-season, may have offered a more rounded picture with regard to seasonal variation in performance variables within the squad, performance transfer and measures in relation to strength gains, and the implementation of a different periodisation strategy for team sports performance and its transfer potential is worthy of investigation.

To gain a full understanding of the interaction of the energy systems and strength and power profiles of the athletes, it would have been beneficial to monitor the workloads of the athletes training and match play. Incorporating the focus of the field based sessions in to the design and implementation of the S&C programme would be vital to minimise the interference of training stimulus on desired adaptations. Current resistance training prescription is also currently planned on measures of external load, discussed earlier in this document. Football specific training is currently planned and monitored using measures of internal load such as heart rate zones and measures such as TRIMP, a measure of internal load on the athlete through resistance training would enable the S&C professional to achieve the above integration of training required much more accurately. Further to this testing of adaptation to the aerobic system over the course of the intervention would have given a clear picture of the holistic training effect on the athletes and could incorporate the measurement of aerobic performance and parameters associated with improved aerobic performance such as running economy and lactate profiles. As aerobic performance is considered as important in performance of football as strength and power parameters and anaerobic fitness, the impact of an S&C programme on variables may be of benefit to the current literature, particularly in elite level players. Current research suggests that strength training may have positive effects on endurance performance (Stlølen *et al*., 2005).

5.6 Conclusion

The current training study conducted a 26 week S&C intervention in elite senior academy football players. The implementation of a programme targeted at both performance gain and injury reduction established positive impacts on the absolute strength profiles of all the players. The transfer of strength gains to performance was demonstrated in improvements in CMJ and sprint performance and a reduction in asymmetry of agility performance. The potential of in-season demands of training and match play is a proposed mechanism for the lower levels of transfer to performance, with reductions in performance noted in other studies not implementing S&C over a season and similar values reported through the in-season in studies implementing S&C. Other methods of periodisation than the CT utilised in this study may enhance performance transfer further and are worthy of investigation. Injury rates for the player group utilised in this study were considerably lower than those reported in football, and improvements in players FMS™ scores and a reduction in numbers of asymmetries illustrated a there may be present a positive relationship between S&C and injury risk reduction in elite academy football players however due to the limitations outlined above further examination would be required.

6. References

Almasbakk, B., Hoff, J. (1996) 'Coordination, the determinant of velocity specificity'. *Journal of Applied Physiology*, 80 (5), 2046-2052.

Armitage-Johnson, S. (1994) 'Two assisting exercises for teaching the power clean and power snatch'. *Strength and Conditioning*, 16 (4), 51-54.

Andersson, H., Raastad, T., Nilsson, J., Paulsen, G., Garthe, I., Kadi, F. (2008) 'Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery'. *Medicine and Science in Sports and Exercise*, 40 (2), 372-380.

Backx, F. J., Beijer, H. J., Bol, E., Erich, W. B. (1991). 'Injuries in high-risk persons and high-risk sports. A longitudinal study of 1818 school children'. *American Journal of Sports Medicine,* 19 (2), 124-130.

Baechle, T.R. (1997) 'National study produces a new CSCS job description'. *Strength and Conditioning*, 19, 64-65.

Baechle, T.R., Earle, R.W. (2008) *Essentials of Strength Training and Conditioning. Third Edition*. Champaign, IL. Human Kinetics.

Baker, D., Wilson, G., Carlyon, R. (1994) 'Periodization: The effect on strength of manipulating volume and intensity'. *Journal of Strength and Conditioning Research*, 8, 235-242.

Baker, D. (2001) 'The effects of an in season of concurrent training on the maintenance of maximal strength and power in professional and college aged rugby league football players'. *Journal of Strength and Conditioning Research*, 15 (2), 172-177.

Bangsbo, J., Norregaard, L., Thorsoe, F. (1991) 'Activity profiles of competitive soccer'. *Canadian Journal of Sports Science,* 16, 110-116.

Behm, D.G., Sale, D.G. (1993) 'Velocity specificity of resistance training'. *Sports Medicine*, 15 (6), 249-295.

Bompa, T.O., Carrera, M.C. (2005) *Periodization Training For Sports: Science-based strength and conditioning plans for 20 sports. Second Edition*. Champaign, IL: Human Kinetics.

Bompa, T.O., Haff, G.G. (2009) *Periodization: Theory and Methodology of Training. Fifth Edition*. Champaign, IL: Human Kinetics.

Brandon, R., Cleather, D. (2007) 'Training the hamstrings for high speed running: Part 2'. *Professional Strength and Conditioning*, 7, 18-23.

Brewer, C. (2006) 'Weight lifting technique: Observations and coaching practice'. *Professional Strength and Conditioning*, 4, 19-23.

Brewer, C., Pettigrew, C. (2009) 'Getting to the bottom of locomotor control'. *Professional Strength and Conditioning*, 13, 19-28.

Brockett, C. L., Morgan, L. M., Proske, U. (2004) 'Predicting hamstring strain in elite athletes'. *Medicine and Science in Sports and Exercise,* 36 (3), 379-387.

Brzycki, M. (1993) 'Strength Testing - Predicting a One-Rep Max from Reps-to-Fatigue'. *Journal of Health, Physical Education, Recreation and Dance*, 64, 88-90.

Brzycki, M. (1998) *A Practical Approach To Strength Training*. McGraw-Hill

Buchheit, M., Mendez-Villanueva, A., Delhomel, G., Brughelli, M., Ahmaidi, S. (2010) ‘Improving repeated sprint ability in young elite soccer players: Repeated shuttle sprints vs. explosive strength training. *Journal of Strength and Conditioning Research*, 24 (10), 2715-2722.

Bullock-Saxton, J.E., Janda, V., and Bullock, M.I. (1994) ‘The influence of ankle sprain injury on muscle activation during hip extension’. *International Journal of Sports Medicine*, 15, 330–334.

Caldwell, B.P., Peters, D.M. (2009) ‘Seasonal variation in physiological fitness of a semiprofessional soccer team’. *Journal of Strength and Conditioning Research*, 23 (5), 1370-1377.

Carling, C., Orhant, E. (2010) ‘Variation in body composition in professional soccer players: Intraseasonal changes and the effects of exposure time and player position’. *Journal of Strength and Conditioning Research*, 24 (5), 1332-1339.

Casajus, J.A. (2001) ‘Seasonal variation in fitness variables in professional soccer players’. *journal of Sports Medicine and Physical Fitness*, 41, 463-469.

Chad, N. (2010) ‘An approach to the periodisation of training during the in-season for team sports’. *Professional Strength and Conditioning*, 18, 5-10.

Chapman, P.P., Whitehead, J.R., Binkert, R.H. (1998) ‘The 225-1b reps-to-fatigue test as a submaximal estimate of 1-RM bench press performance in college football players’. *Journal of Strength & Conditioning Research*, 12(4), 258-261.

Chelly, M.S., Fathloun, M., Cherif, N., Amar, M.B., Tabka, Z., Van Praagh, E. (2009) 'Effects of a back squat training programme on leg power, jump, sprint performances in junior soccer players'. *Journal of Strength and Conditioning Research*, 23 (8), 2241-2249.

Chelly, M.S., Cherif, N., Ben Amar, M., Hermassi, S., Fathloun, M., Bouhlel, E., Tabka, Z., Shephard, R.J. (2010) 'Relationships of peak leg power, 1 maximal repetition half back squat, and leg muscle volume to 5-m sprint performance of junior soccer players'. *Journal of Strength and Conditioning Research*, 24 (1), 266-271.

Cleather, D., Brandon, R. (2007) 'Training the hamstrings for high speed running: Part 1-Theoretical considerations'. *Professional Strength and Conditioning*, 7, 10-14.

Cook, G., Burton, L., Hoogenboom, B. (2006). 'Pre-participation screening: The use of fundamental movements as an assessment of function- Part 1'. *North American Journal of Sports Physical Therapy*, 1 (2), 62-72.

Cook G, Burton L, Hoogenboom B. (2006). 'Pre-participation screening: The use of fundamental movements as an assessment of function- Part 2'. *North American Journal of Sports Physical Therapy*, 1 (3), 132-139.

Cormie, P., McCaulley, G.O., McBride, J.M. (2007) 'Power versus strength-power training jump squat training: influence on the load power relationship'. *Medicine and Science in Sports and Exercise*, 39, 996-1003.

Cotterman, M.L., Darby, L.A., Skelly, W.A.(2005) 'Comparison of muscle force production using the Smith machine and free weights for bench press and squat exercises'. *Journal of Strength and Conditioning Research*, 19(1), 169-176.

Croisier, J., Ganteaume, S., Binet, J., Genty, M., Ferrett, J. (2008) ‘Strength imbalances and prevention of hamstring injury in professional soccer players’. *American Journal of Sports Medicine,* 28, 69-74.

Davis, J.A., Brewer, J., Atkin, D. (1992) ‘Pre-seasonal physiological characteristics of English first and second division soccer players’. *Journal of Sports Sciences*, 10 (6), 541-547.

De Loes, M., Goldie, I. (1988). ‘Incidence rate of injuries during sports activities and physical exercise in rural Swedish municipality: incidence rates in 17 sports’. *International Journal of Sports Medicine.* 9, 461-467.

De Loes, M. (1995) ‘Epidemiology of sports ijuries in Swiss organization ‘youth and sports’ 1987-1989. Injuries, exposure and main risks of diagnoses’. *International Journal of Sports Medicine*, 16, 134-138.

Dooman, C.S., Titlebaum, P.J., DeMarco, G.M. (1998) ‘More weight on the bar: being a strength and conditioning coach today’. *Strength and Conditioning*, 20, 31-34.

Dorgo, S. (2009) ‘Unfolding the Practical Knowledge of an Expert Strength and Conditioning Coach’. *International Journal of Sports Science and Coaching*, 4 (1), 17-30.

Dos Remedios, K., Dos Remedios, R., Loy, S., Holland, G., Vincent, W., Conley, L., Hing, M. (1995) ‘Physiological and field test performance changes of community college football players over a season’. *Journal of Strength and Conditioning Research*, 9 (4), 211-215.

Duba, J., Kraemer, W.J., Martin, G. (2007) ‘A 6-step progression model for teaching hang power clean’. *Strength and Conditioning Journal* 29, 26-35.

Dupont, G., Nedelec, M., McCall, A., McCormack, D., Berthoin, S., Wisloff, U. (2010) 'Effect of 2 soccer matches in a week on physical performance and injury rate'. *The American Journal of Sports Medicine*, 38 (9), 1752-1758.

Durnin J., Womersley J. (1974) 'Body fat assessed from total body density and its estimation from skin fold thickness: measurements on 481 men and women aged from 16 to 72 years'. *British Journal of Nutrition*, 32, 77-97.

Durell, D.L., Pujol, T.J., Barnes, J.T. (2003) 'A survey of the scientific data and training

methods utilized by collegiate strength and conditioning coaches'. *Journal of Strength and Conditioning Research*, 17 (2), 368–373.

Dvorak, J., Junge, A., Grimm, A., Kirkendall, D. (2007) 'Medical report from the 2006 FIFA World Cup Germany'. *British Journal of Sports Medicine*, 41, 578–581.

Dvorak, J., Junge, A., Derman, W., Schwellnus, M. (2011) 'Injuries and illnesses of football players during the2010 FIFA World Cup'. *British Journal of Sports Medicine*, 45, 626–630.

Ekstrand, J., Gillquist, J. (1983a). 'The avoidability of soccer injuries'. *International Journal of Sports Medicine,* 4, 124-128.

Ekstrand, J., Gillquist, J. (1983b) 'Soccer injuries and their mechanism: a prospective study'. *Medicine and Science in Sports and Exercise,* 15 (3), 267-270.

Ekstrand, J., Waldén, M., Hägglund, M. (2004) 'A congested football calendar and the wellbeing of players: correlation between match exposure of European footballers before the World Cup 2002 and their injuries and performances during that World Cup'. *British Journal of Sports Medicine*, 38 (4), 493-497.

Ekstrand, J., Hägglund, M., Waldén M. (2011a) 'Injury incidence and injury patterns in professional football: the UEFA injury study'. *British Journal of Sports Medicine*, 45,553–558.

Ekstrand, J., Hägglund, M., Waldén M. (2011b) 'Epidemiology of Muscle Injuries in Professional Football (Soccer)'. *American Journal of Sports Medicine,* 39 (6), 1226-1232.

Elias, S. R. (2001) '10-year trend in USA cup soccer injuries: 1988-1997'. *Medicine and Science in Sports and Exercise.* 33 (3), 359-367.

Engstrom, B., Forssblad, M., Johansson, C., Tornkvist, H. (1990) 'Does a major knee injury definitely sideline an elite soccer player'. *American Journal of Sports Medicine,* 18 (1), 101-105.

Ericsson, K., Anders, L., Charnes, N. (1994). 'Expert Performance: its Structure and Acquisition'. *American Psychologist,* 49, 725-747.

Fleck, S.J. (1999) 'Periodized strength training: A critical review'. *Journal of Strength and Conditioning Research*, 13 (1), 82-89.

Fleck, S. and Kramer, W. (2007) *Optimizing strength training: Designing non linear periodisation workouts*. Champaign, IL: Human Kinetics.

Froholdt, A., Olsen, O.E., Bahr, R. (2009). 'Low Risk of Injuries Among Children Playing Organized Soccer: A Prospective Cohort Study'. *American Journal of Sports Medicine,* 37 (6), 1155-1160.

Frost, D.M., Beach, T.A., Callaghan, J.P., McGill, S.M. (2011). 'Movement screening for performance: What information do we need to guide exercise progression?' *Journal of Strength and Conditioning Research*, 25, S1-S3.

Fry, A., Kraemer, W., Stone, M., Koziris, L., Thrush, J., Fleck, S. (2000) 'Relationships between serum testosterone, cortisol, and weightlifting performance'. *Journal of Strength and Conditioning Research*, 14, 383-343.

Gamble, P. (2006) 'Periodization of training for team sports athletes'. *Strength and Conditioning Journal*, 28 (5), 56-66.

Garcia- Pallares, J., Sanhez-Medina, L., Carrasco,L., Diaz, A., Izquiendo, M. (2009) 'Endurance and neuromuscular changes in world class level kayakers during a periodized training cycle'. *European Journal of Applied Physiology*, 106, 629-638.

Garhammer, J. (1993) 'A review of power output studies of Olympic and powerlifting: methodology, performance prediction, and evaluation tests'. *Journal of Strength and Conditioning Research,* 7 (1), 76-78.

Garhammer, J. (1998) 'Do you qualify to be a strength and conditioning professional?' *Strength and Conditioning*, 20 (1), 62-63.

Gribble, P., Brigle, J., Pietrosimone, B., Pfile, K., Webster, K. (2012) 'Intrarater Reliability of the Functional Movement Screen™'. *Journal of Strength and Conditioning Research.*

Gonzalez-Rave, J.M., Arija, A., Clemente-Suarez, V. (2011) 'Seasonal changes in jump performance and body composition in women volleyball players'. *Journal of Strength Conditioning Research*, 25 (6), 1492–1501.

Greig, M. (2008) 'The influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors'. *American Journal of Sports Medicine*, 36, 1403-1409.

Haff, G.G., Whitley, A., McCoy, L.B., O'Bryant, H.S., Kilgore, J.L., Haff, E.E., Pierce, K., Stone, M.H. (2003) ‘Effects of different set configurations on barbell velocity and displacement during a clean pull’. *Journal of Strength and Conditioning Research*, 17 (1), 95-103.

Haff, G. (2010) ‘Quantifying workloads in resistance training: A brief review’. *Professional Strength and Conditioning*, 19, 4-13.

Hägglund, M., Waldén, M., Bahr, R., Ekstrand J. (2005) ‘Methods for epidemiological study of injuries to professional football players: developing the UEFA model’. *British Journal of Sports Medicine*, 39, 340-346.

Hägglund, M., Waldén, M., Ekstrand J. (2009) ‘UEFA injury study—an injury audit of European Championships 2006 to 2008’. *British Journal of Sports Medicine*, 43, 483–489.

Harman, E.A., Rosenstein, M.T., Frykman, P.M., Rosenstein, R.M., Kraemer, W.J. (1991) ‘Estimation of human power output from the vertical jump’. *Journal of Applied Sports Science Research*, 5, 116-120

Hawkins, R.D., Fuller, C.W. (1998) ‘An examination of the frequency and severity of injuries and incidents at three levels of professional football’. *British Journal of Sports Medicine*, 32, 326–332.

Hawkins, R. D., Fuller, C. W. (1999) ‘A prospective epidemiological study of injuries in four English professional football clubs’. *British Journal of Sports Medicine*, 33, 196-203.

Hawkins, R. D., Hulse, M. A., Wilkinson, C., Hodson, A., Gibson, M. (2001) ‘The association football medical research program: an audit of injuries in professional football’. *British Journal of Sports Medicine,* 35, 43-47.

Heidt, Jr. R.S., Sweeterman, L.M., Carlonas, R.L., Traub, J.A., Tekulve, F.X. (2000) 'Avoidance of Soccer Injuries with Pre-season Conditioning'. *American Journal of Sports Medicine*, 28 (5), 650-662.

Helgerud, J., Kemi, O.J., Hoff, J. (2002) 'Pre-season concurrent strength and endurance development in elite soccer players'. in *Football: New developments in physical training research*. ed. by Hoff. J., Helgerud, J. Trondheim: Norwegian University of Science and Technology.

Hoff, J., Helgerud, J. (2002) 'Maximal strength training enhances running economy and aerobic endurance performance'. in *Football: New developments in physical training research*. ed. by Hoff. J., Helgerud, J. Trondheim: Norwegian University of Science and Technology.

Hoff, J., Helgerud, J. (2004) 'Endurance and strength training for soccer players'. *Sports Medicine*, 34 (3), 165-180.

Hoff, J. (2005) 'Training and testing physical capabilities for elite soccer players'. *Journal of Sports Sciences*, 23 (6), 573-582.

Hoffman, J., Maresii, C., Armstrong, L., Kraemer, W. (1991) 'Effects of off season and in season resistance training programs on a collegiate male basketball team'. *Journal of Human Muscle and Performance*, 1, 48-55.

Hoffman, J.R., Cooper, J., Wendell, M., Kang, J. (2004) 'Comparison of Olympic vs. traditional power lifting programs in football players'. *Journal of Strength and Conditioning Research*, 18 (1), 129-135.

Hopkins, W.G., Schabort, E.J., Hawley, J.A. (2001) 'Reliability of Power in Physical Performance Tests'. *Sports Medicine*, 31(3), 211-234.

Inklaar, H. (1994) 'Soccer injuries. I: Incidence and severity'. *Sports Medicine*, 18*,* 55-73.

Ispirlidis, I., Fatouros, I.G., Jamurtas, A.Z., Nikolaidis, M.G., Michailidis, I., Douroudos, I., Margonis, K., Chatzinikolaou, A., Kalistratos, E., Katrabasas, I., Alexiou, V., Taxildaris, K. (2008) 'Time-course of changes in inflammatory and performance responses following a soccer game'. *Clinical Journal of Sports Medicine*, 18 (5), 423-431.

Issurin, V. (2008) 'Block periodzation versus traditional training theory: A review'*. Journal of Sports Medicine and Physical Fitness*, 48 (1), 65-75.

Issurin, V. (2010) 'New Horizons for the methodology and physiology of training periodization'. *Sports Medicine*, 40 (3), 189-206.

Jensen, R.L., Furlong, L.M., Graham, D., Harrison A.J. (2011) 'Reliability of Jump and Performance Measures in Rugby Union Players'. *Portuguese Journal of Sport Sciences*, 11 (Suppl. 2), 93-96.

Jullien, H., Bisch, C., Largouët, N., Manouvrier, C., Carling, C., Amiard, V. 'Does a short period of lower limb strength training improve performance in field-based tests of running and agility in young professional soccer players?' *Journal of Strength & Conditioning Research*, 22 (2), 404-411.

Junge, A., Dvorak, J. (2000) 'Influence of Definition and Data Collection on the Incidence of Injuries in Football'. *American Journal of Sports Medicine,* 28, S40-S46.

Junge, A., Dvorak, J., Graf-Baumann, T., Peterson, L. (2004a) 'Football injuries during FIFA tournaments and Olympic games 1998–2001. Development and implementation of an injury-reporting system'. *American Journal of Sports Medicine,* 32, S80-S89.

Junge, A., Dvorak, J., Graf-Baumann, T. (2004b) 'Football injuries during the World Cup 2002'. *American Journal of Sports Medicine,* 32, S23-S27.

Junge, A., Cheung, K., Edwards, T., Dvorak, J. (2004c) 'Injuries in youth amateur soccer and rugby players-comparison of incidence and characteristics'. *British Journal of Sports Medicine*, 38, 168–172.

Junge, A., Langevoort, G., Pipe, A., Peytavin, A., Wong, F., Mountjoy, M., Beltrami, G., Terrell, R., Holzgraefe, M., Charles, R., Dvorak, J. (2006) 'Injuries in team sport tournaments during the 2004 Olympic Games'. *American Journal of Sports Medicine,* 34, 565-576.

Junge, A., Engebretsen, L., Mountjoy, M.L., Alonso, J.M., Renström, P., Aubry, M.J., Dvorak, J. (2009) 'Sports injuries during the summer Olympic Games 2008'. *American Journal of Sports Medicine,* 37 (11), 2165-2172.

Junge, A., Dvorak, J. (2010) 'Injury risk of playing football in Futsal World Cups'. *British Journal of Sports Medicine*, 44, 1089–1092.

Keller, C. S., Noyes, F. R., Buncher, C. R. (1987). 'The medical aspects of soccer injury epidemiology'. *American Journal of Sports Medicine,* 15 (3), 230-237.

Kiesel, K., Plisky, P., Voight, M. (2007). 'Can serious injury in professional football be predicted by a pre-season functional movement screen?' *North American Journal of Sports and Physical Therapy*, 2 (3), 147-158.

Kiesel, K., Plisky, P., Kersey, P. (2008) 'Functional movement test score as a predictor of time-loss during a professional football team's pre-season'. *American College of Sports Medicine Annual Conference*, Indianapolis.

Kiesel, K., Plisky, P., Butler, R. (2009) 'Functional movement test scores improve following a standardized off-season intervention program in professional football players'. *Scandinavian Journal of Medicine and Science in Sports*, 21 (2), 1038-1044.

Kleiner, D.M. (1999) 'Strength and conditioning education for the 21st century'. *Strength and Conditioning Journal*, 21, 7-8.

Kontor, K. (1989) 'Defining a profession'. *National Strength and Conditioning Association Journal*, 11, 75.

Kraemer, W.J. (1997) 'A series of studies: The physiological basis for strength training in American Football: Facto over philosophy'. *Journal of Strength and Conditioning Research*, 11, 131-142.

Kraemer, W.J., French, D.N., Paxton, N.J., Hakkinen, K., Volek, J.S., Sebastianelli, W.J., Putukian, M., Newton, R.U., Rubin, M.R., Gomez, A.L., Vescovi, J.D., Ratamess, N.A., Fleck, S.J., Lynch, J.M., Knuttgen, H.G. (2004) 'Changes in exercise performance and hormonal concentrations over a big ten soccer season in starters and nonstarters'. *Journal of Strength Conditioning Research*, 18, 121-128.

Kritz, M.F., Cronin, J. (2008) 'Static posture assessment screen of athletes: Benefits and considerations'. *Strength and Conditioning Journal*, 30 (5), 18-27.

Leatt, P., Shepard, R.J., Plyley, M.J. (1987) 'Specific muscular development in under-18 soccer players'. *Journal of Sports Science*, 5 (2), 165-175.

Le Gall, F., Carling. C., Reilly, T., Vandewalle, H., Church, J., Rochcongar, P. (2006) 'Incidences of injuries in elite French youth soccer players: a 10-season study'. *American Journal of Sports Medicine,* 34, (6), 928-938.

Legg, D., Burnham, R. (1999) 'In season shoulder abduction strength changes in football players'. *Journal of Strength and Conditioning Research*, 13 (4), 4381-4383.

Lephart S.M., Pincivero D.M., Giraldo J.L., Fu F.H. (1997) 'The role of proprioception in the management and rehabilitation of athletic injuries'. *American Journal of Sports Medicine*, 25, 130-138.

LeSuer, D.A., McCormick, J.H., Mayhew, J.L., Wasserstein, R.L., Arnold, M.D. (1997) 'The Accuracy of Prediction Equations for Estimating 1-RM Performance in the Bench Press, Squat, and Deadlift'. *Journal of Strength & Conditioning Research*, 11 (4), 211-213.

McMillan, K., Helgerud, J., MacDonald, R., Hoff, J. (2005) 'Physiological adaptations to soccer specific endurance training in professional youth soccer players'. *British Journal of Sports Medicine*, 39 (5), 273-277.

Magal, M., Smith R.T., Dyer, J.J., Hoffman, J.R. (2009) 'Seasonal variation in physical performance –related variables in male NCAA division III soccer players'. *Journal of Strength and Conditioning Research*, 23 (9), 2555-2559.

Marfell-Jones M. (1991*) Kinanthropometric assessment. Guidelines for athlete assessment in New Zealand sport*. Sport Science New Zealand, Wellington, NZ.

New Zealand, Wellington, New Zeeland, 1991.Marshall, J. (2005) 'In season periodisation with youth rugby players'. *Strength and Conditioning Journal*, 27 (5), 10-19.

Martinez, D. (2004) 'Study of the key determining factors for the NCAA Division I head strength and conditioning coach'. *Journal of Strength and Conditioning Research*, 18 (1), 5–18.

Massey, D. (2010) 'Program for Effective Teaching: A Model to Guide Educational Programs in Strength and Conditioning'. *Strength and Conditioning Journal*, 32 (5), 79-85.

McBride, J.M., Triplett-McBride, T., Davie, A., Newton, R.U. (2002) 'The effect of heavy vs. light-load jump squats on the development of strength, power, and speed'. *Journal of Strength and Conditioning Research*, 16, 75-82.

McBride, J.M., Mccaulley, G.O., Cormie, P., Nuzzo, J.L., Cavill, M.J., Triplett, N.T. (2009a) 'Comparison of methods to quantify volume during resistance exercise'. *Journal of Strength and Conditioning Research*, 23, 106-110.

McBride, J.M., Blow, D., Kirby, T.J., Haines, T.L., Dayne, A.M., Triplett, N.T. (2009b) 'Relationship between maximal squat strength and five, ten and 40 yard sprint times'. *Journal of Strength and Conditioning Research*, 23 (6), 1633-1636.

Minick, K.I., Kiesel, K.B., Burton, L., Taylor, A., Plisky, P., Butler, R.J. (2010) 'Interrater reliability of the Functional Movement Screen'. *Journal of Strength and Conditioning Research*, 24 (2), 479-486.

Mirkov, DM, Nedeljkovic, A, Kukolj, M, Ugarkovic, D, and Jaric, S. (2008) 'Evaluation of reliability of soccer-specific field tests'. *Journal of Strength and Conditioning Research*, 22 (4), 1046-1050.

Moore, E.W.G., Hickey, M.S., Reiser II, R.F. (2005) 'Comparison of two twelve week off-season combined training programs on entry level collegiate soccer players' performance'. *Journal of Strength and Conditioning Research*, 19 (4), 791-798.

Morgan, B. E., Oberlander, M. A. (2001) 'An examination of injuries in major league soccer'. *American Journal of Sports Medicine,* 29 (4), 426-430.

Nadler, S.F., Malanga, G.A., Bartoli, L.A., Feinberg, J.H., Prybicien, M., Deprince, M. (2002) 'Hip muscle imbalance and low back pain in athletes: Influence of core strengthening'. *Medicine and Science in Sports and Exercise*, 34, 9–16.

Neely, F.G. (1998) 'Intrinsic risk factors for exercise-related lower limb injuries'. *Sports Medicine*, 26, 253-263.

Nielsen, A. B., Yde, J. (1989) 'Epidemiology and traumatology of injuries in soccer'. *American Journal of Sports Medicine,* 17 (6), 803-807.

Nilsson, S., Beitostolen, M.D., Roass, A. (1978) 'Soccer injuries in adolescents'. *The American Journal of Sports Medicine*, 6 (6), 358-361.

Okada, T., Huxel, K.C., Nesser, T.W. (2011) 'Relationship between core stability, functional movement and performance'. *Journal of Strength and Conditioning Research*, 25 (1), 252-261.

Olsen, O.E., Myklebust, G., Engebretsen, L. (2004) 'Injury Mechanisms for Anterior Cruciate Ligament Injuries in Team Handball'. *American Journal of Sport Medicine,* 32, 1002-1012.

Ostojic, S.M. (2003) 'Seasonal alterations in body composition and sprint performance of elite soccer players'. *Journal of Exercise Physiology*, 6, 11-14.

Parchmann, C.J., McBride, J.M. (2011) 'Relationship between functional movement screen and athletic performance'. *34th National Strength and Conditioning Association National Conference & Exhibition Abstracts*.

Perini, T.A., de Oliveira, G.L., dos Santos Ornellas, J., de Oliveira, F.P. (2005) 'Technical error of measurement in anthropometry'. *Rev Bras Med Esporte*, 11, (1), 86-90.

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

Plisky, P.J., Rauh, M.J., Kaminski, T.W., Underwood, F.B. (2006) 'Star excursion balance

test as a predictor of lower extremity injury in high school basketball players'. *Journal of Orthopaedic Sports Physical Therapy*, 36, 911-919.

Plisk, S. and Stone, M. (2003) 'Periodization strategies'. *Strength and Conditioning Journal*, 25 (6), 19-37.

Price, R. J., Hawkins, R. D., Hulse, M. A., Hodson. (2004) 'The Football Association medical research programme: an audit of injuries in academy youth football'. *British Journal of Sports Medicine,* 38, 466-471.

Pritchett, J.W. (1981) 'Cost of high school soccer injuries'. *The American Journal of Sports Medicine*, 9 (1), 64-66.

Pullo, F.M. (1992) 'A Profile of NCAA Division I Strength and Conditioning Coaches'. *Journal of Applied Sports Science Research*, 6, 55-62.

Quatman, C. E., Ford, K. R., Myer, G. D., Paterno, M, V., Hewett, T. E. (2008) 'The effects of gender and pubertal status on generalised joint laxity in young athletes'. *Journal of Science and Medicine in Sports,* 11 (3), 257-267.

Rahnama, N., Reilly, T., Lees, A., Graham-Smith, P. (2003) 'Muscle fatigue induced by exercise simulating the work rate of competitive soccer'. *Journal of Sports Sciences,* 21, 933-942.

Reilly, T., Williams, A.M., Nevill, A., Franks, A. (2000) 'A multidisciplinary approach to talent identification in soccer'. *Journal of Sports Sciences*, 18 (9), 695-702.

Reilly, T., Ekblom, B. (2005) 'The use of recovery methods post-exercise'. *Journal of Sports Sciences*, 23 (6), 619-627.

Requena, B., Gonzalez-Badillo, J.J., Saez de Villareal, E.S., Ereline, J., Garcıa, I., Gapeyeva, H., Paasuke, M. (2009) 'Functional performance, maximal strength, and power characteristics in isometric and dynamic actions lower extremities in soccer players'. *Journal of Strength and Conditioning Research*, 23 (5), 1391-1401.

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'. *Journal of Strength and Conditioning Research*, 16 (2), 250-255.

Rhea, M.R., Phillips, W.T., Burkett, L.N., Stone, W.J., Ball, D.D., Alvar, B.A., Thomas, A.B. (2003) 'A comparison of linear and daily undulating periodized programs with equated volume and intensity for local muscular endurance'. *Journal of Strength and Conditioning Research*, 17 (1), 82-87.

Ronnestad, B.R., Kvamme, N.H., Sunde, A., Raastad, T. (2008) 'Short-term effects of strength and plyometrics training on sprint and jump performance in professional soccer players'. *Journal of Strength and Conditioning Research*, 22 (3), 773-780.

Sassi, R.H., Dardouri, W., Yahmed, M.H., Gmada, N., Mahfoudhi, M.E., Gharbi, Z. (2009) 'Relative and absolute reliability of a modified agility t-test and its relationship with vertical jump and straight sprint'. *Journal of Strength and Conditioning Research*, 23 (6), 1644–1651.

Sato, K., Smith, S.L., Sands, W.A. (2009) 'Validation of an accelerometer for measuring sport performance'. *Journal of Strength and Conditioning Research*, 23 (1), 341-347.

Schmidt-Olsen, S., Buneman, L.K.H., Lade, V., Brassoe, J.O.K. (1985) 'Soccer Injuries of Youth'. *British Journal of Sports Medicine*, 19 (3), 161-164.

Schneider, V., Arnold, B., Martin, K., Bell, D., Crock, P. (1998) 'Detraining effects in college football players during the competitive season. *Journal of Strength and Conditioning Research*, 12 (1), 42-45.

Seyle, H. (1974) *Stress without distress*. J.B. Lippincott: New York.

Silvestre, R., Kraemer, W.J., West, C., Judelson, D.A., Spiering, B.A., Vingren, J.L., Hatfield, D.L., Anderson, J.M., Maresh, C.M. (2006) 'Body composition and physical performance during a National Collegiate Athletic Association division I mens's soccer season'. *Journal of Strength and Conditioning Research*, 20 (4), 962-970.

Shankar, P.R., Fields, S.K., Collins, C.L., Dick R.W., Comstock, R.D. (2007) 'Epidemiology of High School and Collegiate Football Injuries in the United States, 2005-2006'. *American Journal of Sports Medicine*, 35 (8), 1295-1303.

Shultz, R., Mooney, K., Anderson, S., Marcello, B., Garza, D., Matheson, G.O., Besier, T. (2011) 'Functional Movement Screen: Inter-rater and Subject Reliability. *British Journal of Sports Medicine*, 45, 374.

Siff,M. (2004) *Supertraining*. Denver: Supertraining Institute.

Smith C.A., Chimera N.J., Wright N., Warren M. (2012) 'Interrater and Intrarater Reliability of the Functional Movement Screen.' *Journal of Strength and Conditioning Research*.

Sporis, G., Jukic, I., Ostojic, S.M., Milanovic, D. (2009) 'Fitness profiling in soccer: Physical and physiologic characteristics of elite players'. *Journal of Strength and Conditioning Research*, 23 (7), 1947-1953.

Sporis, G., Jukic, I., Milanovic, D., Vucetic, V. (2010) 'Reliability and factorial Validity of Agility Test for Soccer Players'. *Journal of Strength and Conditioning Research*, 24(3), 679-686.

Stolen, T., Chamari, K., Castagna, C., Wisloff, U. (2005) 'Physiology of Soccer: An Update'. *Sports Medicine*, 35 (6), 501-536.

Stone, M.H., O'Bryant, H.S., Schilling, B.K., Johnson, R.L., Pierce, K.C., Haff, G.G., Koch, A.J., Stone, M. (1999) 'Periodization: effects of manipulating volume and intensity. Part 1'. *Strength and Conditioning*, 21 (2), 56-62.

Stone, M.H., Pierce, K., Sands, W.A., Stone, M. (2006) 'Weightlifting: program design'. *Strength and Conditioning*, 28 (2), 10-17.

Stowers, T., McMillan, J., Scala, D., Davis, V., Wilson, D., Stone, M. (1983) 'The short-term effects of three different strength-power training methods'. *National Strength and Conditioning Association Journal*, 5, 24-27.

Strudwick, A., Reilly, T., Doran, D. (2002) 'Anthropometric and fitness profiles of elite players in two football codes'. *Journal of Sports Medicine and Physical Fitness*, 42 (2), 239-242.

Svensson, M., Drust, B. (2005) 'Testing soccer players'. *Journal of Sports Sciences*, 23 (6), 601-618.

Sullivan, J.A., Gross, R.H., Grana, W.A., Garcia-Moral, C.A. (1980) 'Evaluation of injuries in youth soccer'. *American Journal of Sports Medicine*, 8, 325–327.

Tan, B. (1999) 'Manipulating resistance training program variables to optimize maximum strength in men: A review'. *Journal of Strength and Conditioning Research*, 13 (3), 289-304.

Taskin, H. (2008) 'Evaluating sprinting ability, density of acceleration, and speed dribbling ability of professional soccer players with respect to their positions'. *Journal of Strength Conditioning Research*, 22 (5), 1481-1486.

Thomas, V. and Reilly, T. (1979) 'Fitness assessment of English League soccer players through the competitive season'. *British Journal of Sports Medicine*, 13, 103-109.

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, 402-410.

Turner, A. (2009) 'Training for power: Principles and practice'. *Professional Strength and Conditioning*, 14, 20-32.

Turner, A. (2011) 'The science and practice of periodisation: A brief review'. *Strength and Conditioning Journal*, 33 (1), 34-46.

Verkhoshansky, Y.V. (2006) *Special strength training: A practical manual for coaches*. Michigan: Ultimate Athlete Concepts.

Wainner, R.S., Whitman, J.M., Cleland, J.A., Flynn, T.W. (2007) 'Regional interdependence: A musculoskeletal examination model whose time has come'. *Journal of Orthopaedic Sports Physical Therapy*, 37, 658–660.

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, 542-546.

Waller, M., Townsend, R. (2007) 'Application of the power snatch for athletic conditioning'. *Strength and Conditioning Journal*, 29 (3), 10-20.

Willoughby, D.S. (1993) 'The effects of meso-cycle length weight training programs involving periodisation and partially equated volumes on upper and lower body strength'. *Journal of Strength and Conditioning Research*, 7, 2-8.

Wisløff, U., Helgerud, J., Hoff, J. (1998) 'Strength and endurance of elite soccer players'. *Medicine and Science in Sports and Exercise*, 30 (3), 462-467.

Wisløff, U., Castagna, C., Helgerud, J., Jones, R., Hoff, J. (2004) ‘Maximal squat strength is strongly correlated to sprint performance in elite soccer players’. *British Journal of Sports Medicine*, 38 (3), 285-288.

Woods, C., Hawkins, R., Hulse, M., (2002) ‘The football association medical research programme: an audit of injuries in professional football: analysis of pre-season injuries’. *British Journal of Sports Medicine*, 36, 436-441.

Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., Hodson, A. (2004) ‘The Football Association Medical Research Programme: an audit of injuries in professional football-analysis of hamstring injuries’. *British Journal of Sports Medicine,* 38, 36-41.

Wong, P., Hong, Y. (2005) ‘Soccer injury in the lower extremities’. *British Journal of Sports Medicine,* 39, 473-482.

Yard, E., Schroeder, M.J., Fields, S.K., Collins, C.L., Comstock, R.D. (2008) ‘The epidemiology of United States high school injuries, 2005-2007’. *The American Journal of Sports* Medicine, 36 (10), 1930-1937.

Yde, J., Nielsen, A. B. (1990) ‘Sports injuries in adolescents’ ball games: soccer, handball and basketball’. *British Journal of Sports Medicine.* 24, 51-54.

Youngs W.B. (2006) ‘Transfer of strength and power training to sports performance’. *International Journal of Sports Physiology and Performance,* 1, 74-83.

7. Appendices

7.1: Muscular Endurance/Hypertrophy Plan Example Session

Weight Training Programme

Name:		Sport:	Football
Phase	General Prep	Mass:	
Dates:		Height:	
Aims:	Strength Endurance/Hypertrophy		

General Prep Session 1

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted	Volume Load	Volume Intensity
1	Skipping/Boxing/Squat Stretch	Do in Circuit/Warm Up	30s	3	30s					
2	Overhead Squat	Elbows locked, Big toe up, Arse back	10	2	Active					
3	Push Press	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active					
4	Stiff leg deadlift- from floor	Big Chest, Drag bar down thighs	10	2	Active					
5										
6	Shoulder Press		12	3	60-90s	75				
7	Back Squat	Big chest, Big toe up, Get deep	12	3	60-90s	75				
8	Bench Row	Elbows bend 90°, Pull bar to nipples -Slow down fast up	12	3	60-90s	75				
9	NHE	Hips forward, Keeps Hams switched on to the floor	12	3	60-90s					
10	Bench Press	Elbows bend 90°, Push bar from nipples -Slow down fast up	12	3	60-90s	75				
								Total	0	0

General Prep Session 2

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted	Volume Load	Volume Intensity
1	Skipping/Boxing/Squat Stretch	Do in Circuit/Warm Up	30s		30s					
2	Front Squat	High elbows, Big toe up	10	2	Active					
3	Split Jerk - Alternate legs	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active					
4	Stiff leg deadlift- from floor	Big Chest, Drag bar down thighs	10	2	Active					
5										
6	Deadlift	Big chest, hips through at top	12	3	60-90s	75				
7	Dips	Elbows In, Bend + cross legs -Slow down fast up	12	3	60-90s	75				
8	Single Leg Squat	Big chest, hips forward	12	3	60-90s					
9	Chin ups	Wide (elbows at 90°) - controlled drop	12	3	60-90s	75				
10	NHE	Hips forward, Keep Hams switched on	12	3	60-90s					
								Total	0	0
								Weekly Total	0	0

7.2: Basic Strength Example Session

Weight Training Programme

Name:		Sport:	Football
Phase	Basic Strength	Mass:	
Dates:		Height:	
Aims:	Increase Basic Strength		

Basic Strength Session 1

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted	Volume Load	Volume Intensity
1	Skipping/Boxing/Squat Stretch	Do in Circuit/Warm Up	30s	3	30s					
2	Overhead Squat	Elbows locked, Big toe up, Arse back	10	2	Active					
3	Push Press	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active					
4	Stiff leg deadlift- from floor	Big Chest, Drag bar down thighs	10	2	Active					
5										
6	Shoulder Press		12	3	90-120	85				
7	Back Squat	Big chest, Big toe up, Get deep	12	3	90-120	85				
8	Bench Row	Elbows bend 90°, Pull bar to nipples -Slow down fast up	12	3	90-120	85				
9	NHE	Hips forward, Keeps Hams switched on to the floor	12	3	90-120					
10	Bench Press	Elbows bend 90°, Push bar from nipples -Slow down fast up	12	3	90-120	85				
								Total	0	0

Basic Strength Session 2

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted	Volume Load	Volume Intensity
1	Skipping/Boxing/Squat Stretch	Do in Circuit/Warm Up	30s	3	30s					
2	Front Squat	High elbows, Big toe up	10	2	Active					
3	Split Jerk - Alternate legs	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active					
4	Stiff leg deadlift- from floor	Big Chest, Drag bar down thighs	10	2	Active					
5										
6	Deadlift	Big chest, hips through at top	12	3	90-120	85				
7	Dips	Elbows In, Bend + cross legs -Slow down fast up	12	3	90-120	85				
8	Single Leg Squat	Big chest, hips forward	12	3	90-120					
9	Chin ups	Wide (elbows at 90°) - controlled drop	12	3	90-120	85				
10	NHE	Hips forward, Keep Hams switched on	12	3	90-120					
								Total	0	0
								Weekly Total	0	0

7.3: Strength and Power One Example Session

Weight Training Programme

Name: | Sport: Football
Phase: Sports Specific Strength and Power | Mass:
Dates: | Height:
Aims: Increase Strength and Power

Strength and Power Session 1

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted		Volume Load	Volume Intensity
1	Boxing		1m	2							
2	Overhead Squat	Elbows locked, Big toe up, Arse back	10	2	Active						
3	Push Press	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active						
4	Olympic lifting Technique	Various Pulls, catches, and presses	3	5	Active						
5											
6	Olympic lift	Jump+shrug/hang pull/hang clean/clean - Depend ability	3	4	120S	75					
7	Back Squat	Big chest, Big toe up, Get deep	4	3	120S	85					
8	Bench Row	Elbows bend 90°, Pull bar to nipples -Slow down fast up	4	3	120S	85					
9	NHE	Hips forward, Keeps Hams switched on to the floor	4	3	120S						
10	Bench Press	Elbows bend 90°, Push bar from nipples -Slow down fast up	4	3	120S	85					
									Total	0	0

Strength and Power Session 2

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted		Volume Load	Volume Intensity
1	Boxing		1m	2							
2	Front Squat	High elbows, Big toe up	10	2	Active						
3	Split Jerk - Alternate legs	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active						
4	Olympic lifting Technique	Various Pulls, catches, and presses	3	5	Active						
5											
6	Olympic lift	Jump+shrug/hang pull/hang clean/clean - Depend ability	3	4	120S	75					
7	Single Leg Squat	Big Chest, Hips forward	4	3	120S						
8	Dips	Elbows In, Bend + cross legs -Slow down fast up	4	3	120S	85					
9	Stiff Leg Deadlift	Big Chest, Drag bar down thighs	4	3	120S	85					
10	Chin ups	Wide (elbows at 90°) - controlled drop	4	3	120S	85					
									Total	0	0
									Weekly Total	0	0

7.4: Strength and Power Example Session

Weight Training Programme

Name: | Sport: Football
Phase: Sports Specific Strength and Power | Mass:
Dates: | Height:
Aims: Increase Strength and Power

Strength and Power Session 1

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted		Volume Load	Volume Intensity
1	Boxing		1m	2							
2	Overhead Squat	Elbows locked, Big toe up, Arse back	10	2	Active						
3	Push Press	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active						
4	Olympic lifting Technique	Various Pulls, catches, and presses	3	5	Active						
5											
6	Olympic lift	Jump+shrug/hang pull/hang clean/clean - Depend ability	3	4	120S	75					
7	Back Squat	Big chest, Big toe up, Get deep	4	3	120S	85					
8	Bench Row	Elbows bend 90°, Pull bar to nipples -Slow down fast up	4	3	120S	85					
9	NHE	Hips forward, Keeps Hams switched on to the floor	4	3	120S						
10	Bench Press	Elbows bend 90°, Push bar from nipples -Slow down fast up	4	3	120S	85					
									Total	0	0

Strength and Power Session 2

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted		Volume Load	Volume Intensity
1	Boxing		1m	2							
2	Front Squat	High elbows, Big toe up	10	2	Active						
3	Split Jerk - Alternate legs	Elbows high, Quarter Squat-Bang-Hold, Bar behind ears	10	2	Active						
4	Olympic lifting Technique	Various Pulls, catches, and presses	3	5	Active						
5											
6	Olympic lift	Jump+shrug/hang pull/hang clean/clean - Depend ability	3	4	120S	75					
7	Single Leg Squat	Big Chest, Hips forward	4	3	120S						
8	Dips	Elbows In, Bend + cross legs -Slow down fast up	4	3	120S	85					
9	Stiff Leg Deadlift	Big Chest, Drag bar down thighs	4	3	120S	85					
10	Chin ups	Wide (elbows at 90°) - controlled drop	4	3	120S	85					
									Total	0	0
									Weekly Total	0	0

7.5: Max Strength and Power Example Session

Weight Training Programme			
Name:		Sport:	Football
Phase	Max Strength and Power	Mass:	
Dates:		Height:	
Aims:	Increase Max Strength and Power		

Max Strength and Power Session 1

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted				Volume Load	Volume Intensity
1	WU - Olympic lifting Technique	Teaching Progressions - 1st Pull, 2nd Pull, Catches etc.			Active								
2													
3	Olympic lifting		3	3	2-5 mins	75							
4	Bench Press		2	3	2-5 mins	90/95							
5	Back squat		2	3	2-5 mins	90/95							
6	Chin Ups		2	3	2-5 mins	90/95							
7	NHE		6	3	2-5 mins								
8	Stretches for glutes, lowerback	Twist and Knee Tuck											
9	Stretch and hold squat position												
10	Stretch hip flexors/lumbar curve												
											Total	0	0

Max Strength and Power Session 2

	Exercise	Comments	Reps	Sets	Rest	%1RM	Weight	Recorded Weights Lifted				Volume Load	Volume Intensity
1	WU - Olympic lifting Technique	Teaching Progressions - 1st Pull, 2nd Pull, Catches etc.			Active								
2													
3	Olympic lifting		3	3	2-5 mins	75							
4	Dips		2	3	2-5 mins	90/95							
5	Back squat		2	3	2-5 mins	90/95							
6	Prone Row		2	3	2-5 mins	90/95							
7	Stiff Leg Deadlift		6	3	2-5 mins	90/95							
8	Stretches for glutes, lowerback	Twist and Knee Tuck											
9	Stretch and hold squat position												
10	Stretch hip flexors/lumbar curve												
											Total	0	0
											Weekly Total	0	0

7.6: Worked Example of 1RM Estimation Equation (Brzycki, 1993)

For an athlete that lifts 100kg through 6RM the following 1RM score would be predicted:

1RM = Weight Lifted/(1.0278-(0.0278 x number of reps))

= 100/(1.0278-(0.0278 x 6))

=100/(1.0278-0.1668)

=100/0.861

=116 kg

7.7: Performance Measure and Anthropometric *P* values

Assessed using paired *t-test*:

Table 7.1: Anthropometric Data

Test	**Pre to Post**
Height	p=0.047
Mass	p=0.048
LBM	p=0.001
BF%	p=0.015

Table 7.2: 5, 15 and 30m Sprint times, CMJ, PP, AP

Test	**Pre to Post**
5m	p=0.279
15m	p=0.235
30m	p=0.058
CMJ	p=0.004
AP	p=0.007
PP	p=0.005

Table 7.3: 1RM and 1RM/LBM

Test	**1RM Pre to Post**	**1RM/LBM Pre to Post**
Squat	p<0.0001	p <0.0001
Bench Press	p <0.0001	p <0.0001
Prone Row	p <0.0001	p <0.0001

7.8 Ethical Approval

REGISTRY RESEARCH UNIT

ETHICS REVIEW FEEDBACK FORM

(Review feedback should be completed within 10 working days)

Name of applicant: James Keenan .... **Faculty/School/Department:** HLS: Biomolecular and Sports Sciences……………………………………

Research project title: The Impact of a Periodised Strength and Conditioning Programme on Performance in Elite Football Academy Players

Comments by the reviewer

1. Evaluation of the ethics of the proposal:

The application has considered the general points raised by the form. However, please note the comments below regarding formatting and further information that will be helpful and should be amended.

Section 1. The DoS is named but this name does not appear as a Co-investigator. This is unusual, surely the DoS is part of the research team? Please amend as appropriate for the team / supervision arrangements. Done

There are some instances of typographical / grammatical errors e.g. ;
Section 5: Aims; Missing word/s 'In addition to this [a further aim is] understand the relationship….'
Aim 2; '… on [a] subsequent…'. Etc Done

Sections are worded in the past tense indicating that the work has already been done – at this point of reading the application it is not noted that the study is retrospective (as the reviewer understands it). Please stat this when introducing the study and prior to the aims. Have stated that the work was done as part of existing consultancy agreement. The application does state (later) that the procedures are being undertaken whether this research was being done or not. Furthermore, the form does note that the consent of participants is based on their employment contract.

Add to the aims to clarify that one aspect is a chronic comparison of responses due to training and that the other is an examination of the acute effects of resistance training on performance variables. Done

Phase 2 – how will the participants be organised into hypertrophy and strength training groups? Are you expecting equal group numbers or is it based on the fitness coaches / teams requirements? Could you end up with n=12 requiring all the same training method? Clearer

Research instruments – wording – '…four [site] skin fold…'. Done.

Section 3. Please give the age range that you will be dealing with e.g. 16 – 18 years, so the reader knows how young the participants are likely to be. Note that the testers were / are currently CRB checked. Done.

Section 6: Probably worth noting that locked filling cabinet is in a 'swipe card limited access office' or similar. Done.

Section 7: Informed consent. By this point the reader should know that due to the nature of the study the data has already been collected and the contractual agreements facilitate participation. Keep this here but make sure it is noted earlier (as previous comment). OK.
Make sure you have a copy of the agreement / email etc for use of data and anonymity. Presumed.

Section 8: Risk of harm: Please add that appropriate first aid procedures are provided at the club / testing venues. Line 2; 'weights' not 'weigths'. Both done.

2. Evaluation of the participant information sheet and consent form:

Not seen, as not required based on the research design.

3. Recommendation:

(Please indicate as appropriate and advise on any conditions. If there any conditions, the applicant will be required to resubmit his/her application and this will be sent to the same reviewer).

☐ Approved - no conditions attached Approved.

☐ Approved with minor conditions (no need to resubmit)

☑ Conditional upon the following – please use additional sheets if necessary (please re-submit application)

Please amend as suggested above as although the ethics application does provide the information required it needs to be clear about the design of the study etc from the beginning. This won't take long to amend.

☐ Rejected for the following reason(s) – please use other side if necessary

☐ Further advice/notes - please use other side if necessary

Name of reviewer: Dr. Mike Price. ....

Signature: ....

Date: 26/05/11