Abstract

The primary objective of the study is to investigate the relationship of the Stretch Shortening Cycle with primary performance indicators for rugby union, and to determine the physiological differences between forwards and backs.

A total of 20 (forwards, n=10; backs, n=10) trained semi-professional rugby union males aged between 19 – 22 years were analysed as a combined group (Group 1), and as two separate groups (Forwards = Group 2; Backs = Group 3). Each subject underwent physiological measurements of height, body mass, muscular power (Vertical Jumping for height, using a Squat Jump, Countermovement Jump, and a 5 Bound Jump for height with minimum ground contact time), speed (10m and 40m), and leg strength (5RM Squat).

Forwards were taller and heavier than backs (184.7 ± 10.9cm and 107.5 ± 18.9kg vs 180.6 ± 5.6cm and 88.5 ± 5.9kg) but were shown to be significantly slower over the 10m and 40m sprint distances ($p<0.05$) which can be reflected by the significant difference in jump height ability between forwards and backs ($p<0.05$; Forwards SJ and CMJ: 33.53 ± 2.98cm and 35.68 ± 3.62cm vs Backs: 40.33 ± 7.45cm and 42.65 ± 7.44cm). SJ and CMJ were significantly related to sprint performance in the whole group analysis ($p<0.05$, SJ – 10m and 40m: r – 0.74 and r – 0.77; CMJ – 10m and 40m: r – 0.74 and r – 0.76). Scores for 5BJ and Sprint Performance were not significantly related, although there was a significant difference between forwards and backs for the 5BJ test, and Squatting for absolute leg strength did not significantly related to any of the measured variables. There were no significant differences ($p>0.05$) evident between forwards and backs' squatting ability.

Results show that jumping ability reflects performance in sprint running, and physiological characteristics can determine an individuals role within the game. There is no direct effect between leg strength and sprint running,

however and increase in the ability to produce a higher force can effect an improvement in other variables which are related to sprint performance. These finding provide performance standards for sub-elite trained athletes.

CHAPTER I

INTRODUCTION

1.0 Introduction

Increased professionalism in rugby has elicited rapid changes in the fitness profile of elite players. Rugby Union requires a vast array of specific movements and exercises for an athlete to compete at the elite end of the spectrum, along with a high technical ability to perform complex skills. The demands of competition are channelling the players to meet a criteria regarding physiological and anthropometrical characteristics, which are measured using standardised testing protocols. Athletic success in the modern era is greatly determined by the manner of which a force can be produced. Athletes involved in intermittent sports such as rugby union strive to be able to produce a high explosive force whenever possible. Having the ability to produce this amount of force will allow potential to generate high speed movements (Manning *et al,* 1988).

Movement requires basic muscle function, which is defined as the Stretch-Shortening Cycle. This movement pattern follows an eccentric-concentric action where the pre activated muscle is stretched and then shortened (Nicol *et al,* 2006). This is found in upper body and lower body activities, with ground contact phases such as running jumping and hopping examples of this specific movement pattern in the lower extremities. The SSC underpins most movement during human exercise, explaining the sequence of events during locomotion. The high explosive movements that follow this movement pattern require the energy generated from the ATP-PC system, to allow sufficient force to be produced (Mcardle *et al,* 1996).

Understanding the effect that specific SSC movements have on critical performance indicators in rugby union can provide a vast amount of information to a wide variety of the population. The study aims to investigate previous research into SSC movements and how force is produced and inter-related with other high explosive exercises, and determine the correct methods and protocols to measure the movement pattern within a rugby union sample. Strength and power are considered to be a vital part of rugby union (Nicholas, 1997) and various methods are employed to measure the strength and power of the lower limbs, including the analysis of an athletes jumping and/or hopping ability (Manning *et al,* 1988).

Previous literature have made assumptions regarding the effect of the SSC and its relationships with movements that inherit this movement pattern, however, there is limited literature regarding the SSC in a rugby specific population. The SSC movement pattern can be developed specifically through various types of training, which can benefit athletes from one sporting background compared to another, due to the training history and nature that the sport demands. Athletics training is an example of common exercises that follow the SSC movement pattern, hence the high correlations within an athletic sample (Hennessy and Kilty, 2001). Laboratory – based tests using isokinetic, dynamometry, and force plate devices and field – based jumping tests are used to assess the leg strength and power of athletes. These performance tests seem to demonstrate a high degree of specificity to sprint running and other lower limb strength tests (Hennessy and Kilty, 2001; Walshe *et al,* 1998). Field based team games, such as rugby union are complex in terms of determining the specific physiological demands of a player, which vary depending on the position played (McLean *et al,* 1992).

1.1 Aim of the Study

For the above reason, the present study is aiming to investigate the effect and the relationships the SSC have on performance indicators that are imperative to rugby union players, and to assess the differences between forwards and backs with regards to the physiological attributes and relationships that the SSC exercises and performance variables demonstrate.

The study intends to determine if the relationships shown in other research mimics the effect in rugby union players, and therefore provide a base for coaches to structure relevant training programmes for players to develop the specific physical attributes that are demanded.

CHAPTER II

REVIEW OF LITERATURE

2.0 Review of Literature

2.1 Rugby Performance / Profiling

Rugby Union is an interval or intermittent sport. The athlete is required to continually produce short bursts of high intensity work with minimal loss of power (Nicholas, 1997). A vast amount of movements in rugby such as sprinting, tackling, jumping and rucking, require the break down of energy from the anaerobic system for them to be performed effectively. To perform these skills the athlete needs to possess high levels of speed, strength, and power along with other specific techniques. Strength is the maximal force produced by a muscle or muscles at a given speed, and power is the product of force and velocity (Knuttgen & Kraemer, 1987). These components require the breakdown of energy from the ATP-CP system, which is considered the primary system within rugby.

The ATP-CP or high energy phosphate system provides a rapid supply of energy from stored ATP or CP in the muscle (McArdle *et al*, 1996). The ATP is composed of a molecule of adenosine and three phosphates. The phosphates are bound together with high energy bonds. In an enzymatically controlled reaction, the bonds are broken to release energy:

$$ATP\ ^{ATPase}\ ADP + P_i + ENERGY$$

In the presence of the enzyme ATPase, ATP breaks down to adenosine diphosphate, inorganic phosphate and energy:

$$CP\ ^{CPase}\ C + P + ENERGY$$

Creatine kinase provides the catalyst for the hydrolysis of creatine phosphate. The energy provided by this reaction provides the energy for the phosphorylation of ADP back to ATP. The CP provides a small reservoir of energy (McArdle *et al,* 1996). The ATP-CP system is able to supply energy required for maximal activity of five to six seconds duration. This short term power source is vital for short sprints or explosive accelerations to make or break tackles. Both of these activities are intrinsic to rugby union. This immeadiate energy system may also be utilised for explosive movements in the scrum or vertical jump in the lineout (Nicholas, 1997).

Various physiological tests have been described for the assessment of rugby union players. Standard anaerobic power testing within a rugby player sample tend to use jump techniques, a sprint of no more than 40 metres, gym related exercises such as squatting and benchpress, medicine ball throwing, agility tests and abdominal strength tests (Carlson *et al,* 1994; Jenkins and Reaburn, 1998; Maud, 1983; Nicholas, 1997; Quarrie *et al,* 1995).

The ability to sprint is undeniably an important fitness component of rugby union (Nicholas, 1997). Test procedures to asses this capacity have been described over short distances from standing or rolling starts (Carlson *et al*, 1994; Quarrie *et al*, 1995). Explosive leg power is a major criterion when considering sprint ability and it is vital for all participants of rugby. If an athlete possesses high levels of leg power it allows for a quicker muscle contraction during movement with higher force, producing a quicker leg turnover speed with increased distance (Farly & Morgentroth, 1999). However, leg power is not only essential for rugby players when required to sprint, the forwards require power in the lineouts and scrummage situations. The backline players need the ability to accelerate over short distances and to make and break tackles (Nicholas, 1997).

Whilst sprinting is a major component required to play rugby union, forwards and backs possess different qualities, due to their primary objectives and roles within the game. Forwards are normally bigger and heavier which is required to withstand large forces in the contact areas such as scrums, rucks and mauls. Backs are often quicker as speed is essential with backs often finding themselves with lots of space (Quarrie *et al*, 1996). These different qualities have been declared important via motion analysis studies, which have shown on average, that first class forwards spend 8 minutes in intense static activity scrummaging during the game, and 5 minutes in rucks and mauls, a significant amount more than backline players (Carter, 1996). Given that forwards spend more time in the contact area, and muscle strength is required during contact situations in rugby, forwards should possess greater strength than backs, however, when evaluated on a range of strength tests, collegiate forwards and backs performed the same, possibly due to the young training age of the athletes (Duthie *et al,* 2003).

Backs were found to cover greater distances at sprinting speed compared to the forwards (253 ± 45m vs 94 ± 27m), and this signifies the importance of sprint ability, particularly in backline players (Deutsch *et al*, 1998). It was also found that forwards carry the ball into contact on more occasions than backs. It seems logical that forwards require greater body mass when compared to backs, and a review by Duthie *et al* (2003) included literature from Dacres–Manning (1998) where front row forwards from the New South Wales super 12 rugby team weighed 112.8 ± 5.7kg, and the remainder of the forwards at 108.3 ± 5.3kg, whilst the backs were only 89.0 ± 6.8kg. The anaerobic energy systems that were earlier suggested to be the primary source of energy metabolism has also been quantified via motion analysis research (McLean, 1992). Work : rest ratios were found to be in the 1 : 4 range in International Five Nations rugby, with many of the rest periods due to injury stoppages and kicks at goal. McLean (1992) also found that 63% of these ratios had work periods less than the rest periods. Literature in this area suggest's that sample's including rugby players at the elite end of the spectrum should be tested with sufficient rest in between bouts of exercise, allowing the testing procedure to be game related. Due to the anthropometric issues (Stature and Body Mass), scores between backs and forwards produce some variability. Carlson *et al* (1994) suggested that the vertical jump allowed discrimination between backs and forwards. These findings are consistent with those of Quarrie *et al* (1996) who reported that the front row forwards had the lowest vertical jump height. These studies investigated the performance charachteristics of first grade players. The vertical jump heights reported by Maud (1983) on an amateur rugby side show no such trends between forwards and backs, and relatively lower values than the values obtained by more skilled players. It may be suggested that as the skill of the player is increased, then so is the difference between the physiological performance of the players.

Rugby players typically sprint between 10 and 20m, but may be required to sprint distances of around 50 metres. It is often found that backs are faster than forwards over various distances between 10 and 40metres (Quarrie *et al*, 1995 & 1996; Carlson *et al*, 1994), and it has been observed that first class players are faster than second class players (Quarrie *et al*, 1995). First class players are defined as players who generate their entire income from playing rugby at a professional standard. They compete in leagues where large amounts of prize money can be earned as opposed to second class players, who receive moderate remuneration to play, but also rely on additional employment to generate income (Gabbett, 2005). These results indicate that speed is a discriminating factor between forwards and backs. Duthie *et al* (2003) suggests that testing of rugby players should include both acceleration and maximal velocity testing ovr distances of 40 metres with acceleration intervals (0-10m).

Gabbett (2002b) also found that forwards are heavier, which was evident in all observed teams. Although the study was conducted on rugby league players, the sport displays a high similarity to rugby union as it is physically demanding and requiring players to participate in frequent bouts of intense activity such as sprinitng, physical collisions and tackling.

Previous literature containing methods of testing between varying standards of ability is relevant as it distinguishes standard measuring protocols between amateur, semi-professional and profesional players. Various studies have used identical methods of testing the physiological requirements of rugby league and union players between different playing standards (O' Connor, 1995; Quarrie *et al,* 1996; Nicholas, 1997; Gabbett, 2000b; Gabbett, 2002a) which justifies the relevance it has on using these protocols in the present study, as it can then be compared to the previous literature.

Recent literature suggests that physiological capacities are related to playing ability. Table.1 Highlights the differences in previous research between amateur, semi-professionl and professional rugby league players.

Table 1. Comparison of physiological characteristics of amateur, semi-pro and pro rugby league players (mean ± sd). Adapted from Gabbett (2002a)

	Amateur	Semi-professional	Professional
Age (years)	27 ± 5	24 ± 4	-
Body mass (kg)	86 ± 11	89 ± 11	90 ± 10
Vertical jump (cm)	38.1 ± 7.1	42.5 ± 8.8	-
10m sprint (s)	2.58 ± 0.15	2.17 ± 0.13	1.82 ± 0.10
40 m sprint (s)	6.63 ± 0.27	6.04 ± 0.23	5.36 ± 0.27
Estimated V_{O2max} (ml ´ kg $^{-1}$´ min $^{-1}$)	39.0 ± 5.3	46.0 ± 4.4	53.2 ± 4.5

*Source*s: Amateur (Gabbett, 2000b), semi-professional (Gabbett, 2002a), professional (O' Connor, 1995)

These figures provide the information that is needed to distinguish between players of various playing standards. These are deemed the main components required to play the game (McLean, 1992; Carlson *et al*, 1994; Quarrie *et al*, 1996) , however, as the level of playing performance and standard increses, so does the physiological attributes. In addition, although playing performance may be related to the physiological capacities of players, improved fitness may not always equate to improved performance.

2.2 The Stretch-Shortening Cycle

Rugby union, as well as any other sport or movement, requires muscular function in order to perform simple exercises. The basic muscle function is defined as the Stretch-Shortening Cycle (Nicol *et al,* 2006), where the preactivated muscle is first stretched (eccentric action) and then followed by the shortening (concentric action).

The progressive evolution of athletic performance and specific conditioning techniques is dependent on a thorough understanding of the mechanisms underlying this dynamic muscular function (Walshe *et.al*, 1998).

Rugby union is a sport where players are continually required to apply large ground reaction forces in order to perform various skills and techniques including running, jumping and hopping, and these are all examples of the SSC for leg extensor muscles.

Komi (2000) believes that the Stretch-Shortening Cycle of muscle function originates from the observation that body segments are periodically subjected to impact or stretch forces. External forces such as gravity lengthen the muscle in human locomotion, typically in running, hopping and walking.

The functional phase of a given Stretch-Shortening Cycle movement, e.g the ground contact for the leg extensor muscles during running, is comprised of two important aspects that characterise SSC. These are: (i) the pre-activation, and (ii) the braking and push off phase of a movement. The SSC consists of an interaction between eccentric contractions, immediately followed by a concentric contraction (Nicol *et.al,* 2006). An illustration (Figure 1) demonstrates a three phase SSC movement pattern during human walking, hopping and running.

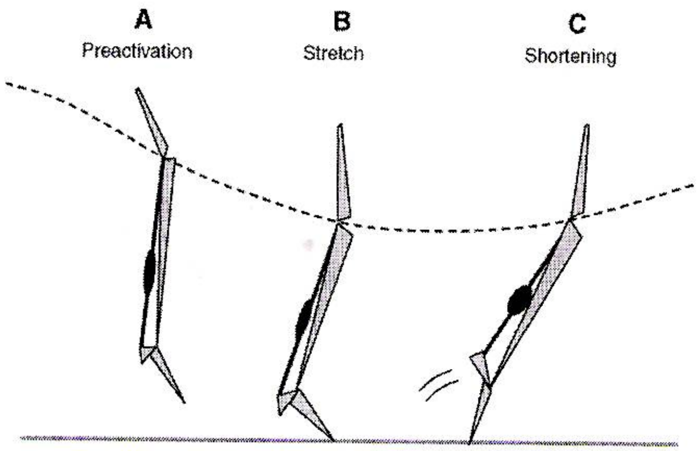

Figure 1. Komi's (2000) 3 phase SSC movement pattern during walking, hopping and running

The pre-activation phase, (a), activates the lower-limb extensor muscles to prepare for resistance against ground contact prior to the impact. This is followed by phase (b), described as the stretch / braking phase, where the eccentric contraction stretches the muscles for a short duration of 50-120ms during running, prior to the final phase, (c), where the muscles are shortened during the concentric action of the movement.

The force production is a questionable issue during a SSC. Many authors have explored the field, providing various explanations relating to the mechanism of power production. Theories such as stored elastic energy is primarily accountable for the production of force are available (Cavagna *et.al* 1965). Avis *et.al* (1986) and Ettema *et.al* (1990) also accounted stored elastic energy to attribute to the force production. Komi and Ishikawa (2003) found that potential energy from increased dropping height is utilised effectively by the elastic stretching in regulating the fascicle stiffness and the recoil of tendinous tissues. Higher pre stretch intensity leads to an increased efficiency of the positive work during SSC (Komi and Ishikawa, 2003), this is due to the decrease in stretch of the fascicle during the braking phase and an increase in electromyographic activity in the pre activation and braking phases, enhancing muscle stiffness. In the subsequent push-off phase, the recoil of tendinous tissues increased. At the onset of shortening, elastic recoil would add to the work output of the muscle-tendon complexities involved in actions such as running, jumping, and hopping.

Leg stiffness is one of the elastic components of the muscle-tendon complex behaviour. It differs from leg strength in that it influences the mechanics and kinematics of the human body's interaction with the ground (Farly and Morgenroth, 1999). Impact forces caused by gravity acting against body weight, requires a stiffer leg to absorb the impacts, so that the stored elastic energy can be effectively utilised. Kuitunen *et al*. (2002) found that a stiffer leg allows a faster rebound when sprinting, reflected by a shorter ground contact time at increasing running speeds.

However, there are alternative explanations provided for force production in a SSC (Komi and Gollhofer, 1997). The SSC force production ability has been recognised to be facilitated via a prior high force eccentric stretch of the muscle tendon, so that it establishes a functional state. Many questions have been raised regarding the contribution of the active pre stretch to enhance the performance of muscle in SSC contractions (Avis *et.al* 1986), where the mechanisms concerned include elastic strain energy. However, Bobbert *et.al* (1996) proposed that during dynamic multi joint movements, the benefits of the mechanisms in question are insignificant. Their study produced evidence that during a SSC movement, the concentric phase is greater when compared with a purely concentric action, due to the prior higher active state of the muscle before the concentric action, which corresponded to a higher level of force.

Walshe *et.al* (1998) investigated muscular performance within three different squat test groups. When the mean force that was produced during a concentric only squat, a concentric squat preceded by an isometric pre load, and a SSC squat was analysed, it was found that the differences between the three performance groups were significant. The mean force for the concentric only group (489 ± 131N) was significantly lower than the isometric and the SSC conditions (1,168 ± 216N & 1,193 ± 222N). It was shown that subjects' who's squat was preceded by an active stretch rather than an isometric contraction were initially able to produce more work during the first

300ms of the concentric movement. However these benefits, as a percentage of total work, are insignificant after the first 300ms of the concentric action. These findings enhance prior discoveries of the importance of pre stretch before muscle shortening (Jensen *et al* 1991). Jumping with and without prior stretch found that greater jumps are observed with a pre stretch followed by the concentric action (Bobbert *et.al* 1996). This is also related to prior muscle state activation, however it is also though that increase in extrinsic muscular stiffness leading to the use of stored elastic energy may also be accountable.

As previously mentioned, leg power is a vital factor when determining rugby performance, where various skills are performed with explosive movements. If the underpinning factors of force production in several movements are derived from the SSC movement pattern, then it is important to know the extent of which the SSC effects and relates to primary performance paramaters required for rugby union. By understanding the relationship between the SSC movement pattern and rugby performance criteria it can allow for specific development via training programmes in order to enhance performance related variables.

2.3 Tests to measure the SSC

The effectiveness of the SSC can be measured using various methods. They can be tested in a laboratory setting, or field based, which allows a more accesible and cheap approach to the measure. A series of jumps is often evaluated in order to determine the force produced by an SSC movement including a counter-movement jump (CMJ), a squat jump (SJ), bounce drop jumps (BDJ) and rebound jumps (Linthorne, 2001; Hennessy and Kilty, 2001). A CMJ is an example of a movement that benefits from the SSC (Linthorne 2001) and is administered with the athlete starting in an upright standing position, then making a downward movement by flexin at the knees and hips, then immeadiately extends the knees and hips to jump off the ground in a vertical direction. The squat jump, however, is suggested not to be used to assess the SSC as it depicts a non specific movement pattern. It can still be used as a functional measure of strength, which is important to rugby union players, and is considered to be a performance characteristic of sprint performance, in particular to the acceleration phase, but may also be related to the performance of a squat test.

The motions involved between a) the CMJ and b) the SJ can be seen in Figure.2.

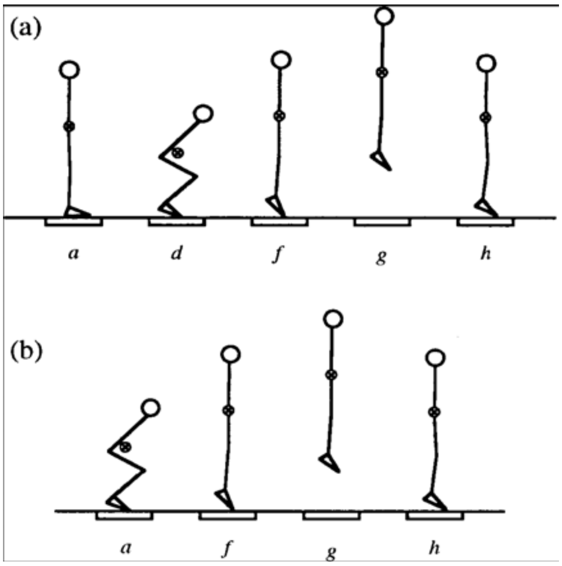

Figure 2. Motions a) in a countermovement jump and b) in a squat jump. The CoM indicates moves strictly in the vertical direction (adapted from Linthorne, 2001)

Linthorne (2001) compared these two types of jumps and found that the CMJ was far superior to the SJ when comparing the force, displaying an increase in take off velocity and subsequent jump height.

Hennesy and Kilty (2001) suggest that the CMJ and BDJ demonstrate a high degree of specificity to sprint running and the SSC action. The support phase during the jumping action mimics the eccentric – concentric contractions of the leg extensor muscles during the sprint action. Although these two types of jumps are related to sprint performance, they both attribute differently to the SSC action.

Schmidtbleicher (1994) has noted that the long SSC action is characterised by large angular displacements of the hip, knee, and ankle joints, and the total ground contact time (GCT) for this SSC action is more than 250 milliseconds. In contrast, the short SSC action is characterised by small angular displacements in the cited joints and lasts 100-250 milliseconds. The CMJ is typically characterised by large angular displacement in the lower limbs, whereas the BDJ requires the subject to limit lower limb angular displacement and GCT. However, previous studies have reported significant relationships between the CMJ and short sprint performances (Bosco et al, 1995, Nesser et al, 1996, Young et al 1996), as well as longer sprint distances up to 300m (Hennesy and Kilty 2001). Hennessy and Kilty (2001) also produced evidence that the CMJ is related to sprint running distances as low as 30m. A 5 bound test was also used by Hennessy and Kilty (2001) to assess the repetitive action of the SSC, which was another measure of a short SSC action. It is possible for 5 rebound jumps (RJ) to be performed vertically on a jump mat. This method is still a measure of repeated SSC and is able to produce an index of reactive strength (RSI). It is similar to a BDJ, only it is repeated with 5 consecutive attempts after an initial CMJ instead of a drop to initiate the movement. Rebound exercises require great strength (Mero et al, 1992), and due to this are considered sprint specific exercises and are subsequently widely used in plyometric programmes.

Previous studies have used the vertical jump and reach test to measure leg power (Gabbett 2002a). This test is administered with the subject being instructed to extend one arm and hand in the air and mark with a piece of chalk the highest point reached. They then jump and attempt to reach the highest point possible on a wall mounted board to provide a recording of leg power. However, there is a limitation associated with this method, that can be problematic to the validity of the test. During the test, the assessor may be unaware that some subjects may not fully extend their arm in the air prior to the jump, which will consequently overestimate the subjects jump height.

The instruction received by the subject has an effect on the outcome of a jump (Young *et al*, 1995). During the study by Young et al (1995), subjects were instructed on how to perform a particular jump, to determine a particular outcome. It was found that subjects who were told to concentrate on achieving a large jump height produced longer ground contact times, and vice-versa. When the subjects were instructed to jump for maximum height and minimum contact time, mean contact times were reduced by 56-57% compared to the jump for height condition. The jump height, however, was also reduced by 18-21% compared to the jump for height condition due to the less time for force production against the ground. Therefore it is essential that the present study provides the subjects with a clear understanding of the aim of the jump tests, so that one component of the test is not sacrificed for improvement in the other (Jump Height vs Ground Contact Time).

The RSI is an index determined from jump height (mm) divided by flight time (ms). This provides an accurate score of reactive strength as it accounts for the two underpinning factors related to reactive strength. Some people posses the ability to jump high, but at a slow rate, improving their height score but deteriorating their ground contact time score. On the other hand, some may have the ability to jump repetitively at a quicker rate whilst reaching shorter heights on their jumps. The RSI provides a consistent value across a population. It is suggested that the index represents an appropriate tool for examining the short SSC and high load action common to plyometric exercise and movements (Young et al, 1995).

As previously mentioned, the squat test (for lower limb strength), and sprint tests (for speed) are important variables for rugby performance and follow SSC movement patterns. The performance in these tests are often related to performances in strict SSC movements such as the jump tests previously discussed. Comyns et al (2007) found that heavier loads when performing squats will improve ground contact time and leg stiffness, suggesting that heavy lifting will encourage the fast stretch-shortening cycle activity to be performed with a stiffer leg spring action, which in turn may benefit performance. The more the squat repetition increases, the ability to maintain a heavy load decreases, therefore, no more than 5 repetitions is recommended for a strength induced lift.

Much of the literature regarding the SSC have been studied on various sporting populations, however there is a lack of research in the area concerning male rugby union players. It is therefore, the researcher's primary objective to determine the relationship and the effect that SSC has on various rugby performance indicators, with a reflection on the differences that may be evident between forwards and backs, whilst using appropriate and standardised testing protocols.

CHAPTER III

METHODOLOGY

3.0 Methodology

3.1 Sample Group

20 male undergraduate students from the University of Wales Institute, Cardiff volunteered to participate in the study. The subjects were advised as to the nature of the experimental protocol and were ensured that all data would remain anonymous at all times (Informed Consent Form – Appendix 1). All of the subjects involved (n = 20) were currently representing UWIC rugby football club, at semi-professional level and were regularly involved in explosive movements as part of their training. The subjects were divided into two groups according to their playing position, and also combined as a whole for analysis, Group 1 (Full Sample Group, n = 20), Group 2 (Forwards, n = 10) and Group 3 (Backs, n = 10). This was considered a practical sample size. The power of statistical tests are influenced by the number of subjects; Cohen and Holiday (1982) stated that at approximately n = 15 the power levels off. Therefore the sample size was large enough to ensure that the statistics that were applied to the results were sensitive enough to detect any significance.

All subjects had performed the experimental procedures on a number of occasions before the field testing session as part of their team's physical conditioning programme. It was important that all subjects were familiar with the procedures in order to nullify any learning effect that may be present. Subjects were requested to refrain from strenuous exercise for at least 48 hours before the field testing and consume their normal pre training diet before the testing session.

3.2 Controlled Warm-Up

All subjects were required to undertake a controlled warm up prior to any testing. Measures for height and body mass were collected prior to the warm up. The speed and jump testing were collected on day one, and the squat test was administered on the following day, so that the subjects were able to perform maximally in all tests.

A 10 minute warm up, consisting of 5 minutes low intensity running followed by a series of dynamic stretches determined by the individual, and short sprints was performed by all subjects prior to the testing procedure.

3.3 Testing For Height Measurement

This test was conducted to attain the stature of each subject. The apparatus used for this test was a Leicester Height Measurer (SECA: Hamburg, Germany), where the distance between the floor and the vertex of the head was measured, providing a reading to the closest 0.01 cm. Subjects were required to remove shoes and stand up straight with their feet together. Subjects placed their heels and back against the vertical stand of the height measurer. The subjects were instructed to breath in, stretch up and then breath out, and the reading was taken.

3.4 Testing For Body Mass Measurement

Body mass was measured in units of kilograms using Digital Weighing Scales (SECA, Model 770, Vogel & Halke Hamburg, Germany), which gave a reading closest to 0.1kg. Footwear was removed by each subject along with any loose items that may hinder the measure of body mass, such as mobile phones, wallets, keys etc. The subjects were measured in an upright position with their feet placed firmly on the scales, whilst maintaining a static stance.

3.5 Testing For SSC and Lower Leg Power

Three different jumps were administered to measure various SSC movements. Subjects performed a Squat Jump, a Counter-Movement Jump, and a 5 Rebound Jump test in a randomised order. All three jumps were performed over three attempts, with sufficient recovery between trials. The recovery was set at 1 – 2 minutes, so that the subjects could ensure maximum effort was exerted on each trial. They were instructed to inform the test administrator once they were ready to perform the next trial. These tests were conducted shortly after the Sprint Test. There was a large recovery period between each sprint trial, to help delete any fatigue that may have occurred (Manning *et al*, 1988), to ensure it had no effect on the outcome of the jump test. . The sprint test was considered to be an acceptable warm up for the jump tests. All jump tests were measured using the SmartJump equipment (Fusion Sport, Brisbane, Australia) and data was then collected, processed and stored wirelessly onto the control PDA. The PDA control was able to calculate flight time (ms), power (W), ground contact time (ms), and peak height (cm) for each jump, along with a Reactive Strength Index for the 5BJ.

It has been observed that different instructions on the objectives of jumping, when supplemented with feedback, produced clear differences in jumping characteristics (Young *et al,* 1995), therefore, clear instructions were provided for each jumping condition.

Initially, the subjects were instructed to stand upright on the jump mat facing the reactive unit, with their heels on the ground with their feet placed shoulder width apart.

3.5.1 The Squat Jump Protocol

On the command of the test administrator, the subjects were required to squat to a 90^{o} angle at the knee joint and hold that position for two seconds, counted by the administrator. This is to nullify or decrease any eccentric action that may aid the performance of the jump (Walshe *et al,* 1998). After two seconds the subjects were instructed to explode up and jump for maximum height. Any movement such as jumping forwards was discouraged, so that any effort was not lost horizontally, and a true representation of jump height could be displayed. The subjects were instructed to place their hands above the hips so that there was no arm drive affecting vertical displacement. Jump height was the objective and primary observation for this condition, which was measured in centimetres.

3.5.2 The Counter-Movement Jump Protocol

From a standing position the subject was instructed to dip by bending the knees and immediately jump for maximum height. The take-off was to be done as a continuous movement with no observable pause between downward and upward phases. Hands were placed above the hips to remove any arm drive effect and forward motion was discouraged. There were no instructions provided to the subjects regarding the depth of the dip/squat, but the importance of a continuous movement was emphasised. Subjects were informed that the main objective of this condition was jump height (cm).

3.5.3 The 5 Rebound Jump Protocol

To initiate the movement, the subjects were instructed to perform one CMJ following the above protocol which was then followed by 5 consecutive rebound jumps. The subjects were instructed to perform the rebound jumps by jumping as high as possible and as quick as possible. The objective was to observe the combination of height and ground contact time, which provides an index of reactive strength. The rebound jumps were performed with hands above the hips, and each subject were instructed to avoid heel contact with the ground. Subjects were also instructed to maintain their position throughout the jumps as much as possible, so that any effort wasn't lost horizontally.

3.6 Speed Measurement

Speed was measured by trials performed over distances of 10 and 40 metres that were accurately measured using a standard measuring tape to calculate the distances. Smartspeed timing gates (Fusion Sport, Brisbane, Australia), were placed at the start point, and at each of the distances measured. Two lanes were used so that 2 subjects could perform at the same time, in an attempt to ensure that every subject produced a maximal effort over the required distances, by simulating a competitive environment. Both distances were measured each time the subject performed the test. The timing gates provided a split time (s) for the first 10m and the following 30m, along with a total time for 40m.

3.6.1 Speed Test Protocol

Subjects were instructed to start 30 cm behind the starting gate, using a marker cone, to avoid breaking the beam of the gate prematurely (Carlson *et al* 1994). The subjects were instructed to begin motion on the command of the test administrator via a countdown of “3 - 2 - 1- Go” so that reaction was expressed with maximal effort. Reaction time was not present in the results as the timing was started once the subject broke the beam by passing through it, and not on the command of the test administrator. The subject was instructed to run with maximal effort throughout the test until crossing the final gate. Each subject performed 3 trials with a minimum recovery of 3 minutes and a maximal recovery of 5 minutes between each trial, and received words of encouragement throughout each trial from the test administrator to enhance motivation and ensure maximal effort was exerted. The best score for each subject, to the nearest 0.001s, was used for analysis. The distances measured have been used to measure similar subjects (Gabbett 2000b, 2002, 2005; Carlson *et al,* 1994; Quarrie *et al,* 1995) and other sporting populations (Hennessy and Kilty, 2001) so that data can be compared to previous literature.

3.7 Testing For Lower Leg Strength

Leg strength was measured using a 5 repetition maximum squat test. The squat test was administered using a squat rack within a cage to enhance safety precautions, as squatting can be a dangerous exercise and cause injury. The cage has adjustable safety bars running horizontally either side of the cage which can take the weight of the barbell should a subject fail the lift.

3.7.1 Squat Test Protocol

Each subject performed two warm up sets prior to the test. The first set was performed with a low load determined by the subject for 10 repetitions, followed by a second set with a slightly higher load for 8 repetitions, to pre-activate and prepare the working muscles for high intensity exercise.
Following the warm up sets, the subject was allocated two attempts to perform a 5 repetition maximum squat. The best score of the two sets was recorded and used for analysis along with a relative score for each subject (Weight lifted / body mass). The subjects were instructed to squat to a 90º angle at the knee, so that the thigh was in a horizontal position at the lowest point of the eccentric contraction, which was measured using a protractor. A recovery period of 5 minutes was permitted for the subjects, to allow sufficient time to make a full recovery prior to their next bout of exercise. During that 5 minute recovery it was recommended that the subjects engaged themselves in light stretching and slow movements to maintain a warm body temperature and maintain an active state in the working muscles.

3.8 Statistical Analysis

After the completion of the data collection, all scores were saved onto a computerised file using Microsoft Excel. The best score from each measured variable by each subject was selected and used for analysis via the statistical package, Minitab version 14 software. Minitab was used to discover the differences between each variable for two groups (Forwards and Backs). A variance tests was run between the two groups for each variable to detect whether equal variance was present between the data, and determine whether it was homogenous, or heterogeneous using the Levene statistic test ($p>0.05$). A one way ANOVA was then performed to determine the significance of the differences between the two groups and the variable in question. The data was considered significantly different with a p-value

<0.05. Using an ANOVA allowed for saving the residuals between the two groups which were then used to be tested for normality using the Anderson-Darling Normality test. This could then confirm that the data as being drawn from a population of scores in which the residuals for the variable of interest are normally distributed ($p>0.05$).

Pearson's Product Correlation Coefficient was employed to test the degree of linear relationship between each type of jump, and the remaining variables in question (10m and 40m sprint, and 5RM squat) for both groups. Significance of this test was set at $p<0.05$, with an r-value being produced to determine the strength of the relationship. The coefficient of determination was produced (r^2) where the portion of common association of the factors that influence the two variables is determined. The coefficient of determination indicates the portion of the total variance in one measure that can be explained, or accounted for by the variance in the other measure (Thomas and Nelson, 1996)

The r value obtained from the correlation was then inputted onto a pre-prepared software using Microsoft Excel to determine the 95% confidence interval for each correlation. The software was used through a spreadsheet prepared by www.sportsci.org (2007), using the statistic and confidence intervals of correlation section. The 95% confidence interval allows the reader to assume, with 95% confidence, that the rest of the population (Rugby Union Males) will show results to fall between two distinguished figures. A larger sample size will decrease the variance between the two figures, whilst a smaller sample size will increase the variance between the two figures.

CHAPTER IV

RESULTS

4.0 Results

Table 2. Mean and Standard Deviation Values For All Subjects in Each Variable

Variable	Group (n=20)		Forwards (n=10)		Backs (n=10)	
	Mean	SD ±	Mean	SD ±	Mean	SD ±
Height (cm)	182.63	8.67	184.7	10.86	180.55	5.58
Weight (kg)	98.03	16.80	107.52	18.98	88.53	5.96
SJ (cm)	36.93	6.53	33.53	2.98	40.33	7.45
CMJ (cm)	39.16	6.72	35.68	3.62	42.65	7.44
5BJ (rsi)	1.51	0.39	1.31	0.34	1.72	0.36
10m (s)	1.688	0.103	1.810	0.097	1.721	0.094
40m (s)	5.392	0.287	5.531	0.233	5.253	0.277
5RM Squat (kg)	202.5	31.31	211	20.66	194	38.5
5RM Relative Squat (kg/bm)	2.09	0.36	2.00	0.25	2.20	0.44

Table 2 shows the mean and standard deviation values for three groups (Full Sample, Forwards and Backs) across each variable measured. The forwards group had observed the biggest variation about the mean with regards to stature, mass and 10m sprint time, with backs recording the biggest variation in all other variables.

4.1 Differences

To determine whether the data collected between backs and forwards were significantly different a statistical analysis was employed using a Oneway ANOVA test. All data was homogenous, determined at the significance level of p>0.05 using Levene's test for variance. Results are shown in Table 3.

Table 3. Significance Level Between Forwards and Backs for Each Variable

Variable	Oneway ANOVA
SJ Forwards - SJ Backs	p = 0.02*
CMJ Forwards - CMJ Backs	p = 0.006*
5BJ Forwards - 5BJ Backs	p = 0.016*
10m Forwards - 10m Backs	p = 0.05*
40m Forwards - 40m Backs	p = 0.026*
5RM Squat Forwards - 5RM Squat Backs	p = 0.234
5RM Relative Squat Forwards - Backs	p = 0.244

***P-Value <0.05 (Significantly Different)**

- Squat Jump – Countermovement Jump: p = 0.000 (p<0.05) Paired Sample T-test.

4.2 Relationships

Table 4. Full Group (n=20) Correlations (r-value) (and 95% Confidence Intervals)

Variable	SJ	CMJ	5BJ	10m	40m	5RM Sq	5RM Rel
SJ (cm)	1						
CMJ (cm)	0.97* (0.94–1.00)	1					
5BJ (rsi)	0.46* (0.10–0.82)	0.45* (0.08–0.82)	1				
10m (s)	-0.74* (-0.51– -0.97)	-0.74* (-0.51– -0.97)	-0.30 (-0.71-0.11)	1			
40m (s)	-0.77* (-0.57– -0.97)	-0.76* (-0.55– -0.97)	-0.38 (-0.77-0.1)	0.93* (0.86-1)	1		
5RM Sq (kg)	0.13 (-0.31–0.57)	0.11 (-0.33–0.55)	-0.14 (-0.58-0.3)	-0.21 (-0.64-0.22)	-0.23 (-0.65-0.19)	1	
5RM Rel (kg/bm)	0.58* (0.27–0.89)	0.59 (0.28-0.90)	0.42 (0.004-0.80)	-0.62* (-0.91- -0.33)	-0.70* (-0.45- -1)		1

***P-Value <0.05 (Significant Relationship)**
All data were normally distributed.

Table 5. Forward (n=10) Correlations (and 95% Confidence Intervals)

Variable	SJ	CMJ	5BJ	10m	40m	5RM Sq	5RM Rel
SJ (cm)	1						
CMJ (cm)	0.96* (0.88-1)	1					
5BJ (rsi)	-0.39 (-0.96-0.18)	-0.33 (-0.92-0.26)	1				
10m (s)	-0.76* (-1- -0.42)	-0.80* (-1- -0.5)	0.37 (-0.44-1)	1			
40m (s)	-0.90* (-1- -0.72)	-0.91* (-1 - -0.75)	0.31 (-0.28-1)	0.92* (0.77-1)	1		
5RM Sq (kg)	0.16 (-0.72-0.78)	-0.04 (-0.67 -0.59)	-0.34 (-0.92-0.24)	0.03 (-0.6-0.66)	-0.03 (-0.66-0.6)	1	
5RM Rel (kg/bm)	0.59 (1-0.11)	0.59 (1-0.11)	0.33 (-0.26-0.92)	-0.47 (-1-0.07)	-0.65* (0.21-1)		1

***P-Value <0.05 (Significant Relationship)**
All data were normally distributed.

A common variance >50% was observed in 6 pairs of variables in Table 5 (SJ – CMJ, SJ – 10m, CMJ – 10m, SJ – 40m, CMJ – 40m, 10m – 40m).

Table 6. Back (n=10) Correlations (r-value) and (95% Confidence Intervals)

Variable	SJ	CMJ	5BJ	10m	40m	5RM Sq	5RM Rel
SJ (cm)	1						
CMJ (cm)	0.96* (0.88-1)	1					
5BJ (rsi)	0.51 (-0.01-1)	0.50 (-0.02-1)	1				
10m (s)	-0.71* (-1- -0.32)	-0.67* (-1- -0.25)	-0.52 (-1-0.02)	1			
40m (s)	-0.67* (-1- -0.25)	-0.62 (-1- -0.16)	-0.52 (-1-0.02)	0.91* (0.75-1)	1		
5RM Sq (kg)	0.38 (-0.19-0.95)	0.40 (-0.16-0.96)	0.18 (-0.44-0.8)	-0.64* (-1- -0.2)	-0.64* (-1- -0.2)	1	
5RM Rel (kg/bm)	0.53 (0.02-1)	0.51 (-0.01-1)	0.36 (-0.22-0.94)	-0.69* (-1- -0.28)	-0.71* (-1- -0.25)		1

***P-Value <0.05 (significant Relationship)**
All data were normally distributed.

A common variance >50% is evident in 4 pairs of variables in Table 6 (SJ – CMJ, SJ – 10m, 10m – 40m, 40m – 5RM Rel).

Table 7. Common Variance Values For All Subjects

Variable	SJ	CMJ	5BJ	10m	40m	5RM Sq	5RM Rel
SJ (cm)							
CMJ (cm)	94.1%						
5BJ (rsi)	21.2%	20.3%					
10m (s)	54%	55.4%	9%				
40m (s)	60%	58.4%	14.4%	86.5%			
5RM Sq (kg)	1.6%	1.1%	1.9%	4.4%	5.3%		
5RM Rel (kg/bm)	33.4%	33%	17.6%	38.4%	49%		

Table 7 shows the common variance between each of the variables for the full sample. There is a common variance >50% evident in 6 pairs of variables (SJ - CMJ, SJ – 10m, CMJ – 10m, SJ – 40m, CMJ – 40m, 10m – 40m).

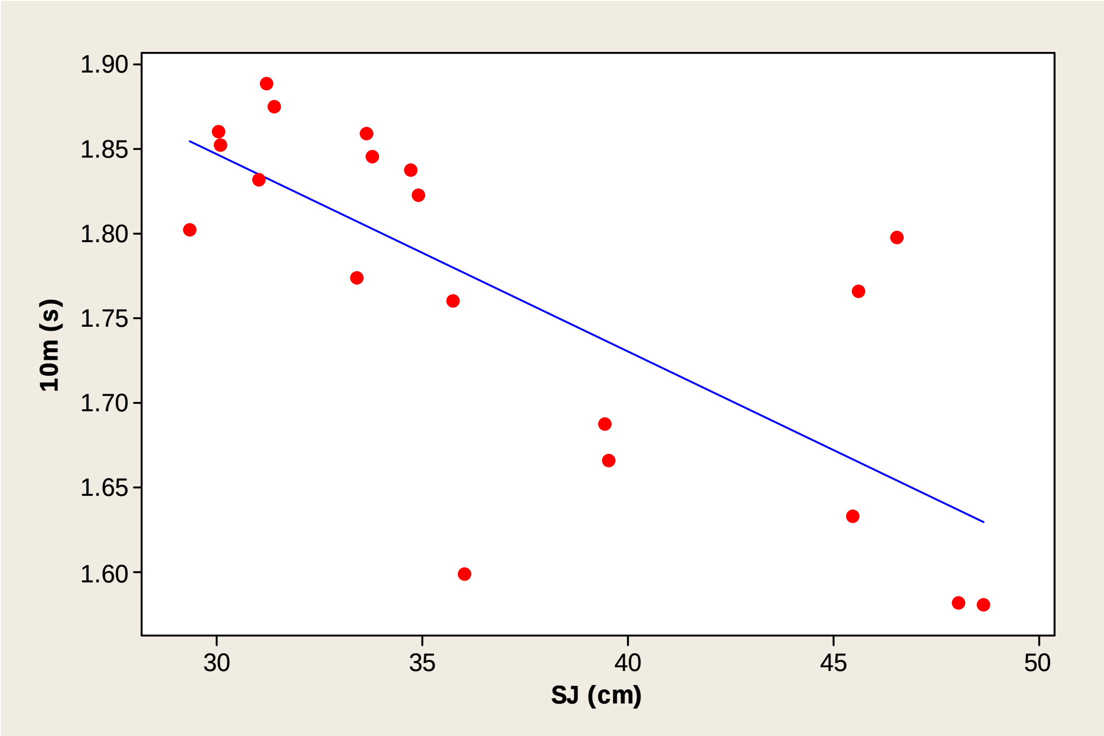

Figure 3. Relationship Between Full Sample Squat Jump and 10m Sprint

Figure 3 shows the strength of the relationship between the forwards and backs combined SJ scores and 10m sprint scores. There is a significantly strong relationship in a negative direction between forwards and backs combined SJ and Sprint times.

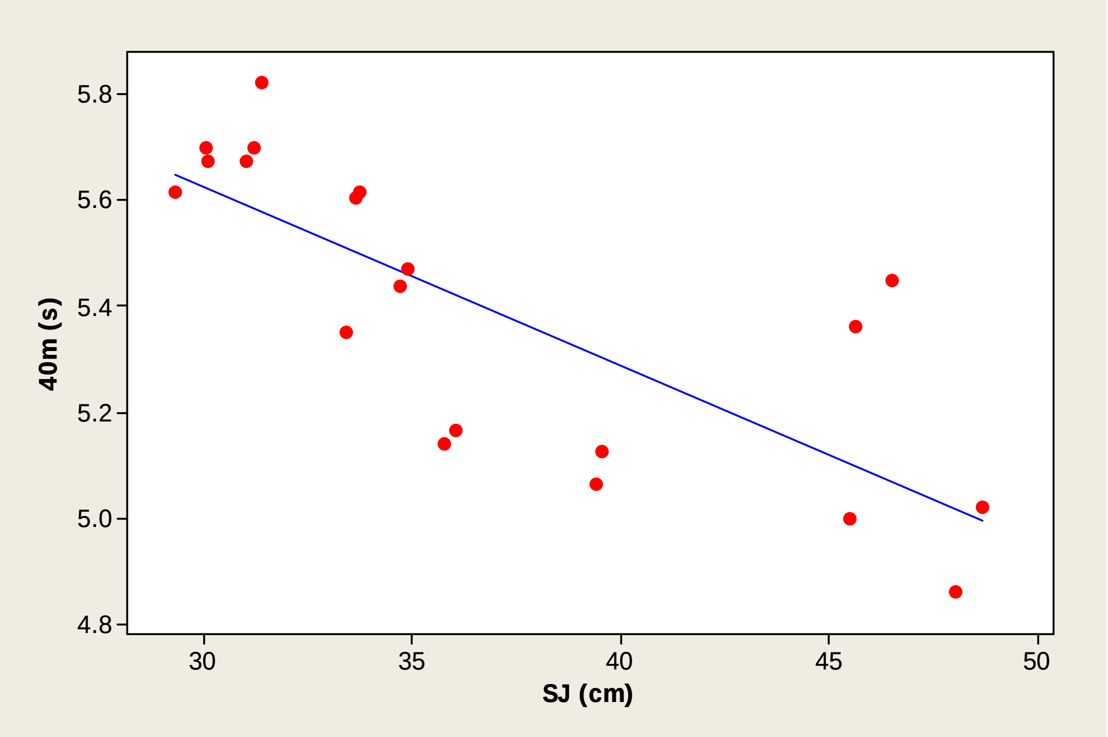

Figure 4. Relationship Between Full Sample Squat Jump and 40m Sprint

Figure 4 shows the degree of the linear relationship between the forwards and backs combined Squat Jump and 40m Sprint scores. There is a significantly strong relationship between the two variables in a negative direction.

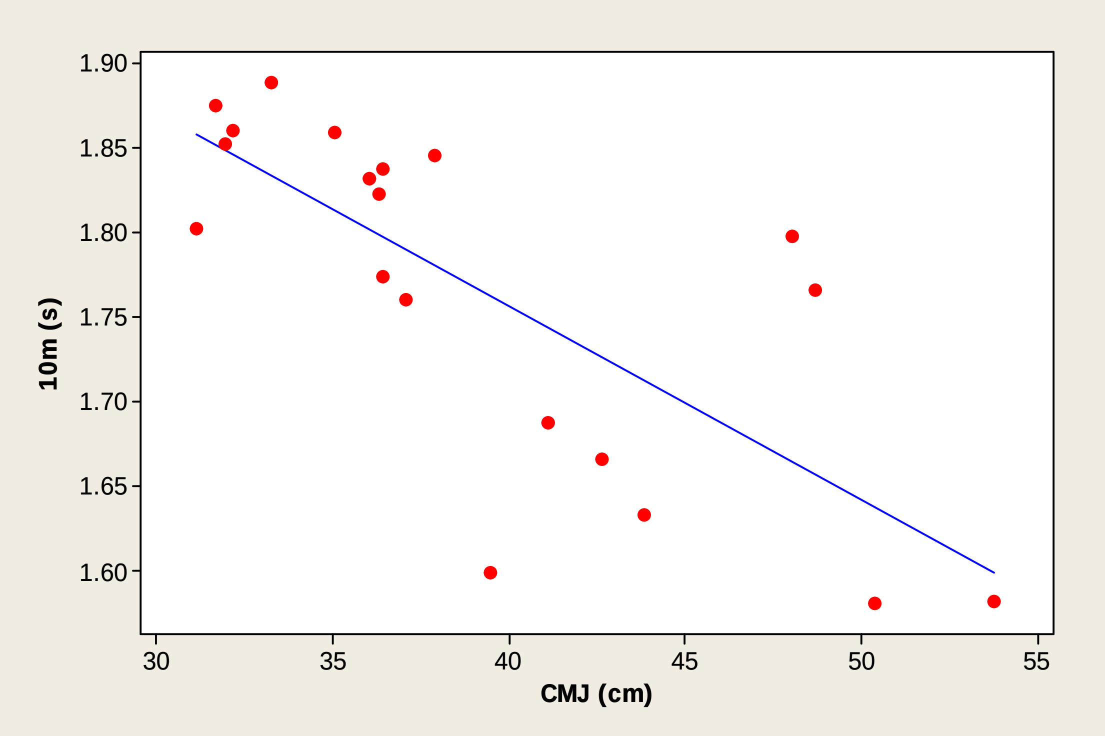

Figure 5. Relationship Between Full Sample CMJ and 10m Sprint

Figure 5 shows the strength of the relationship between the combined forwards and back scores for the CMJ and 10m Sprint. There is a significantly strong correlation in a negative direction between the two variables.

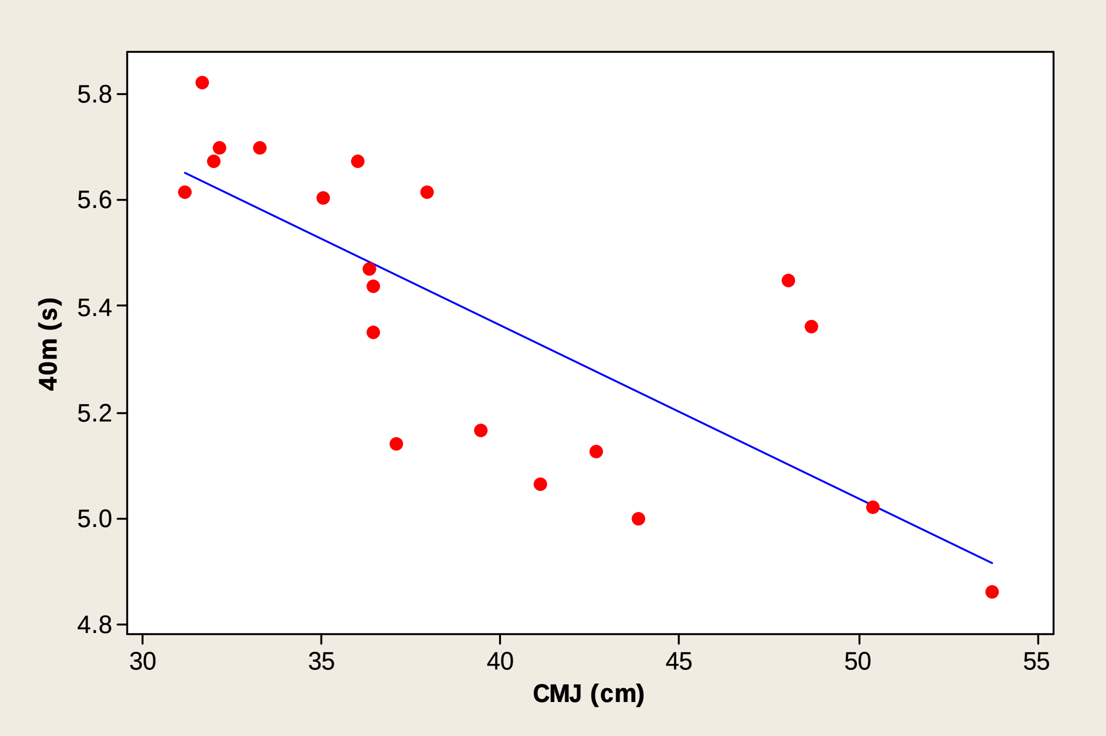

Figure 6. Relationship Between Full Sample CMJ and 40m Sprint

Figure 6 shows the degree of the correlation between the full sample CMJ and 40m sprint scores. There is a significantly strong relationship between CMJ and 40m sprint times for the combined sample.

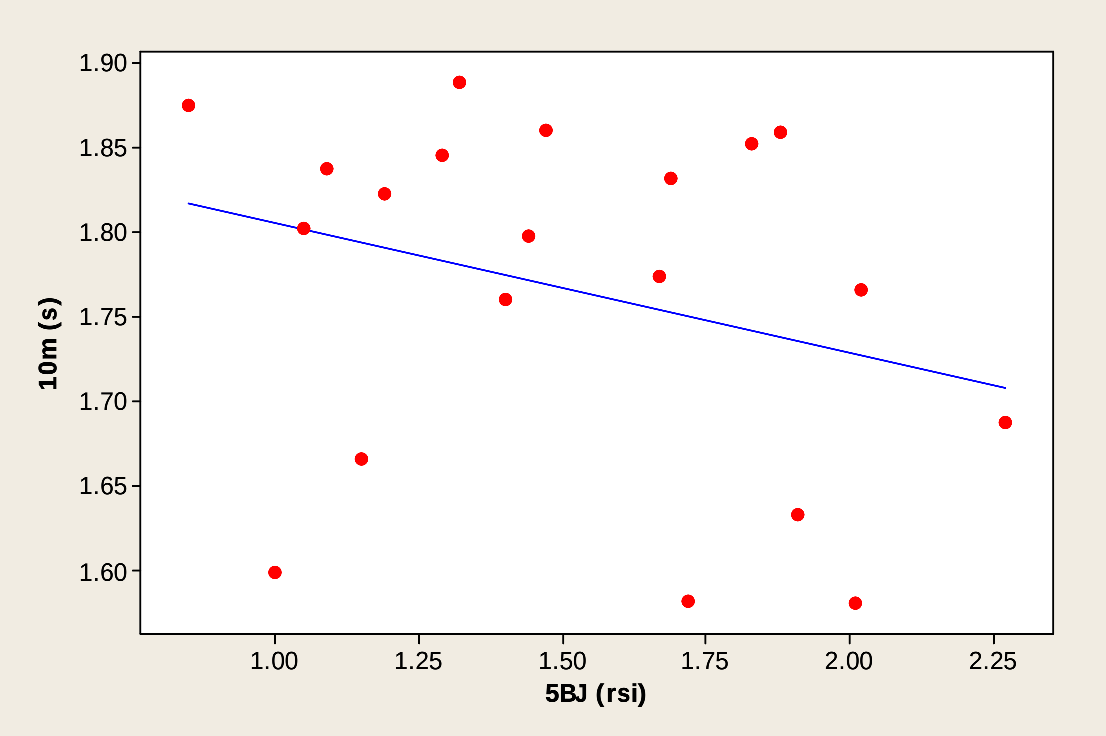

Figure 7. Relationship Between Full Sample 5BJ and 10m sprint

Figure 7 shows the linear regression between 5BJ and 10m for the backs and forwards combined. The correlation is insignificant.

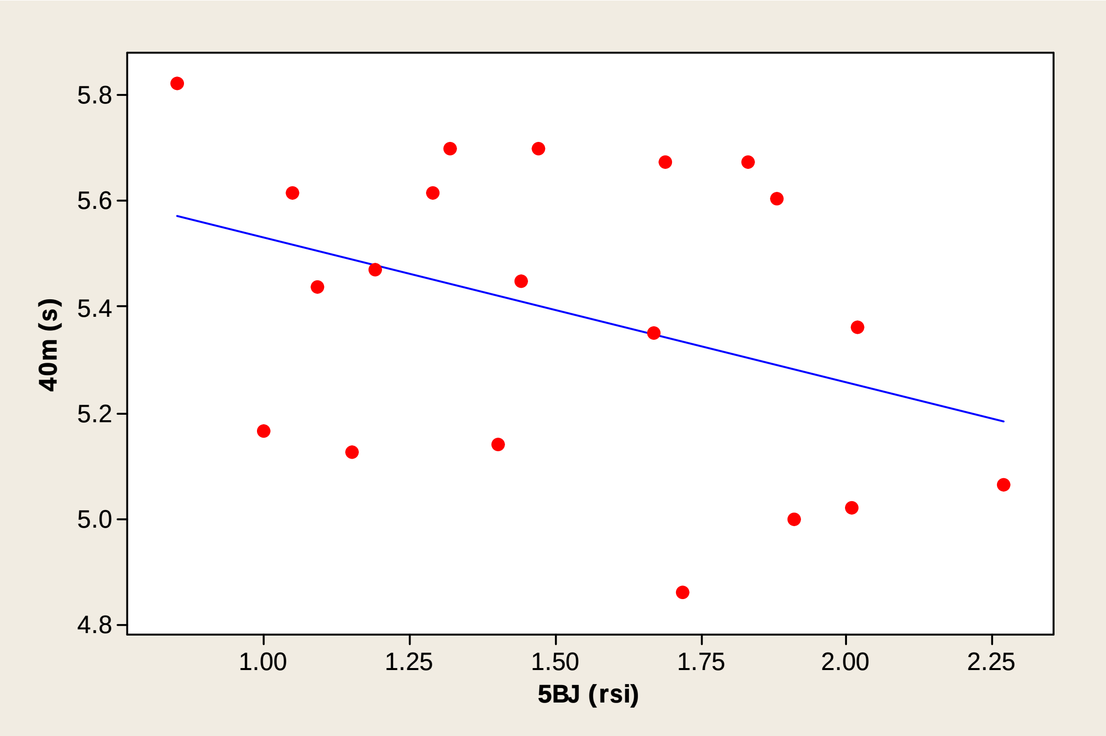

Figure 8. Relationship Between Full Sample 5BJ and 40m sprint

Figure 8 displays the degree of the relationship between the full sample 5BJ and 40m sprint scores. The relationship is weak and insignificant.

CHAPTER V

DISCUSSION

5.0 Discussion

The primary aim of the present study was to assess the relationship between the SSC movement pattern and primary rugby performance variables in semi-professional rugby union males, and to then distinguish the differences, if any, between forwards and backs players. The researcher showed that there are significant differences between forwards and backs for each of the variables other than the 5RM Squat. Forwards were shown to be taller and heavier whilst backs had the ability to jump higher and run faster. The researcher also showed that the full group analysis displayed significant relationships between both the SJ and CMJ with Sprint running ability, although the 5BJ showed no such correlation when analysed with sprint running. The squat test for strength was shown to be significantly related to sprint performance only when relative values were displayed, the absolute values showed no significant correlations. The 5RM relative squat test also showed a significant relationship with the SJ.

Previously, research has discovered that forwards are typically bigger in stature and larger in mass than backline players (Quarrie *et al,* 1996; Gabbett, 2002b; Duthie *et al,* 2003). The present study re-assures the strength of previous assumptions regarding stature and body mass between forwards and backs, with a significant difference between forwards stature and body mass (184.7 ± 10.9cm and 107.5 ± 18.9kg) and backs stature and body mass (180.6 ± 5.6cm and 88.5 ± 5.9kg). The reason for these differences may be attributed to the specific demands of the positional roles within the team. Motion analysis has signified that forwards spend a significant amount of time in the contact area, more so than backs (Carter, 1996), and therefore the increases in stature and body mass are essential for success in competing in contact situations, such as rucks, mauls and scrummaging. Due to the motion analysis discoveries, it is assumed that forwards should posses greater muscle strength than backs, in order to challenge the contact areas of the game, however previous literature has found no difference in strength scores between forwards and backs (Duthie *et al,* 2003). The present study has also failed to find any significant difference between backs and forwards based on a 5RM Squat test, in both absolute and relative terms ($p>0.05$). The previous literature discussed had used a sample of collegiate players and it was believed that no difference was found due to the young training age of the athletes, however the present study's subjects was a more mature sample group with enough training experience behind them. The strength test in the present study was only measuring the lower limb strength of the subjects, avoiding any discoveries regarding upper body strength, which can equally attribute to the effectiveness and success at contact situations in games.

The differences evident in stature and mass between forwards and backs may contribute to the explanation of the differences in sprint ability between the two groups. Backs were found to be significantly quicker than forwards in sprint performance over 10m and 40m distances (Forwards 1.81 ± 0.09s and 5.53 ± 0.23s; Backs 1.72 ± 0.09s and 5.25 ± 0.28s). These results supports the previous literature into sprint performance between backs and forwards (Quarrie *et al* 1995 &1996; Carlson *et al,* 1994) and increases the validity of the suggestion that sprint ability is important, in backline players in particular, due to previous studies finding that backs cover greater distances at sprinting speeds (Deutsch *et al,* 1998). It is clear that speed is a discriminating factor between forwards and backs and this may be evident due to the specific training nature of the backs, which involves more plyometric and speed based movement exercises compared to the forwards' slow strength exercises.

Vertical Jumping ability has often allowed discrimination between the two groups (Forwards and Backs). Prior to the present study, literature suggested that forwards' performance in vertical jump tests was far more inferior to the performance of backs, with front row forwards achieving the lowest jump height (Carlson *et al,* 1994; Quarrie e*t al,* 1996). These scores were achieved using an old version of the vertical jump test where body mass was not taken into consideration, potentially causing the large variance between players of different positions. The present study used a modernised technological method to measure vertical jump performance via two different jumps. The previous findings, however, do equate to the results obtained from the present study, with backs being able to jump significantly higher in both the squat jump test and countermovement jump test (40.33 ± 7.45cm and 42.65 ± 7.44cm) than forwards (33.53 ± 2.98cm and 35.68 ± 3.62cm). The present study's method allowed for the body mass of the subject to be taken into account, providing an accurate measure of lower limb power between forwards and backs. The results still allowed for discrimination between backs and forwards regarding the vertical jump scores but not due to the anthropometry issues previous literature have found. These differences may again be due to the training nature between different positions. As speed is essential in backs, a series of training sessions involving bounding is customary for backline players to undertake, which is somewhat more specific to the demands of the test than the forwards are more likely to encounter during their training sessions.

The SSC has been divided into two types, long and short, and leg stiffness is one of the elastic components of the muscle-tendon complex behaviour and is believed to have an effect on the performance of a SSC movement. It is believed that a stiffer leg will allow for a faster rebound when sprinting, an example of a short SSC movement pattern, which is reflected by a shorter ground contact time at increasing running speeds (Kuitunen *et al,* 2002). The present study tested the short SSC movement pattern via a 5BJ, focusing on the RSI. The 5BJ was deemed a valid test to measure the short action of the SSC as it requires the subject to rebound against the ground with minimum ground contact time, whilst attempting to achieve as much height as possible. The method used in the present study required the subjects to bound with a stiffer leg compared to a SJ or CMJ test and was considered to be highly specific to sprint performance. However, the present study found no significant relationship between the 5BJ and sprint performance in any of the groups (Table 2; Table 3; Table 4). Although it was still insignificant, backs scores in the 5BJ did relate stronger to sprint performance in both 10m and 40m than forwards. The 5BJ only accounted for 14% of the variance in forwards for the 10m and 9% of the variance in the 40m, whilst the backs 5BJ accounted for 27% of the variance in the 10m and 28% in the 40m. This interestingly, is in great contrast to the study by Hennessy and Kilty (2001), where their short SSC action jump accounted for 70.5% of the variance in the 30m sprint performance. The sample used by Hennessy and Kilty (2001), however, were trained female sprint athletes, who are often involved in various plyometric and bounding exercises which may account for the difference between them and the present study's sample of male rugby players. The difference in relationships between forwards and backs may be accounted for through their differences in stature and mass, along with their demands within the game. Backs seem more able to apply the short SSC than forwards as they are more accustomed to the movement. Backs are regularly required to sprint for longer distances, which is performed by applying less ground contact time, while forwards are heavy and take longer to achieve that high speed, where smaller ground contact time is essential, and they are not able or required to sustain such high speeds when playing.

In the SSC, the sequence in muscle function (stretch-shortening) involves the important features of pre activation and variable activation. SSC muscle function has a well recognised purpose, which is the enhancement of performance during the final phase (concentric action) when compared with the isolated concentric action, and concentric action only movements. Previous studies have included numerous reasons for the increased force production in eccentric-concentric movements (Cavagna *et al,* 1965; Avis *et al,* 1986; Ettema *et al,* 1990; Komi and Ishikawa, 2003). The present study shows that a CMJ produces significantly greater height than a SJ (39.2 ± 6.7cm vs 36.9 ± 6.5cm), which can be attributed to several mechanical reasons. It is believed that the primary reason behind these results are due to a contribution of an active pre-stretch in a CMJ, where the muscle tendon establishes a functional state prior to the concentric action (Bobbert *et al,* 1996; Komi & Gollhofer, 1997; Walshe *et al,* 1998), and the contribution of elastic strain energy, where there is an elastic recoil reaction in the working muscles between the eccentric and concentric phase (Avis *et al,* 1986; Komi & Gollhofer, 1997). Linthorne (2001) noticed the superiority of the CMJ over the SJ when the force displacement curves were compared, as there is an increase in take off velocity and subsequent jump height. During the SJ, the force at the start of the upward phase of the jump is equal to the jumper's body weight with limited muscle activation. Consequently, it takes longer to achieve peak ground reaction force. In contrast, the ground reaction force at the start of the upwards phase in the CMJ is already much greater than the body weight (Linthorne, 2001). The SJ, as previously mentioned, is suggested not to be used to assess the SSC, due to its concentric only action, however, it has been suggested that it can be used as a measure of strength and have an influence on sprint performance, the acceleration phase in particular (Linthorne, 2001). The results in the present study did show a significant relationship between SJ and sprint performance in all three groups. Regression analysis shows that the common variance between SJ and 10m within group one is high (54%), and that SJ accounts for 60% of the variance in the 40m sprint, indicating the influence of lower limb power on sprint running. Table 3 displays the relationship between SJ and sprint performance in forwards, and shows that the relationship in both the acceleration and 40m speed was stronger than the backs' correlation (Table.4). However, whereas previous studies found the SJ to be more related to the acceleration phase, the forwards group show a stronger correlation in the 40m compared with the 10m scores. The backs, do in fact relate to the previous literature and show a stronger correlation between SJ and 10m, than in the 40m. There was no significant relationship displayed for any of the groups between SJ and 5RM Squat when concerned with absolute scores, however when body mass was considered, and a relative 5RM squat was determined, SJ and 5RM relative squat in group 1 was significantly related. The common variance between these two variables however, was <50%, which means the two measures are independent and measure two specific (different) qualities (Thomas and Nelson, 1996). The relative scores nullified any differences between the subjects in terms of body mass, which shows a true score of leg strength, and increases the correlation. However, rugby union is a high collision sport, and an increased body mass is essential to compete in many area's of the game, so it is not always advantageous to posses increased levels of power whilst attaining a low body mass score.

The present study also suggests that the CMJ can affect the outcome of sprint performance, where significant correlations are observed in table 1. Previous research has suggested that the support phase during the jumping action is similar to the eccentric – concentric contractions of the leg extensor muscles during the sprint action, leading to the assumption that the CMJ demonstrates a high degree of specificity to sprint running (Hennessy and Kilty, 2001). The relationship between the CMJ and sprint performance in group 1 (Figure 5 and Figure 6) are similar to the relationship between the SJ and sprint performance (Figure 3 and Figure 4), suggesting that both types of jumps have an equal amount of effect on sprint performance across the whole sample group, showing similar common variances with 55.4% being accounted for in the 10m sprint and 58.4% in the 40m sprint. When the groups are split and backs and forwards are independent groups there is a degree of variability within the scores. The CMJ and sprint performance correlations are higher in group 2 (Table 3) than in group 3 (Table 4). Surprisingly, there was no significant correlation recorded in the backs group between the CMJ and 40m performance, although previous literature has stated that the CMJ relates to long sprint running distances (Hennessy and Kilty, 2001), due to the large angular displacements characterised by the CMJ in the lower limbs. Previous literature had also suggested that the CMJ has a significant relationship with shorter sprint distances (Bosco *et al,* 1995; Nesser *et al,* 1996; Young *et al,* 1996; Hennessy and Kilty, 2001), which is also evident in the present study. The insignificant correlation in the backs between CMJ and 40m may be explained due to positional demands and consequent training methods. There is a high degree of directional variability within the forwards with regards to specific roles within the game. For example, front row forwards aren't required to sprint around the playing field making long distance breaks and chasing players down. They are primarily involved in most of the contact areas (Carter, 1996) and high body mass scores and strength scores are the key parameters to their roles within the game along with technical ability in the scrum and line-outs. This leads to a lack of involvement in plyometric and sprint based training, as it is not a primary performance parameter for these types of positions. This positional role inherits the poor jump height in the vertical jump scores along with slow times in the sprint performances. The variability increases as the positions in the scrum are accounted for when analysing from front (front row), to the back (back row). In contrast, the back row are expected to be first to most breakdowns and close down the opposition quickly, requiring speed and stamina, as well as strength to compete at the contact area. A typical training session may include a variety of exercises consisting of power lifts, strength exercises along with speed training. This may account for the improved jumping and sprint performance compared to the other positions in the forwards. However, the variability within backs has less of a direction, which is considered to be a heterogenous sample, and may have been the reason why there is no significant relationship between the CMJ and 40m sprint time. Every position in the backs requires similar parameters. Some positions may have a primary performance criterion, but each position will acquire elements of speed, power and strength. For example, wingers are typically the fastest players in the game, but it is not strange to see a centre or a full back have a quicker sprint time, but maybe less powerful and not jump as high, or vice-versa. This is common among many positions, where some may be the quickest and most powerful, or most powerful but not have the ability to sprint the fastest. This can decrease the strength of the relationship between the two variables in back players, as it has done in the present study, but it is still suggested that speed and lower body power are important to back line players.

Squatting has previously been determined to effect performances in sprint running and bounding (Comyns *et al*, 2007). It is suggested that heavier loads will in turn improve ground contact time and leg stiffness in fast SSC movements. The present study showed insignificant relationships in all groups between squatting in both absolute and relative terms and 5BJ. The forwards only showed a significant relationship between 5RM relative squat scores and 40m sprint times, while the backs showed significant relationships between absolute and relative squat scores and both sprint performance times, even though no relationships were observed between the 5BJ and sprint times, which was previously suggested to be highly related due to the similarity in ground contact time and leg stiffness. Group 1 also showed a significant relationship between relative squat scores and sprint performance. Even though the relationships were strong and significant (5RM relative -10m: r = -0.62; p = 0.003, and 5RM relative – 40m: r = -0.702; p = 0.001) the common variances were considered to be low (38.6%, and 49.3%). The researcher had previously discussed the insignificant relationship between the squat test and the SJ, which was accountable for the development of sprint ability in previous studies. Whilst the present study showed no relationship between 5RM squat and SJ or Sprint ability, the rate of force production in the lower limbs will be extremely slower in the squat test due to the resistant nature of the test when compared to the SJ or Sprint ability. It may therefore be suggested that squat may not have a direct effect on sprint ability, but may improve the performance of the SJ which may improve the performance in sprint running.

5.1 Limitations

There are several limitations surrounding the study including problems associated with flight time related to the jump mechanics on the calculated jump height. For the equation to be accurate, the performer needs to take off and land in the same position. Although strict and precise instructions were given to the subjects to avoid any movement that may unfairly benefit performance, the performer, during flight, may flex their knees and subsequently land in a flexed position at the knee. This would increase their flight time and overestimate jump height.

The field based sprint test was conducted on an indoor athletics track and subjects were permitted to wear trainers. This decreases the validity of the test somewhat, as the natural environment for rugby players to run on is on the playing field wearing appropriate playing footwear such as rugby/football boots. However, speed training is often conducted indoors, as adverse weather conditions can affect the performance in such tests.

The present study expressed the RSI as a peak value as opposed to an average value, taken from across the 5 rebound jumps. The variance between the peak RSI and the average RSI can often be quite large, sometimes due to a 'freak' one off jump, which doesn't provide the researcher with an accurate measure. This may have had an affect in the present study, where some subjects could have jump consistently throughout the test, while others would have shown a lower average score but performed one rebound to great effect, and therefore were considered to have a better RSI.

Cohen and Holiday (1982) expressed that the power of statistical analysis is effective with a sample of no less than 15 subjects. When the present study analyses the sample group as a whole the results obtained from the analysis are considered to be valid and are strong enough to express. When the sample are split into two separate groups (Forwards and Backs), the sample size decreases to two groups of 10, which depletes the strength of the statistic. The confidence interval expressed is also then increased and produces a wider variation. Such variation within the confidence intervals can potentially damage the observations the researcher has provided. Where some correlations are insignificant, the confidence intervals vary to an extent that it could cause the correlation to become significant due to the low sample size.

5.2 Future Research

It is important for measures to be accurate so that the observations can be expressed strongly so that the study is worthwhile to the population. A vast amount of literature have made assumptions that rebound jumping displays a high similarity to sprint running and the short SSC, which was not evident in the present study. It is recommended that various methods are used to collect and analyse data with regards to rebound jumping. Data such as average RSI as well as peak RSI will resolve issues such as one off jumps, and an accurate measure across the whole sample can be made. Assessing the CMJ height in the CMJ test and the initial jump in the 5BJ may prove to be an interesting area. This can determine whether subjects are applying maximum effort in the initial CMJ which is followed by 5 rebound jumps. A lack of effort may affect the outcome of the RSI.

Several of the correlations observed by the researcher were insignificant, however, the confidence intervals suggest that they could prove to be significant within that sample size should a similar population be measured. In order to remove this effect and produce a stronger confidence interval it is beneficial and highly recommended to use a larger sample size, which will decrease the variation in the intervals.

CHAPTER VI

CONCLUSION

6.0 Conclusion

With reference to the present study, it can be explained, to an extent, that lower limb SSC actions relate to and affect various primary performance indicators in male rugby union players at semi professional level. The researcher confirms that many differences lie between forwards and backs with the assessment of stature and body mass being a discriminating factor between the two groups. The divide that is evident between forwards and backs is also reflected in other physiological characteristics that have been measured by the researcher and previous studies. It can be accepted that backs possess a greater ability in sprint running, which is largely attributed to lower leg power, following the assessment of jump height across various jumping methods. The backs also possess a greater ability to perform better in short SSC actions due to the regular involvement in longer sprinting distances compared to forwards. A large degree of these differences are accounted for due to the specific positional demands that are placed upon the players within the game. Some positions require more mass and stature with and ability to apply as much force as possible, regardless of the speed of force production, as opposed to some positions demanding more explosive, quicker actions, which are more attainable with less body mass. Coaches are able to assess performance indicators in rugby union athletes accurately through standardised testing protocols which are used time and time again. With the testing protocols in place along with the present study's observations it can allow for a coach to implement and structure relevant training programmes, in order to allow development in specific physiological areas, that may increase performance in several variables associated with rugby performance. The development in vertical jumping, using various plyometric drills can develop a player's ability to produce force at a high speed, which in turn will reflect reflects their sprint performance, regarded as one of the main variables required for success in rugby. The SSC is applied to many movements of various speeds. The inclusion, in future research, of an endurance run may add another dimension to literature regarding the SSC movement pattern. It is still the function of the SSC movement pattern but at a different rate and range of motion, which may be effective in some players over others, regardless of the explosive, shorter SSC movement pattern relationships previously observed. Future studies should aim to use a large sample size so that results can be expressed with more statistical power.

REFERENCES

References

Avis, F.J., Toussaint, H.M., Huijing, P.A., and Van Ingen Schenau, G.J. (1986). Positive Work as a Function of Eccentric Load inMaximal Leg Extension Movements. *European Journal of Applied Physiology.* **55.** 562-568.

Bobbert, M.F., Gerritsen, K.G.M., Litjens, M.C.A., and van Soest, A.J. (1996). Explanation of the differences in Jump Height Between Countermovement and Squat Jumps. In: *XV Congress of the International Society of Biomechanics.* Edited by Hakkinen, K., Keskinen, K.L., Komi, P.V., and Mero, A. 110-111.

Bosco, C., Belli, A., Astrua, M., Tihanyi, J., Pozzo, R., Kellis, S., Tsarpela, O., Foti, C., Manno, R., and Tranquilli, C. (1995). A Dynamometer For Evaluation of Dynamic Muscle Work. *European Journal of Applied Physiology.* **70.** 379-386.

Carlson, B.R., Carter, J.E.L., Patterson, P., Petti, K., Orfanos, S.M., and Noffal, G.J. (1994). Physique and Motor Performance Charactersitics of US National Rugby Players. *Journal of Sports Sciences.* **12.** 403-412

Carter, A. (1996). Time and Motion Analysis and Heart Rate Monitoring of a Back Row Forwards in First Class Rugby Union Football. In: Hughes, M. Editor: Notational Analysis of Sport: 1 & 2. Cardiff: Centre of Notational Analysis. University of Wales Institute, Cardiff. 213-224.

Cavagna, G.A., Komarek, L. and Mazzoleni, S. (1965) The mechanics of spring running. *Journal of Physiology.* **117.** 709-721.

Cohen, L and Holiday, M (1982). *Statistics for Social Sciences. London:* Harpers Row

Comyns, T.M., Harrison, A.J., Hennessy, L., and Jensen, R.L. (2007). Identifying the Optimal Resistive Load for Complex Training in Male Rugby Players. *Journal of Sports Biomechanics.* **6 (1).** 59-70.

Dacre-Manning, S. (1998). Anthropomentry of the NSW Rugby Union Super 12 Team. In: Australian Conference of Science and Medicine in Sport. Adelaide. *Sports Medicine Australia.* **94.**

Deutsch, M.U., Maw, G.J, Jenkins, D., and Reaburn, P. (1998). Heart Rate, Blood Lactate and Kinematic Data of Elite Colts (under 19) Rugby Union Players During Competition. *Journal of Sports Sciences.* **16.** 561-570.

Duthie, G., Pyne, D., and Hooper, S. (2003) Applied Physiology and Game Analysis of Rugby Union. *Sports Medicine*: **33** (**13**) 973-991.

Farley, C.T. and Morgenroth, D.C. (1999). Leg stiffness primarily depends on ankle stiffness during human hopping. *Journal of Bimechanics.* **32(3).** 267-273.

Ettema, G.J.C., Van Soest, A.J., and Huijing, P.A. (1990). The Role of Series Elastic Structures in Prestretched-induced Work Enhancement During Isotonic and Isokinetic Contractions. *Journal of Experimental Biology.* **154.** 121-136.

Gabbett, T.J. (2000b). Physiological and Anthropometric Characteristics of amateur Rugby League Players. *British Journal of Sports Medicine.* **34.** 98-103.

Gabbett, T.J. (2002a). Influence of Physiological Characteristics on Selection in a Semi-Prefessional Rugby League Team. A Case Study. *Journal of Sports Sciences.* **20.** 399-405.

Gabbett, T.J. (2002b). Physiological Characteristics of Junior and Senior Rugby League Players. *British Journal of Sports Medicine.* **36.** 334-339.

Gabbett. T.J. (2005). A Comparison of Physiological and Anthropometric Characteristics Among Playing Positions in Sub-Elite Rugby League Players. *Journal of Sports Sciences.* **24 (12).** 1273-1280.

Hennessy, L., and Kilty, J. (2001). Relationship of The Stretch-Shortening Cycle to Sprint Performance in Trained Female Athletes. *Journal of Strength and Conditioning Research.* **15 (3).** 326-331.

Jenkins, D., and Reaburn, P. (1998). Protocols for the Physiological Assessment of Rugby Union Players. Australian Institute of Sport Test Methods Manual. Chapter 23

Jensen, R.C., Warren, B., Laursen, C., and Morrissey, M.C. (1991). Static Pre-load Effect on Knee Extensor Isokinetic Concentric and Eccentric Performance. *Medicine in Science of Sports and Exercise.* **23.** 10-14.

Knuttgen, H.G., and Kraemer, W.J. (1987). Terminology and Measurement in Exercise Performance. *Jornal of Applied Sport Science Research.* **1**. 1-10.

Komi, P.V. (2000). Stretch-shortening cycle: a powerful model to stidy normal and fatigued muscle. *Journal of Biomechanics.* **33.** 1197-1206.

Komi, P.V., and Gollhofer, A. (1997). Stretch Reflex Can Have an Important Role in Force Enchancement During SSC-Exercise. *Journal of Applied Biomechanics.* **33.** 1197-206

Komi, P.V., and Ishikawa, M. (2003). Effects of different dropping intensities on fascicle and tendinous tissue behavior during stretch-shortening cycle exercise. *Journal of Applied Physiology* **96**. 848-852

Kuitunen, S., Avela, J., Kyrolainen, H., Nicol, C. and Komi, P.V. (2002). Acute and prolonged reduction in joint stiffness in humans after exhausting stretch-shortening cycle exercise. *European Journal of Applied Physiology.* **88.** 107-116.

Linthorne, N.P. (2001). Analysis of Standing Vertical Jumps Using a Force Platform. *American Journal of Physiology.* **69 (11).** 1198-1204.

Manning, J.M., Dooley-Manning, C., and Perrin, D.H. (1988). Factor Analysis of Various Anaerobic Power Tests. **5 (3).** 116-120.

Maud, P.J. (1983). Physiological and Anthropometric Paramaters That Describe a Rugby Union Team. *British Journal of Sports Medicine.* **17.** 16-23

McArdle, W.D., Katch, F.I., and Katch, V.L. (1996). Exercise Physiology: Energy, Nutrition and Human Performance. Fourth Edition. Baltimore: Williams and Wilkins

McLean, D.A. (1992). Analysis of the Physical Demands of International Rugby Union. *Journal of Sports Science.* **10.** 285-296

Mero, A., Komi, P.V. and Gregor, R.J. (1992). The biomechanics of sprint running. *Sports Medicine.* **13(6).** 376-392

Nesser, T.W., Latkin, R.W., Berg, K., and Prentice, E. (1996). Physiological Determinants of 40-meter Sprint Performance in Young Male Athletes. *Journal of Strength and Conditioning Research.* **10.** 263-267.

Nicholas, C.W. (1997). Anthropometric and Physiological Characteristics of Rugby Union Football Players. *Sports Medicine.* **19.** 375-395

Nicol, C., Avela, J., and Komi, P.V. (2006). The Stretch-Shortening Cycle: A Model to Study Naturally Occurring Neuromuscular Fatigue. *Sports Medicine.* **36 (11).** 977-999

O'Connor, D. (1995). Fitness Profiles of Professional Rugby League Players. *Journal of Sport Sciences.* **13.** 505.

Quarrie, K.L., Handcock, P., Waller, A.E., Chalmers, D.J., Toomey, M.J., and Wilson, B.D. (1995). The New Zealand Rugby Injury and Performance Project 3. Anthropometric and Physical Performance Characteristics of Players. *British Journal of Sports Medicine.* **29.** 263-270.

Quarrie, K.L., Handcock, P., Waller, A.E., and Toomey, M.J. (1996). The New Zealand Rugby Injury and Performance Project 4. Anthropometric and Physical Performance Comparisons Between Positional Categories of Senior A Rugby Players. *British Journal of Sports Medicine.* **30.** 53-56.

Shcmidtbleicher, D. (1994). Training for power events. In *Strength and Power in Sport.* Komi, P. (1994). ed. London: Blackwell Scientific. 381-395.

Thomas, J.R., and Nelson, J.K. (1996). Research Methods in Physical Activity. Third Edition.

Walshe, A.D., Wilson, G.J., and Ettema, G.J.C. (1998). Stretch-shorten Cycle Compared With Isometric Preload: Contributions to Enhanced Muscular Performance. *Journal of Applied Physiology.* **84.** 97-106

Young, W.B., Pryor, J.F. and Wilson, G.J. (1995) Effect of Instructions on characteristics of countermovement and drop jump performance. *Journal of Strength and Conditioning Research.* **9(4).** 232-236.

Young, E., Hawken, M., and Mcdonald, L. (1996). Relationship Between Speed, Agility and Strength Wualities in Australian Rules Football. *Strength and Conditioning Coaching.* **4.** 3-6.

www.sportsci.org (2007). 95% Confidence Intervals for Pearson's Correlation.

APPENDICIES

Appendix 1. Informed Consent Form

Dear Subject,

I am a Level 3 undergraduate/postgraduate student in the School of Sport, PE, & Recreation, at the University of Wales Institute Cardiff. The title of my dissertation is "The Effect of the Stretch-Shortening Cycle and the Relationship with Primary Performance Parameters in Rugby Union Males" and wonder if you would be kind enough to help with my research.

The research aims to discover how specific SSC movement patterns relate to main performance variables in Rugby Union and the differences that occur between Forwards and Backs. As a participant, you will be asked to perform three different types of jump, followed by short and medium sprint distances, and a 5 repetition maximum squat test. Participation in the research may prove beneficial as it is strongly related to performance in Rugby Union.

There are no risks involved in the study, but in the event of an accident the appropriate services will be contacted immediately as your safety is paramount.

Participation is entirely voluntary. You are free to withdraw at any stage of the research process.

Confidentiality will be upheld as far as humanly possible. The results of your completed tests will be kept strictly confidential in accordance with the provisions of the Data Protection Act (1998). Only the principle investigator and supervisors will have access to the information. Your name or any such identifiable data will not appear in any academic papers resulting from the research.

I would like to express my deep appreciation for your assistance in this investigation. Your part in this research would be significant and influential. If you are willing to participate, please read the slip overleaf carefully, and sign. If you have any queries, please do not hesitate to contact me.

Thank you. I look forward to hearing from you.

Yours sincerely,

M. Mclean

…………………………………………………

I have read and fully understood the request to be a subject in the research of Mr. M. Mclean. I understand my role within the research. I understand the risks involved, and the measures in place in the event of an accident. I understand that participation is entirely voluntary, and that withdrawal is possible at any time. I understand the measures that will be taken to uphold confidentiality as far as possible.

I agree to participate.

Signature…………………………………………….. *Date*……………………

Telephone No…………………………..

Appendix 2. PAR-Q.

Physical Activity Readiness Questionnaire (PAR-Q)

Name: ……………………………………..

Please circle the following questions appropriately:

1. Has your doctor ever said you have heart trouble? Yes / No

2. Do you frequently suffer from pains in the chest? Yes / No

3. Do you often feel faint or have spells of severe dizziness? Yes / No

4. Has a doctor ever said you blood pressure was too high? Yes / No

5. Has your doctor ever said that you have a bone or joint Problem such as arthritis that has been aggravated by exercise, or might be made worse with exercise? Yes / No

6. Have you acquired any ligament damage to your lower limbs that may become injured or aggravated by jumping exercises? Yes / No

7. Is there a good physical reason not mentioned here why you Should not take part in a fitness test? Yes / No

8. Are you **un**accustomed to vigorous exercise? Yes / No

If you have answered yes to any of these questions listed above, please add detail below. Similarly, if there are any situations which will prevent you from exercising write them here (or let us know if they arise through the model)

If your situation changes regarding your responses to these questions, please notify the test administrator.

Signed ………………………………….

Date ……………………………….

Appendix 3. Raw Data Table

Subject Number	Height (cm)	Weight (kg)	10m (s)	40m (s)	5RM Squat (kg)	Squat relative (kg/bm)	SJ (cm)	CMJ (cm)	5BJ (RSI)
Forwards									
1	184.1	93.5	1.666	5.124	210	2.241195304	39.53	42.65	1.15
2	194.6	103.6	1.86	5.7	170	1.640926641	30.05	32.15	1.47
3	183.5	104	1.888	5.7	210	2.019230769	31.18	33.23	1.32
4	197.2	100.4	1.845	5.616	190	1.901901902	33.76	37.91	1.29
5	185.5	105.8	1.822	5.47	210	1.966292135	34.91	36.32	1.19
6	160.5	93.5	1.859	5.605	215	2.299465241	33.64	35.04	1.88
7	185	111.7	1.837	5.438	240	2.148612355	34.71	36.42	1.09
8	185.8	97.7	1.599	5.164	210	2.182952183	36.03	39.45	1
9	195.8	159	1.875	5.823	240	1.547388781	31.4	31.65	0.85
10	175	106	1.852	5.673	215	2.087378641	30.08	31.96	1.83
Mean	**184.70**	**107.52**	**1.81**	**5.53**	**211.00**	**2.00**	**33.53**	**35.68**	**1.31**
SD	**10.86**	**18.98**	**0.10**	**0.23**	**20.66**	**0.25**	**2.98**	**3.62**	**0.34**
Backs									
11	188.2	86	1.766	5.36	190	2.191464821	45.63	48.67	2.02
12	169.5	92.8	1.832	5.675	180	1.939655172	31.03	36.02	1.69
13	182.5	97.8	1.802	5.615	175	1.789366053	29.32	31.15	1.05
14	186.4	86.2	1.633	5	190	2.204176334	45.48	43.85	1.91
15	176.5	81	1.797	5.45	150	1.851851852	46.53	48.05	1.44
16	179	79.7	1.687	5.064	190	2.308626974	39.42	41.11	2.27
17	176.3	89.5	1.774	5.35	135	1.508379888	33.41	36.42	1.67
18	185	92.9	1.76	5.14	245	2.731326644	35.76	37.09	1.4
19	179.6	84.9	1.581	5.02	245	2.885747939	48.67	50.38	2.01
20	182.5	94.5	1.582	4.859	240	2.53968254	48.05	53.74	1.72
Mean	**180.55**	**88.53**	**1.72**	**5.25**	**194.00**	**2.20**	**40.33**	**42.65**	**1.72**
SD	**5.58**	**5.96**	**0.09**	**0.28**	**38.50**	**0.44**	**7.45**	**7.44**	**0.36**