Master of Research Dissertation

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An investigation into the effect of varying plyometric volume on Reactive Strength and Leg Stiffness in collegiate rugby players

Abstract

The purpose of this study was to identify the role that low and high volume plyometric loads have on the effectiveness of developing stretch shortening cycle capability in collegiate rugby players. The experiment was carried out utilising a between- group, repeated measures design. Thirty six participants (Age 20.3 ±1.6 yrs, mass 91.63 ±10.36kg, height 182.03 ±5.24cm) were randomly assigned to one of three groups, a control group (CG), a low volume plyometric group (LPG) and a high volume plyometric group (HPG). Data were collected from a force plate, and measures of reactive strength index (RSI) and leg stiffness were calculated from jump height, contact time and flight time data. Drop Jumps were used to gather data to measure RSI and double leg hops were used to gather leg stiffness data. The analysis demonstrated an overall significance in the interaction effect between group* time ($F = 4.01$, $p < 0.05$) for RSI. Bonferroni post hoc analysis indicated that both the LPG training group ($p = 0.002$) and HPG training group ($p = 0.009$) demonstrated a significance from the control group. No significant interaction effect between time*group or main effect were observed for leg stiffness ($F = 1.39$, $p = .25$). The current study has demonstrated that it is possible to improve reactive strength capabilities to a significant level via the use of a low volume plyometric programme. The low volume programme elicited the same performance improvement in RSI values as a high volume programme whilst undertaking only a quarter of the volume. This suggests that strength and conditioning coaches may be able to benefit from the ability to develop more time efficient and effective plyometric programmes.

Declaration

This dissertation is being submitted in partial fulfilment for the requirements for the degree of Masters in Research (MRes).

This dissertation is the result of my own work and investigation, except where otherwise stated. Other source materials where appropriate have been acknowledged. References can be found at the end of the dissertation.

Signed...

Date..

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Chapter One – Introduction

1.1 Background

Rugby Union is a game which became professional in 1995 and is the third largest team sport in the world. Once the game became professional, Nicholas (1997) identified that it is important to understand the physiological needs of the game of rugby to accurately develop a relevant training programme. Pearson (2001) identified that the modern professional rugby players need speed, power, acceleration, agility, contact and quick response times. This was supported by Babault, Cometti, Bernardin, Pousson and Chatard (2007), who proposes that rugby players need to have sufficiently well developed anaerobic capabilities to produce high levels of muscular strength, power and speed to engage in sprinting activities as well as heavy body contacts. However, Deutsch, Kearney and Rehrer (2007), claim that there is still a lack of research into the exact physiological demands of professional rugby union.

Wilson (2006) points out that rugby is a demanding sport requiring the players to engage in physical contact for eighty minutes. Nicholas (1997) identifies rugby as an interval or intermittent sport where players must be able to perform a large number of intensive efforts of 5 to 15 seconds' duration often with less than 40 seconds' recovery between each bout of high intensity activity. Cunniffe, Proctor, Baker and Davies (2009) also suggest that rugby is an intermittent high intensity sport where activities that require strength and power are interspersed with periods of lower activity.

Gamble (2004) identifies that strength and conditioning coaches working with rugby football players face two main challenges: The first challenge is to provide appropriate metabolic conditioning in the most time-efficient manner. The second challenge is to develop and maintain high levels of strength and power while athletes are concurrently performing high volumes of metabolic training and team practices. It is therefore important that training programmes are designed to be as time efficient as possible. The present study seeks to identify the relationship between low and high volume plyometric programmes on improvements in reactive strength and leg stiffness. It is suggested that if low plyometric volumes are as effective as high volume plyometric programmes then this will be more time efficient and therefore very beneficial to the strength and conditioning coach.

The stretch -shortening cycle (SSC) is a naturally occurring muscle function whereby a muscle is stretched and this is immediately followed by a concentric action of the same muscle. The SSC can be found in common movements such as running, jumping and hopping. When a concentric (shortening) action of the muscle immediately follows an eccentric action, then the concentric action is more powerful than when the shortening action occurs on its own (Nicol, Avela and Komi, 2006; Flanagan and Comyns, 2008). Efficient SSC movements can not only result in a more powerful propulsive force, but can also lead to energy conservation and an athlete can reduce the metabolic costs of such a movement (Turner and Jeffreys, 2010).

It is clear that the increased propulsive force and reduction of metabolic costs would be advantageous when training for sports performance. One of the most common modalities for training the SSC is via the use of plyometrics (Dodd and Alvar, 2007). Plyometrics is a term that is often used to describe powerful, quick movements which utilize the SSC (Sankey, Jones and Bampouras, 2008). Plyometric exercises enable a muscle to attain maximal external force in a very short time, (Brewer, 2005; Baechle and Earle, 2008) and utilize the increased power developed by the SSC (Chandler and Brown, 2008). Literature has demonstrated that plyometric training can be used to improve agility, running economy and power output (Flanagan et al. 2007; Flanagan and Comyns, 2008), as well as strength, coordination and possible reduction of injuries (Saez – Saez de Villareal, Kellis, Kraemer, and Isquierdo,2009)

Although there are many benefits to plyometric training, Saez – Saez de Villareal, et al. (2009) point out that there are a number of factors that may affect the success of a plyometrics programme, including age, gender and training history. They also point out that research studies have differed in terms of duration, volume and intensity within their studies and as such there is still a lack of clarity as to the optimal levels and combinations of these factors to achieve maximum performance. Baechle and Earle (2008) support this by stating that there is little research which identifies the optimal levels of plyometric training to improve performance.

Within a meta-analysis of 56 plyometric studies (Saez – Saez de Villareal et al. 2009) it was postulated that programmes which included training programmes of more than 10 weeks and included more than 20 sessions with more than 50 jumps per session were the programmes that appeared to maximise the probability of obtaining significantly greater improvements in performance. However, a study carried out by some of the same authors (Saez – Saez de Villareal, Ganzalez-Badillo and Isquierdo, 2008) proposed that low and moderate plyometric training frequency (420 and 840 total jumps) produced greater jumping and sprinting gains than a high frequency (1680 total jumps) of plyometric training.

The reactive strength index (RSI) was initially developed at the Australian Institute of Sport (AIS) and was one of the constituent components of the Strength Qualities Assessment Test which was established at the AIS and is calculated by dividing the jump height by contact time (Flanagan and Comyns, 2008). As a calculation of both the jump height and the amount of time spent on the ground to generate that jump height it can therefore be seen as a measure of 'explosiveness' and provides practitioners with a sound indication of an athlete's ability to change from an eccentric contraction to a concentric one, and is therefore a useful measure of SSC capability (Wilson and Flanagan, 2008).

Stiffness can be described in its simplest for as the relationship between a given force and the magnitude of deformation of an object, and in relation to the human body can be observed from a single muscle fibre to the whole body being modelled as a spring-mass system (McMahon, Comfort and Pearson, 2012). In this study leg stiffness will be defined as the ratio between peak ground reaction forces and peak centre of mass displacement as described by Lloyd, Oliver, Hughes and Williams (2009) who also identify that the development of leg stiffness has been associated with maximal running velocity, stride cadence and running economy. McMahon, et al (2012) also identify how leg stiffness can be used to model the mechanics associated with the SSC and as such this measure of SSC capability is of interest within this study.

1.2 Aims

The aim of the proposed study is to identify whether similar SSC performance benefits are gained from a low volume plyometric programme and a high volume plyometric programme for a specific population, namely collegiate rugby union players.

1.3 Objectives

The study will investigate the effect of a low volume plyometric programme and a high volume plyometric programme has on the reactive strength index.

The study will investigate the effect of a low volume plyometric programme and a high volume plyometric programme has on the leg stiffness.

1.4 Hypothesis and Null hypothesis

Hypotheses

Low volume plyometric training will elicit similar significant improvements in reactive strength as high volume plyometric programmes.

Low volume plyometric training will elicit similar significant improvements inleg stiffness as high volume plyometric programmes.

Null Hypotheses

Low volume plyometric training will not elicit similar significant improvements in reactive strength as high volume plyometric programmes.

Low volume plyometric training will not elicit similar significant improvements inleg stiffness as high volume plyometric programmes.

Chapter Two - Review of Literature

2.1 Rugby Union

Rugby Union is a game which is played in over 100 countries, and is one which turned professional in 1995.Quarrie and Hopkins (2007) suggest that the development of the professional game has resulted in major changes to the game in term of the laws, its governance, along with the stature and body mass of the players themselves. Posthumus (2009) identifies how physical conditioning has become far more important within the game of rugby union. He outlines the need for players to have high levels of power, speed, agility and muscular strength. It can be claimed that rugby players need to have sufficiently well-developed anaerobic capabilities to produce high levels of muscular strength, power and speed to engage in sprinting activities as well as heavy body contacts (Babault, et al, 2007; Hene, Bassett and Andrews, 2011). Bevan, Bunce, Owen, Bennett, Cook, Cunningham, Newton and Kilduff (2010) describe the ability to develop high levels of power in a team sport, such as rugby, as essential to success.

Wilson (2006) points out that rugby is a demanding sport requiring the players to engage in physical contact for eighty minutes. Nicholas (1997) identifies rugby as an interval or intermittent sport where players must be able to perform a large number of intensive efforts of 5 to 15 seconds' duration often with less than 40 seconds' recovery between each bout of high intensity activity. Cunniffe, et al (2009) also suggest that rugby is an intermittent high intensity sport where activities that require strength and power are interspersed with periods of lower activity. However, Deutsch, et al (2007), claim that there is still a lack of research into the exact physiological demands of professional rugby union.

Argus, Gill, Keogh, Hopkins and Beaven (2010), identify that rugby is a sport that is played all year, and as a consequence this can lead to preparation time for the range of physical characteristics needed by the rugby player to become limited. Marshall (2005) suggests that the off season for rugby union players may last as little as four weeks and therefore the need for careful planning of the periodised year to ensure fitness is maintained and injuries are prevented becomes increasingly important.

As a result, Gamble (2004) identifies that strength and conditioning coaches working with rugby players face two main challenges: The first challenge is to provide appropriate metabolic conditioning in the most time-efficient manner. The second challenge is to develop and maintain high levels of strength and power while athletes are concurrently performing high volumes of metabolic training and team practices. It is therefore important that training programmes are designed to be as time efficient as possible. Plyometric training is an established method of training for performance based indices of power development and may improve the efficiency of the SSC (Sankey et al, 2008).

The present study seeks to identify the relationship between low and high volume plyometric programmes and their effects on reactive strength and leg stiffness. It is suggested that if low plyometric volumes are as effective as high volume plyometric programmes then this will be more time efficient and therefore potentially beneficial to the strength and conditioning coach.

2.2 Stretch – Shortening Cycle

The stretch -shortening cycle (SSC) is a naturally occurring muscle function whereby a muscle is stretched eccentrically, and immediately followed by a shortening, concentric action of the same muscle. The SSC can be found in common movements such as running, jumping and hopping. When a concentric (shortening) action of the muscle immediately follows an eccentric (lengthening) action with a short isometric (no change in length) or amortization phase, then the concentric action is more powerful than when a concentric action occurs in isolation (Nicol, et al, 2006, Flanagan and Comyns, 2008).Investigations have found that countermovement jumps (CMJ) where there is a small downward movement before the upward movement of a jump result in greater jump heights than a squat jump (SJ) where there is only an upward movement (Bobbert and Cassius, 2005). Efficient SSC movements can not only result in a more powerful propulsive force, but can also lead to energy conservation and reduction in the metabolic cost of human movement (Turner and Jeffreys, 2010).

However, the literature that investigates the SSC suggests that there could be a number of contributing mechanisms which may be used to explain the phenomenon. These include the storage of elastic energy, increased active state, neural potentiation and stretch- reflex utilisation (Turner and Jeffreys, 2010, Flanagan and Comyns, 2008)

The usage of stored elastic energy, sometimes referred to as the mechanical model, proposes that during the eccentric action of the muscle, elastic energy is temporarily stored within the elastic elements of the musculo-tendinous unit (Cavagna and Keneko ,1977). The elastic energy can then be reused during the concentric phase of the SSC. Although it is widely reported that the stored elastic energy helps to increase force output during the concentric action of the muscle (Baechle and Earle, 2008; Chandler and Lee,2008), Ingen Schenau (1997) and Bobbert and Cassius (2005) suggest that the stored elastic energy is important within the SSC in a role of reducing metabolic cost of movement and not in increasing force production. Despite this, Nicol, et al (2006) suggests that there is no convincing evidence to negate the importance of elastic energy within force production during a SSC movement.

Where there does appear to be more agreement within the literature is the importance of a quick transition between the eccentric phase of the SSC and the concentric phase. The shorter the coupling of the eccentric – concentric phases will lead to a greater utilisation of the stored elastic energy (Bober, et al, 2006; Wilson and Flanagan, 2008; Flanagan and Comyns, 2008). It is suggested that if the amortization phase is too long, energy will be dissipated as heat (Turner and Jeffreys, 2010). Fleck and Kraemer (2004) however, claim that any possible amortization phase is likely to be too long and it is probable that the SSC mechanism must be down to other means such as active state and neural potentiation.

If the elastic energy stored within the series elastic component is to be utilised, then the development of stiffness within the muscle is of high importance (Wilson and Flanagan, 2008; Harrison and Gaffney, 2004). Butler, Crowell and Davis (2003) characterize leg stiffness to be the deformation of a given object and a given force, and from a biomechanical standpoint this characterization can be applied to a number of force-deformation relationships varying from a single muscle fibre to an entire limb. As muscle tissue is not as efficient at storing energy as the tendon, this could be a limiting factor in optimising the stored energy. When a greater level of leg stiffness is present the transfer of potential energy is greater (Farley and Gonzalez, 1996; Butler et al, 2003; Turner and Jeffreys, 2010). Wilson and Flanagan (2008) suggest that the greater utilisation of elastic energy is strongly correlated to short ground contact times (GCT), and report that where GCT decrease, an increase of leg stiffness was observed. It is also reported that leg stiffness has been shown to be well related to performance parameters such as faster stride frequencies and running velocity (Flanagan and Harrison, 2007), sub maximal hopping, maximum speed and running economy (Lloyd et al, 2009), force output and velocity (Wilson and Flanagan, 2008). A greater discussion of leg stiffness will take place later in this chapter.

A review of the SSC carried out by Ingen Schenau et al (1997) proposes that greater heights seen in a CMJ as compared to a SJ are almost exclusively due to the ability during the pre-stretch of the muscle to create a greater active state. Active state can be described as the number of actin sites that are available for cross bridge formation. They propose that the storage and utilization of energy play no part in the maximum work in the concentric phase, and other mechanisms such as potentiation of the muscle contractile machinery and neural responses play only a secondary role if any. Bobbert and Cassius (2005) support this proposal and point out that in a CMJ active state can be produced during the pre-stretch as well as the propulsion phase, whereas for a SJ the active state can only be developed during the propulsion phase. The greater ability to create active state during the pre-stretch could lead to greater force development and joint moments at the beginning of the concentric phase. Flanagan and Comyns (2008) report that within a CMJ, due to potential active state, peak force is being reached or closely approximated by the transition between the eccentric and concentric actions. However, with the Bobbert and Cassius (2005) experiment it needs to be considered that active state was measured via the use of a two dimensional model forward dynamic model of the human musculoskeletal system which did not incorporate any reflexes or potentiation. Ingen Schenau et al (1997) whilst supportive of the use of such models to further investigate the mechanisms of the SSC, it is also noted that decisive values for the compliance of the series elastic elements and efficiencies in contraction coupling are still as yet, not available.

The proposed neurophysiological model suggests that the muscle spindle may be responsible for the neural potentiation immediately following the eccentric action by the recruitment of additional motor units and/or the increased firing of those motor units already recruited (Komi and Gollhofer, 1997; Komi and Nicol,2011). Neural potentiation may be seen as a change in the force- velocity characteristics of the contractile components within the muscle. The muscle spindle is a facilitatory mechanoreceptor which is responsible for protecting the muscle tendon complex. The muscle spindle reacts to rapid changes in a muscle's length which causes a reflexive muscle action stimulating the agonist muscle. This fast reflexive action increases the activity (potentiates) within the agonist muscle and subsequently increases the force production within the muscle (Chandler and Brown, 2008; Baechle and Earle, 2008).

A second muscle receptor which is claimed to play an important part within the SSC is the Golgi Tendon Organ (GTO). Whereas the muscle spindle reacts to changes in velocity and length of stretch, the GTO responds to changes in tension within the muscle. Also whereas the muscle spindles act to stimulate the agonist muscles, GTO's act as inhibitors to agonist muscles and act as a protective mechanism against potential damage to the muscle tendon complex (Flanagan and Comyns, 2008). However, Jeffreys and Turner (2010) suggest that through plyometric training it is possible to inhibit the work of the GTO and an athlete may be able to sustain high landing forces with no decrease in the muscular force exerted. Kyrolainen (1991) cited in Jeffreys and Turner (2010) report that it may take up to 4 months to inhibit the work of the GTO to enable potentiation of the muscle spindle. This may be an important consideration for a strength and conditioning coach when deciding on the length of a plyometric programme if it is to successfully utilise neural processes and neural potentiation.

Although the mechanisms that underpin the SSC are contested and remain unclear, Chandler and Brown (2008) and Baechle and Earle (2008) suggest that it is likely that all the proposed mechanisms play a part in the development of power output and the enhancement of force. Flanagan and Comyns (2008) suggest that the role of the different mechanisms may actually be dependent on the type of SSC movement that is being utilised or developed. Schmidtbleicher (1992) proposed that the SSC could be classified as fast SSC movements and slow SSC movements. A fast SSC movement is one where the GCT is <250ms and a slow SSC movement has a GCT of >250ms. Flanagan and Comyns (2008) suggest that fast SSC movements are characterized by small angular displacement at the hips, knees and ankles whereas greater angular displacements at these joints would be seen during a slow SSC movement.

Flanagan and Comyns (2008) go onto suggest that as the muscle spindle reflex is evident when there is a fast rate of eccentric stretching, and elastic energy appears to rely on a short transition phase between the eccentric and concentric actions, then these mechanisms are likely to contribute to fast SSC movements as these movements have quicker eccentric velocities and shorter amortization phases than slow SSC movements. They also suggest that neural potentiation would contribute to fast SSC movements as an increase in the amortization phase has been shown to decrease the extent of the potentiation effect.

It is also hypothesised by Flanagan and Comyns (2008) that slow SSC movements are due to the slower eccentric phase of the movement allowing more time for cross bridge formation to occur and so active state would be a more plausible mechanism for slow SSC movements. They also suggest that greater amortization phase and slower eccentric phase would cause uncertainty as to the role that mechanisms such as elastic energy, the muscle spindle reflex and neural potentiation could play in such a movement. These suggestions are similar to those of Turner and Jeffreys (2010) who conclude that it is elastic energy that contributes to the increase in force after fast SSC actions, whereas the development of active state is most influential in slow SSC movements.

The hypothesis of having fast and slow SSC movements and the potential of differing mechanisms being responsible for the different movements may have meaningful implications for the strength and conditioning coach. For example training movements which are slow SSC movements and develop the active state potential may not produce any benefits to fast SSC movements and vice versa. Any training to increase SSC potential within a rugby player will need to be specific to the types of movement carried out by that particular player. The need for all players to sprint and change direction quickly would rely on fast SSC production whereas jumping in the lineout could utilise a slow SSC movement. Therefore a lineout jumper would need to work on both fast and slow SSC, whereas a winger who will rely more on quick sprinting movements may focus more on just fast SSC development.

2.3 Testing and Monitoring of SSC function

2.3.1 Reactive Strength Index

McClymont and Hore (2004) describe the RSI as a calculated figure derived by dividing the height jumped by the time in contact prior to take-off (height jumped/ contact time). The RSI was first developed by the Australian Institute of Sport as part of the Strength Qualities Assessment Test (SQAT) (Young, 1995). Flanagan, et al (2008) suggest that the RSI represents the ability to change rapidly from an eccentric action to a concentric action and thereby utilizing their SSC capability. The fact that RSI produces a score based on both GCT and JH provides the strength and conditioning coach with a particularly useful measure. Despite the RSI being increasingly utilized within the literature (McGowan et al 2010; Flanagan et al, 2008; McClymont and Hore, 2004), Lloyd et al (2009) point out that there appears to be limited information in relation to the reliability and validity of the measurement. Although Flanagan et al, (2008) reported high levels of reliability ($\alpha > 0.95$), it must be taken into consideration that the data was collected from a single test session and therefore may be misleading. Lloyd (2009) reported moderate reliability (CV<10%), however, it needs to be considered that the population utilized within the study were youths. It is therefore evident that although the

RSI may provide a very useful measurement to the strength and conditioning professional, further study into the reliability of the measure is required.

Where the RSI can provide a useful measure is within the monitoring and evaluating of a plyometric programme (Flanagan and Comyns, 2008; Turner and Jeffreys, 2010). As a monitoring tool the RSI can provide the coach with ongoing feedback in relation to increased performance but also from an injury risk perspective (Flanagan and Comyns, 2008). As a performer carries out drop jumps from greater heights, when the RSI is maintained or improved and GCT is exhibitive of a fast SSC action, then it can be ascertained that a participants' reactive strength capabilities are competent at that drop height. If RSI decreases as drop height increases or the GCT becomes greater than a fast SSC action then the drop height might indicate a level whereby the participant's reactive strength capabilities are no longer sufficient, then an increased injury risk may be evident. It is possible that the RSI can be used to identify the optimal intensity for an individual athlete and this may provide particularly useful information when designing the athlete's training programme.

Flanagan and Comyns (2008) also identify that the RSI can play a motivational role within the plyometric training programme. The RSI can be used to provide knowledge of results by providing scores for JH, GCT and RSI and the use of these results to provide feedback may be motivating to the athletes to work toward their maximal efforts. At the same time, Flanagan and Comyns (2008) warn that feedback on every trial may force the athletes to become over reliant on the feedback and less able to process the information that they require to improve their own performance.

2.3.2 Leg Stiffness

The number of studies investigating leg stiffness is becoming more prevalent as researchers attempt to understand the relationship between the complexities of lower body biomechanics and its relationship with performance measures (Butler, et al, 2003).However, because of the complexities of lower extremity mechanics, there are a number of ways that leg stiffness can be viewed. Butler, et al (2003) state that in its simplest sense the relationship between a given force and the deformation that force has on a given body can be described as stiffness. However, the term stiffness can be described from the whole body down to a single fibre, as such it is important to investigate some of these descriptions and outline the definition that will be used within this study. Hobara, Kimura, Omuro, Gomi, Muraoka, Sakamoto and Kanosue (2008), and Morin, Dalleau, Kyrolainen, Jeannin and Belli (2005) describe how a spring mass model is frequently used to represent the musculoskeletal system when investigating leg stiffness. In this model, leg stiffness is defined as the ratio of maximal ground reaction force to maximal leg compression at the middle of the stance phase (Hobara, at al, 2010). It is suggested that if the spring mass model is to be used then it needs to take into account all the different elements that contribute to that stiffness. These elements include bone, muscle, tendon, ligaments and cartilage (Flanagan and Harrison,2007). In addition, consideration also needs to be given to other factors such as central nervous system control, muscle reflex time delays and viscosity (Butler, et al, 2003).

Due to the complex nature of the spring mass model, a number of equations have been used to calculate leg stiffness. The simplest according to Butler, et al (2003) is a calculation between peak ground reaction forces and the maximal centre of mass displacement. It is this ratio between peak ground reaction forces and peak centre of mass displacement that will be used within this study and it is in this context that the term stiffness will be used for the rest of this study.

Lloyd, et al's (2012) description of leg stiffness can be calculated from a subject's body mass, ground contact times and flight times, and similarly to the RSI can provide the strength and conditioning coach with useful information related to the individual's SSC capabilities. The reason for adopting this field based measure rather than the ‘criterion’ method is due to the applied nature of the study and its application to strength and conditioning coaches.

It has been proposed that the development of leg stiffness can be beneficial to a range of performance parameters including sprinting speed, reduced metabolic cost, and minimised GCT (McCurdy et al, 2010; Flanagan and Harrison, 2007). Dumke, Pfaffenroth, McBride and McAuley have also suggest that greater muscle stiffness is associated with greater running efficiency. However, Walshe and Wilson (1997) suggest that when drop heights are increased above an optimal level those athletes with high stiffness produce poorer capacity than those athletes with lower stiffness levels. It is suggested that this is due to the stiffer athletes having less well developed contractile dynamics (slow SSC mechanisms). This is supported by Wilson and Flanagan (2008) who suggest that elevated stiffness can be detrimental to performance with lower running velocities and lower power outputs observed. This emphasises the need for training to be specific if it is to be both efficient and effective.

The development of optimal stiffness levels then is of importance to both the athlete and the coach. Wilson and Flanagan (2008) also identify that optimal stiffness levels can be beneficial in soft tissue injury prevention and rehabilitation. Similarly to the RSI the measurement of leg stiffness can therefore be useful in the monitoring of a plyometric programme and can help lead to the identification of optimal training variables within that programme.

2.4 Plyometric Training

It is clear that the increased propulsive force and reduction of metabolic costs that can be observed via the SSC would be invaluable when training for sports performance. Therefore, the ability to train and optimise the use of the SSC is of great importance when enhancing performance. Although a range of training modalities to train the SSC are available, including traditional heavy resistance training and weightlifting (Bruce-Low and Smith, 2007), one of the most common modalities for training the SSC is via the use of plyometrics (Dodd and Alvar, 2007). Plyometrics is a term that is often used to describe powerful, quick movements which utilize the SSC (Sankey et al, 2008). Plyometric exercises enable a muscle to attain maximal external force in a very short time, (Brewer, 2005, Baechle and Earle, 2008) and utilize the increased power developed by the SSC (Chandler and Brown, 2008). Literature has demonstrated that plyometric training can be used to improve running speed (Rimmer et al, 2000) , running economy (Turner et al, 2003) and power output (Gehri et al,1998; Meylan and Malatesta, 2009), as well as strength, coordination and possible reduction of injuries (Saez – Saez de Villareal, et al, 2009).

Although there are many benefits to plyometric training, Saez – Saez de Villareal, et al (2009) point out that there are a number of factors that may affect the success of a plyometrics programme, including age, gender and training history. They also point out that research studies have differed in terms of duration, volume and intensity within their studies and as such there is still a lack of clarity as to the optimal levels and combinations of these factors to achieve maximum performance. Baechle and Earle (2008) support this by stating that there is little research which identifies the optimal levels of plyometric training to improve performance. Ebben, et al (2008) also agree with this statement, suggesting that the design of a plyometric training programme is similar to the design of other training programmes and as such an understanding of the type of design variables is necessary. These design variables include; exercise mode, frequency, volume, programme length, recovery, progression, repetition velocity and intensity. However, unlike many other similar types of training modalities, it appears that with plyometrics these variables are not well understood.

2.4.1 Duration

When reviewing programme length for example, there are observable differences to be noted within different research articles. Programme lengths of 4 weeks (Impellizeri et al, 2008; Herrero et al, 2006, Dodd and Alvar, 2007), 6 weeks (Adams et al, 1992; Sankey et al, 2008;Makaruk and Sacewicz, 2010; Turner et al, 2003) 7 weeks (Ronnestad et al, 2008; Saez Saez de Villarreal et al, 2008), 8 weeks (Holcomb et al, 1996; Potteiger, et al 1999;Meylan and Malatesta, 2009), 10 weeks (Markovic et al, 2007) 12 weeks (Vissing, et al, 2008; Gehri et al, 1998) are evident within the literature. Although the programme lengths are considerably different, only three of the aforementioned papers (Dodd and Alvar, 2007; Turner et al, 2003; Potteiger et al, 1999) provide any justification for utilising that particular programme length. The justifications for the duration of the training programme included following procedures identified by other researchers (Dodd and Alvar, 2007; Turner et al, 2003). Potteiger et al’s (1999) justification was based around utilising the time scale that is normal for a pre-season programme. The decision to hold a programme over a particular duration must be an important decision for the researcher, and therefore, seems strange that in the majority of cases it is not reported.

2.4.2 Intensity

Another important variable for the researcher to consider is intensity of the exercise prescribed within the programme. Wallace et al (2010) suggest that intensity could be considered the most important variable when designing a plyometric programme as other factors may be determined by the intensity, such as volume and recovery. Ebben et al (2008) suggest that there are a number of variables which can be determining factors when identifying intensity, including speed of the exercise (Makaruk and Sacewicz, 2010), height of the jump (Gehri et al, 1998), number of foot contacts with the ground (Ronnestad et al, 2008) as well as the body mass of the athlete (Vissing, et al, 2008). This is supported by Wallace et al, who define intensity in plyometrics as ‘ the amount of stress placed on the muscles, joints and connective tissues involved in the movement’ (2010, p:207). Ebben et al (2008) also identify that some researchers utilise anecdotal recommendations for categorising low to high intensity plyometric exercises (Ebben, et al, 2008) although there is little evidence to support these. Their investigation into motor unit recruitment of the quadriceps, hamstrings and gastrocnemius even suggest that some exercises that had previously been thought of as high intensity yielded low motor unit recruitment within those muscle groups. Conversely, some exercises suggested to be low intensity yielded high motor unit recruitment.

Markovic et al (2007) identify the intensity of their exercises via the effort used by the participants (maximum effort = maximum intensity). Participants were instructed to jump as high as they could using minimum GCT. However, this was a subjective measure and therefore this subjectivity has to be taken into consideration. McClymont and Hore (2004) however, have identified that changing the drop height within a drop jump for example can change the jump height achieved and that for each individual an optimal drop height can be identified. This would suggest that although maximal effort may be used by participants, this doesn’t necessarily mean that maximum intensity is being achieved. The identification of the relevant intensity therefore may have an effect on the outcome of a planned plyometric programme.

2.4.3 Volume

Another important variable in the design of a plyometric programme is volume. Volume within plyometrics is normally measured via foot contacts with the floor (Sankey, et al, 2008). Similarly to intensity there are some anecdotal suggestions for plyometric volumes in relation to beginner, intermediate and advanced plyometric trainers (Baechle and Earle, 2008). Yet again these do not appear to be supported by any scientific evidence. It can also be seen that there are not just discrepancies of volume within a single session, but volume per week and volume over the whole training period. This ranged from Dodd and Alvar (2007) who utilised 36 contacts per session, 288 total programme contacts in a 4 week programme to Makaruk and Sacewicz (2010) who utilised 121 contacts per session and 1452 total programme contacts within a 6 week programme and Markovic et al (2007) who utilised an average of 60 contacts per session but 1800 contact overall within a 10 week programme. What is also of note is that, although where some training programmes are included there is evidence that volume has been reduced as the possible intensity has been increased, there is little discussion of the relationship between intensity and volume in the design of the training programme. What is not detailed in these papers is the relationship between volume and intensity. This makes it difficult at times to directly compare purely the volume of a training plyometric training programme. The relationship between intensity and volume is one which merits further research.

Within a meta-analysis of 56 plyometric studies (Saez – Saez de Villarreal, et al, 2009) it was postulated that programmes which included training programmes of more than 10 weeks and included more than 20 sessions with more than 50 jumps per session were the programmes that appeared to maximise the probability of obtaining significantly greater improvements in performance. However, a study carried out by some of the same authors (Saez – Saez de Villarreal, et al, 2008) proposed that low and moderate plyometric training frequency (420 and 840 total jumps) produced greater jumping and sprinting gains than a high frequency (1680 total jumps) of plyometric training. It was proposed by Saez- Saez de Villareal, et al (2009) that there is a cut- off point whereby further plyometric volume has negligible gains. They postulate that this may be a result of overreaching or over training, however, they do point out that the potential of different responses from the altering of plyometric volume and frequency being interceded by biochemical and neuroendocrine mechanisms was beyond the scope of the data collected.

Table 1: Summary of 'volume' based training studies

Authors	Duration	Total Contacts	Outcome
Dodd and Alvar (2007)	4 Weeks	288	+ VJ and standing broad jump (SBJ) - 20, 40, &60 yd sprint. T agility test
Makaruk and Sacewicz (2010)	6 Weeks	1452	+ DJ, CMJ - 5 hop test
Markovic et al (2007)	10 Weeks	1800	+ SJ, DJ , CMJ,SBJ - 20m Sprint, 20 yd shuttle run
Saez, Saez de Vaillareal (2008)	7 Weeks	420	+ 20m sprint + Contact Time -1RM Leg Press -Isometric max strength - CMJ, DJ
		840	+ 20m sprint + 1RM Leg Press + Isometric max strength + CMJ, DJ + Contact Time

Authors	Duration	Total Contacts	Outcome
		1680	+ 20m sprint + 1RM Leg Press + Isometric max strength + CMJ, DJ + Contact Time

+ = Significant improvement, - = no significant improvement

Although it is evident that there is an abundance of literature related to plyometric training, it is also apparent that there is a lack of research identifying optimal variables for the training modality. The aim of the author's current study is to utilise the SSC capability measurements of RSI and Leg stiffness to help identify the optimal plyometric volume (low versus high volume) for a specific population, namely collegiate rugby union players.

2.5 Measurement considerations

As has already been identified, both leg stiffness and RSI are popular measures of SSC function. However, the methods in which they have been utilised, and the participant groups within the research has varied and as such the current study aims to provide a useful addition to the current literature. Flanagan and Harrison (2007), investigated the muscle dynamics differences between legs in healthy adults by utilising measures of both RSI and leg stiffness. Measures of RSI and leg stiffness were used to identify the difference between the participant's preferred and non preferred legs in a range of tasks. This was done using both drop jumps and rebound jumps on a force sledge apparatus. They found that the preferred leg performed equally well on the drop jumps and rebound jumps, whereas the non preferred leg performed better on the more cyclical rebound jumps than the single effort drop jumps. They postulate that the measurement of drop jumps may be more suitable for studies that investigate changes in SSC function or maximal single leg efforts and the rebound jumps are more appropriate where information regarding the effects of running performance is required. As rugby is a game that involves both running and maximal single leg efforts (changing direction, line-out jumping) then the measures used within the current study may produce some useful results for the strength and conditioning specialist. However, any strength and conditioning specialist must exercise caution when interpreting any laboratory- based results as Wilson and Flanagan (2008) point out, movements that differ only slightly, can cause significant changes in leg stiffness.

Hopping frequency can also play an important role. Hobara, et al (2010) and Padua, et al (2005) both report greater leg stiffness at higher frequencies. Hobara et, al (2010) measure hopping at three separate frequencies; 1.5Hz, 2.2Hz and 3.5 Hz, whilst Padua, et al utilises the participants' preferred frequency and 3.0 Hz. Farley, Blickhan, Saito and Taylor found that when participants hop at a rate that ranges from their preferred rate of hopping to any increased level of hopping, then the body still acts like a spring-mass system, however, when any lower hopping frequency is utilised then the body does not act like a simple spring mass system , which they suggest could be attributed to different levels of stiffness within the different parts of the body (e.g. muscle- tendon and joint). Hobara, et al (2010) suggests that the increase in leg stiffness with increased frequency is due to a decrease in vertical displacement of the centre of mass (COM). The data collected in this study indicate that as the stiffness of the spring-mass model increases with an increase in frequency, then the displacement of the COM decreases during contact with the ground and as a result, the system allows the body to bounce off the ground in less time. Due to the scope and timescale available for the current study, the author proposes to measure at only one frequency (Lloyd, et al 2012, Hobara, et al 2007). Padua (2005) and Farley, et al (1991) report that previous research has approximated the preferred frequency to be 2.2±0.7 hops/s. This preferred frequency is the protocol to be utilised within this study.

A study by Kuitunen, Ogiso and Komi (2010) investigated leg and joint stiffness modulation under a series of different conditions. They found that leg stiffness remained consistent throughout a range of hopping intensities, and that hopping intensity was linked to a decrease in hopping frequency. They propose that the participants within their study were accommodating their frequency in order to maintain consistent leg stiffness with increasing intensity. They suggest that leg stiffness adjustments may occur in seemingly similar hopping practices. They go on to suggest that subjects have an optimal leg stiffness that they prefer to utilise (as long as hopping frequency is not preset), and this leg stiffness is independent of the intensity of the hopping.

RSI has already been identified as an effective measure of SSC function, and it has been suggested how it can be used as a monitoring tool (McClymont and Hore, 2005). However, Bober (2006) Flanagan and Comyns (2008), and Byrne, Moran, Rankin and Kinsella (2010) also identify how RSI can be utilised to optimise the plyometric training programme, by optimising the height that is prescribed for any drop jump activity. This optimisation of drop height is described as having potential benefit both in terms of increasing performance and minimising injury. Flanagan and Comyns (2008) identify how by measuring the RSI measures at increasing drop jump heights, it is possible to identify at which heights the RSI scores are maintained or improved. The optimal height to prescribe for drop jumps will be the maximum height that RSI is maintained or improved and they propose the reason for this is two-fold. Firstly a greater level of preactivation can occur at a greater drop height. This preactivation involves the preparatory excitement of motor units prior to an activity. The higher level of neural excitation which may begin before the amortization phase may lead to improved muscle action during the GCT.

Secondly, a greater drop height can lead to a greater eccentric phase velocity. This in turn can lead to a greater potentiation effect of the muscle contractile machinery and improved contributions from the muscle spindle reflex. In this study the pre-testing RSI measures from the 30,45 and 60 cm drop heights will be used to individually prescribe drop heights to each participant during the training phase of the study.

Despite the increased interest in both RSI and Leg Stiffness in the SSC literature, it is interesting to note that the number of training studies that utilise either measure within the research is minimal. Sankey, et al (2008) used the RSI as a measure of the effects of two plyometric programmes of different intensity. One training programme maintained a constant intensity throughout a six week period, whilst the other experimental group carried out a programme with increased intensity as the programme progressed. The RSI was used alongside measurements of contact time, flight time and rebound height using a DJ and measures of net impulse, take off velocity, jump height and peak force using a CMJ. They reported significant pre and post training differences for RSI and contact time for the increased intensity group ($p<0.05$), whilst all other values were found not to be significant. It is interesting to note that no detail is given in this paper relating to instructions given to the participants (e.g. minimise contact time, jump as high as possible), also it identifies that the platform for all plyometric drills was 0.4 metres in height. As previously discussed, this may be an effective height for some participants, whilst others may not be training at their optimum level to improve SSC function.

To the author’s knowledge, the only paper to use leg stiffness as a measure for a plyometric study and the only paper to use both RSI and leg stiffness as measures for a plyometric training study was carried out by Lloyd, et al (2012). In this study, the authors investigated the effect of a four week plyometric programme on reactive strength and leg stiffness in male youths, where the participant groups were aged, 9, 12 and 15. Although the study was carried out on a paediatric population, the methods and findings are still of use to the current study. The results demonstrated a significant improvement in relative leg stiffness performance in both 12 year old (2.9% mean difference) and 15 year old (3.46% mean difference) experimental groups and the 15 year old experimental group also made significant improvements in RSI values (0.06% mean difference). Results also revealed that there was a consistent trend of increased reactive strength along with great absolute and relative leg stiffness amongst the 15 year olds which is likely to be as a result of the effect of maturational status on the natural development of SSC function. As the current study will be using adults, it can be assumed that the SSC function will be at a stage where its natural development will be complete. The practical implications of this study in relation to significant improvement in SSC performance in a short duration (four week) training block could be of particular interest to strength and conditioning coaches.

2.6

Practical Implications for the coach

RFU (2006) identify that the coach needs to plan for the tactical, technical, physical and psychological development of their players. This provides the coach with a diverse range of factors on which to focus. In returning to Gamble's (2004) two main challenges for the strength and conditioning coach ; that of providing appropriate metabolic conditioning in a timely manner, whilst developing and maintaining high levels of strength and power at times when athletes are concurrently performing high volumes of metabolic training and team practices. It is therefore important that training programmes are designed to be as time efficient as possible.

Whilst reviewing the literature relating to both the SSC and plyometric training it became evident that all rugby players need to develop their fast SSC, while some players will also need to develop their slow SSC capabilities (Flanagan and Comyns, 2008). Any plyometric programme design must take the specific needs of the player in mind. Whilst designing the plyometric programme it is also evident that there is a need to identify the optimal values for variables such as volume and intensity. Saez – Saez de Villarreal (2008) proposed that similar results can be obtained from low to moderate plyometric frequencies in comparison to a high frequency. The author's main focus is to identify an optimal plyometric training volume, and although it is also clear that other training variables, such as intensity and programme length must be carefully considered, if it possible to get similar improvements via a smaller plyometric volume then this will make the training programme more efficient for the strength and conditioning specialist. The measurement of both RSI and leg stiffness appears to be fundamental not only in the testing of SSC capability, but also in the monitoring of a plyometric programme. It is hoped that the author's research may help in adding to the research in the area whilst also providing useful applied information to the specialists working in the performance arena.

Chapter Three - Methodology

3.1 Experimental Procedures

The experiment was carried out utilising a between- group, repeated measures design to examine the effect of different plyometric volumes on measures of SSC in collegiate rugby players. The participants were randomly assigned to one of three groups, a control group (CG), a low volume plyometric group (LPG) and a high volume plyometric group (HPG). Data were collected from a force plate, and measures of RSI and leg stiffness were calculated from jump height, contact time and flight time data. A summary of the experimental procedures can be seen in Figure 1:

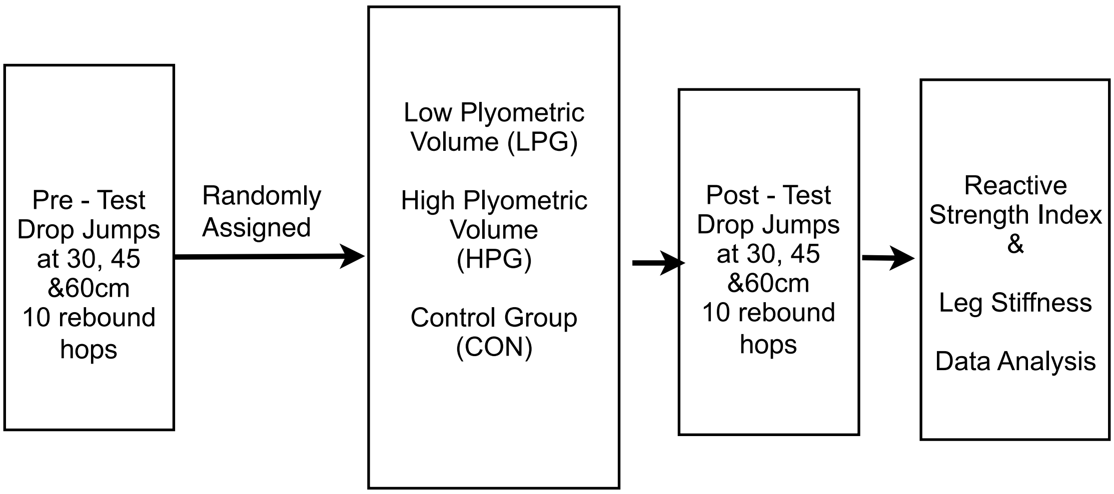

Figure 1: Summary of experimental procedures

The estimation of sample size for the study was calculated from the equation proposed by Hopkins (2004) using data collected from an initial pilot study. 10 male participants (age 20.4±0.8; height 1.86±0.09m and body mass 86.3±15.2Kg) took part in the reliability study. All were members of a collegiate men's rugby union team and took part in both rugby based and conditioning based training sessions on a regular basis. Participants undertook testing during two separate sessions (test – retest) which were held one week apart to ascertain the reliability of the ‘Smart Jump’ contact mat measuring RSI:

RSI CV – 6.1%

Where CV refers to the coefficient of variation, and SWC refers to the smallest worthwhile change [equation 4.1 below] The smallest worthwhile change was calculated as a factor of 0.2 of the between-subject standard deviation.

Sample size = 8*(CV2/SWC2) [equation 4.1]

According to the data, the calculated sample size was initially seven participants per group, however, Hopkins (2000) suggests that although sample sizes of only a few subjects are theoretically possible for measures of sufficiently high reliability, there should always be at least 10 participants in each group to reduce the chance that the sample substantially misrepresents the population.

3.2 Subjects

Thirty six male collegiate rugby union players aged 20.3 ±1.6 yrs, Mass 91.63 ±10.36KG, Height 182.03 ±5.24cm, with 1- 2 years history of plyometric training, volunteered to participate in the study. The participants were randomly assigned to one of three groups, a control group (CG), a low volume plyometric group (LPG) and a high volume plyometric group (HPG). Participants were required to attend at least 80% of the training sessions in order to be included in the final analysis of the study. Following the completion of the training programme, 29 participants qualified for inclusion for the final analysis from the three different groups: LPG (N = 10), HPG (N = 9) and control (N = 10). None of the participants reported and injury at the time of testing.

The project received ethical approval by the University's Research Ethics committee, and participants completed both a participant consent and physical activity readiness questionnaire (PARQ) which were obtained prior to testing. Participant confidentiality was upheld with any information and data being kept in accordance with the Data Protection Act (1998), and participant anonymity was maintained at all times. Participant identification was only known by the principal researcher and the supervisory team.

3.3 Testing protocols

3.3.1 Familiarization

Both Experimental groups – LPG and HPG attended two familiarisation sessions prior to the initial testing procedure. These sessions took place during the two weeks prior to the testing at the same time and place that the testing occurred. The familiarisation sessions included all techniques that would be used during the testing sessions.

Participants were also allowed practice attempts at all techniques as part of the warm up immediately prior to testing. The familiarisation sessions and practice attempts were included to reduce the likelihood of a learning effect. Throughout the familiarisation, participants were encouraged to minimise contact with the ground and maximise height.

3.3.2 Testing

Testing was completed at the same time on each of the testing days at the same indoor venue (biomechanics laboratory). Testing was carried out by the same tester. All participants were asked to refrain from eating, drinking or taking part in any physical activity for up to one hour before testing. All participants were also asked to wear the same footwear and clothing for all testing and training sessions. Testing included drop jumps from 30cm, 45cm, and 60cm along with two footed hopping.

All jump tests were performed on a 900 mm x 600 mm force platform plate (type 9287BA, Kistler Instrumente AG, Winterthur, Switzerland) fitted with an integrated charge amplifier. All output data was automatically captured on a PC and values for peak force and peak rate of force development were calculated from the captured data (Bioware® V.3.2.6, Kistler Instrumente AG, Winterthur, Switzerland). For all jump tests, participants were encouraged to jump as high as possible, whilst minimising ground contact time. Three trials of each drop jump were performed during the testing sessions, with the best score being used for data analysis (Castagna, et al 2009). For the repeated jumps, 10 jumps were completed and the middle 6 were recorded and used for analysis.

3.3.3 Initial testing

Reactive Strength Index: RSI was measured using a drop jump. The drop jump was performed starting from an initial standing position, with the hands placed on the hips (the hands will be kept on the hips throughout the jump). When ready, participants stepped off the box with one foot, they then looked to land with two feet simultaneously onto the contact mat. As soon as contact was made with the mat participants immediately performed a vertical jump. The drop jumps were carried out at heights of 30cm, 45cm and 60cm (Wallace, et al, 2010). Participants were given three trials at each height with the best trial being used for analysis (Castagna, et al 2009). RSI was calculated by dividing jump height (mm) by contact time(ms) (Lloyd, et al, 2009).

RSI = jump height (mm) / ground contact time (ms)

Leg Stiffness: Leg stiffness was measured via the use of double leg rebound jumps (hops). The double-leg 10 multiple hops were performed starting from a standing position. Once ready, participants performed a series of 10 hops at a frequency that was self selected by the participant (Padua, Carcia, Arnold and Granata, 2005; Hobara, et al,2007). During the hopping tests, participants were instructed to hop with their torso's upright and their hands on their hips (Hobara, Inoue, Omuro, Muraoka, Sakamoto and Kanosue, 2010) and encouraged to maximise the rigidity in their lower limbs and minimise the ground contact time (Lloyd, et al, 2009). Leg stiffness ($kN \cdot m^{-1}$) was calculated from force plate data using ground contact times, flight times and body mass, for the middle 6 rebound jumps (jumps 3 – 8) using the methods and equations proposed by Dalleau et al. (2004) cited in Lloyd et al. (2009). Within the equation K_N refers to leg stiffness, M is the total body mass, T_c is equal to ground contact time and T_f represents the flight time.

$$\text{Leg Stiffness } (K_N) = [M * \pi(T_f+T_c)]/Tc^2[(T_f+T_c/\pi)-(Tc/4)]$$

(Lloyd, et al, 2012)

3.3.4 Post testing

The procedures that were carried out post testing were carried out at the same time and place as the initial testing using exactly the same procedures as the initial testing.

3.4 Training

The study involved a 6 week plyometric training programme for both experimental groups, which reflects the training protocol durations reported elsewhere in the literature (Adams et al, 1992; Sankey et al, 2008; Makaruk and Sacewicz, 2010; Turner et al, 2003). The 6 week programme formed part of the club's periodised training programme. The LPG completed a total of 480 contacts across the whole programme (40 contacts per session, 80 contacts per week) and the HPG 1720 contacts across the whole programme (160 contacts per session, 320 contacts per week). A contact can be described as each time the feet come into contact with the ground within a plyometric session (Ebben, et al, 2008). All plyometric training followed a warm up of approximately 10 minutes of duration which included some aerobic activity (low intensity) followed by some mobility exercises which were aimed at the activation of the lower limb musculature to be utilised within the sessions.

3.4.1 Control

The control group undertook their regular club strength and conditioning training of two sessions a week along with the regular in season programme of games and skill based training, but did not undertake any plyometric based training during the duration of the study.

3.4.2 High Volume Group

The HPG carried out 25 – 40 minutes of plyometric training twice per week for the 6 week period. The sessions took place on an indoor surface and were delivered alongside the normal club strength and conditioning programme. Total training time was determined by the intensity of the sessions and the need for participants to be recovered between sets, with more rest provided for those exercises that elicited greater eccentric loading (Lloyd, et al, 2011) At least 48 hours was planned between each plyometric session to allow for relevant recovery.

The HPG sessions consisted of a range of plyometric drills which included drop jumps, lateral and horizontal jumps, hurdle jumps and bounds. The drop jump height was individually prescribed based on the optimal drop jump height identified during the initial testing phase (the height where the RSI score was equalled or bettered). Verbal feedback was provided during each session which was aimed at minimising contact time and increasing flight time wherever possible. Feedback was also provided in relation to any postural or technical issues although this was minimal as each participant had 1 – 2 years of plyometric training history.

The HPG group carried out a total of 1920 contacts across the whole programme (160 contacts per session, 320 contacts per week). The training programme carried out by the HPG can be found in table 2.

3.4.3 Low Volume Group

The LPG carried out 5 – 10 minutes of plyometric training twice per week for the 6 week period. The sessions took place on an indoor surface and were delivered alongside the normal club strength and conditioning programme. Total training time was determined by the intensity of the sessions and the need for participants to be recovered between sets, with more rest provided for those exercises that elicited greater eccentric loading (Lloyd, et al, 2012) At least 48 hours was planned between each plyometric session to allow for relevant recovery.

The LPG sessions consisted of a range of plyometric drills which included drop jumps, lateral and horizontal jumps, hurdle jumps and bounds. The drop jump height was individually prescribed based on the optimal drop jump height identified during the initial testing phase the height where the RSI score was equalled or bettered). Verbal feedback was provided during each session which was aimed at minimising contact time and increasing flight time wherever possible. Feedback was also provided in relation to any postural or technical issues although this was minimal as each participant had 1 – 2 years of plyometric training history.

The LPG group carried out a total of 480 contacts across the whole programme (40 contacts per session, 80 contacts per week). The training programme carried out by the LPG can be found in table 2.

Table 2: Low and High Volume Plyometric Group Training Programme

		LPG	HPG
Week	**Exercises**	**Repetitions**	**Repetitions**
1	Standing vertical jumps (tuck jumps)	1 x 10	4 x 10
2 sessions	Multiple two-foot hurdle jumps	2 x 5	8 x 5
	Repeated 2 foot jumps (horizontal)	2 x 5	8 x 5
	Alternate leg bound	2 x 5	8 x 5
2	Standing vertical jumps (tuck jumps)	1 x 10	4 x 10
2 sessions	Multiple two-foot hurdle jumps	2 x 5	8 x 5
	Repeated 2 foot jumps (horizontal)	2 x 5	8 x 5
	Alternate leg bound	2 x 5	8 x 5
3	Lateral two foot jumps	1 x 10	4 x 10
2 sessions	Multiple two-foot hurdle jumps	2 x 5	8 x 5
	Single foot hops	2 x 5	8 x 5
	Drop Jumps	2 x 5	8 x 5
4	Lateral two foot jumps	1 x 10	4 x 10
2 sessions	Multiple two-foot hurdle jumps	2 x 5	8 x 5
	Single foot hops	2 x 5	8 x 5
	Drop Jumps	2 x 5	8 x 5
5	Lateral one foot jumps	1 x 10	4 x 10
2 sessions	Multiple two-foot hurdle jumps	2 x 5	8 x 5
	Drop Jumps	2 x 5	8 x 5
	Single foot drop jumps	2 x 5	8 x 5
6	Lateral one foot jumps	1 x 10	4 x 10
2 sessions	Multiple two-foot hurdle jumps	2 x 5	8 x 5
	Drop Jumps	2 x 5	8 x 5
	Single foot drop jumps	2 x 5	8 x 5
	Total Foot Contacts	**480**	**1,920**

3.5 Statistical Analysis

Descriptive statistics (mean ± SD) for the different variables were calculated. The training related effects were assessed via a between-group repeated measures analysis of variance (ANOVA). For RSI a 3 x 2 x 3 RMANOVA was performed where drop height, trial and group were the measured variables (group*trial*height). Drop height referrers to the 30cm, 45cm and 60cm heights used for both the pre and post testing, trial refers to the pre and post tests, and the group refers to the Control group, HPG or LPG. For leg stiffness a 3 x 2 RMANOVA was utilised where group and time were the measured variables (group*trial), where group refers to the Control group, HPG or LPG and trial refers to pre or post testing. Mauchly's test was used to test for sphericity of the data and where it was violated a Huynh-Feldt adjustment was utilised. Levene's test was used to assess the equality of variances within the samples. A Bonferronni analysis was used for all post hoc analysis. Three trials of each jump was performed during the testing sessions, with the best score being used for RSI data analysis. The middle 6 rebound jumps (jumps 3 – 8) were used to analyse leg stiffness. All statistical analysis was carried out via SPSS® (version 19) Chicago, Illinois). Significance was set at $p \leq 0.05$

Chapter Four – Results

4.1 Participant characteristics

Descriptive characteristics of the participants in each group can be seen below in table 3.

Table 3. Mean (±SD) descriptive values for experimental and control groups

Group	N	Height(cm)	Weight(KG)
HPG	9	182.14±5.26	90.27±8.09
LPG	10	184.43±5.94	93.65±13.19
CON	10	182.01±4.50	92.90±11.83

4.2 Reactive Strength Index

A between group repeated measures ANOVA [Group (3) x Time (2) x Height (3)] was conducted to explore the impact of a low volume plyometric training programme and a high volume plyometric training programme on reactive strength index. Means (± standard deviations) for reactive strength index for each group are shown in table 4. Mauchly's test indicated that the assumption of sphericity had been violated for the main effects of time* height, $\chi^2(2) = 10.74$, $p<0.01$. Therefore degrees of freedom were corrected using Huynh Feldt estimates of sphericity ($\varepsilon = .84$ for the main effect of time*height).

Table 4: Mean (± SD) for reactive strength index during drop jumps

	Reactive Strength Index (mm/ms)								
	30cm		45cm		60cm		Mean RSI Values		% diff means
Group	Pre	Post	Pre	Post	Pre	Post	Pre	Post	
LPG	1.26±0.35	1.40±0.30	1.33±0.40	1.45±0.38	1.26±0.35	1.48±0.33	1.28±0.36	1.44±0.33	+12.5±2.17
HPG	1.23±0.33	1.30±0.31	1.26±0.36	1.36±0.38	1.25±0.42	1.37±0.34	1.25±0.35	1.34±0.34	+7.2±3.35
CON	0.84±0.18	0.81±0.21	0.91±0.24	0.85±0.22	0.83±0.22	0.87±0.33	0.86±0.21	0.84±0.25	-2.23±2.34

There was an overall significance in the interaction effect between group* time (F =4.01, $p < 0.05$). Bonferroni post hoc analysis indicated that the LPG training group demonstrated a significance ($p = 0.002$) from the control group, whilst the HPG training group ($p = 0.009$) also demonstrated a significant difference from the control group. However, there was no significant difference between those in the LPG training group and the HPG training group. Pre and Post test results for RSI at the different drop heights can be seen in Figure 2.1.

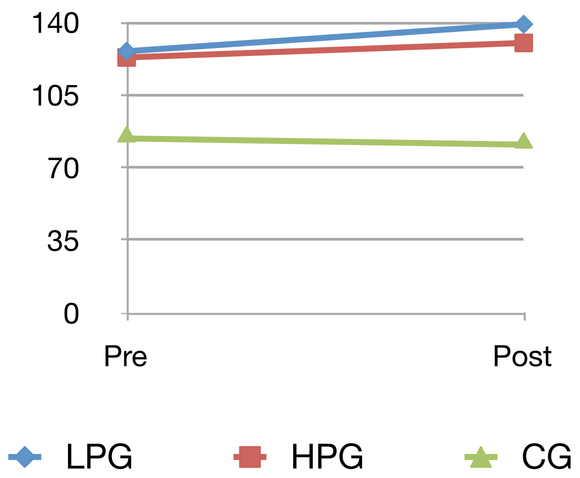

Figure 2.1 (a) 30cm Drop Height RSI

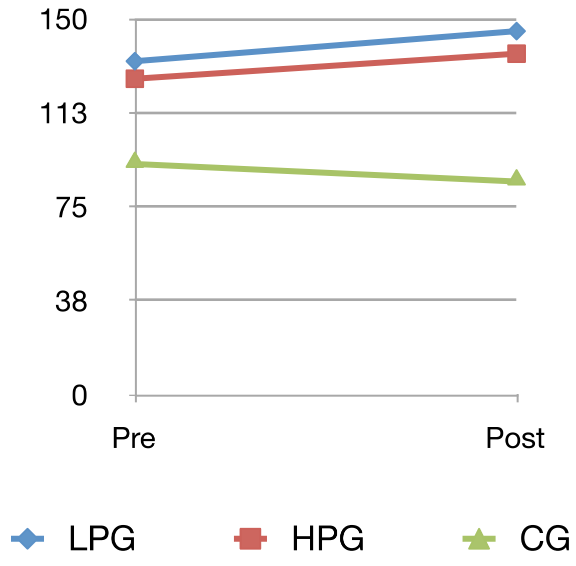

Figure 2.1 (b) 45cm Drop Height RSI

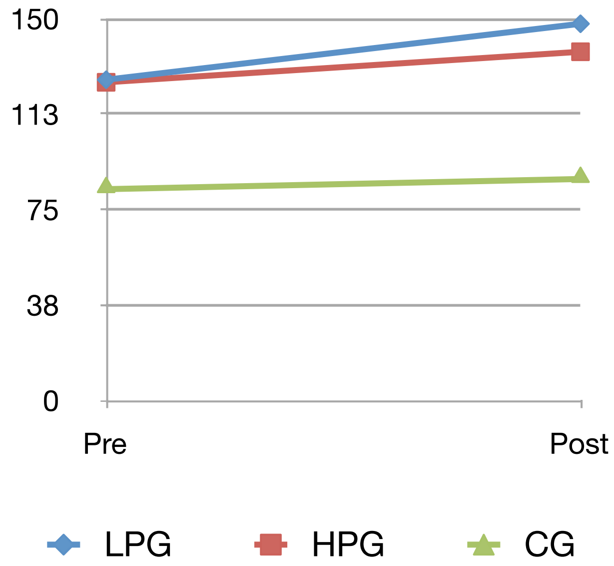

Figure 2.1 (c) 60cm Drop Height RSI

There was no significant effect on jump heights either by group or time with significance being reported as $p > 0.05$ in all cases. Overall RSI and pre and post jump height and contact time results can be seen in figure 2.2

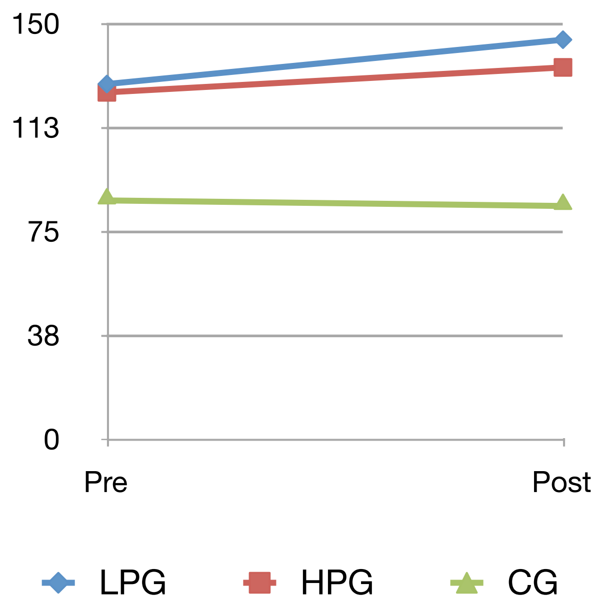

Figure 2.2 (a) Overall RSI

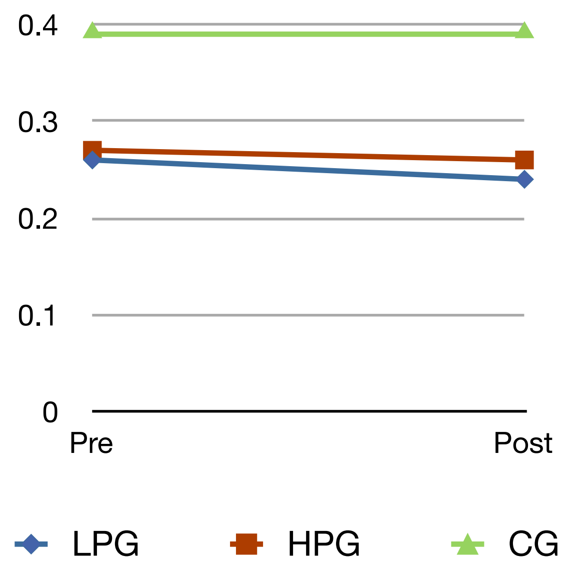

Figure 2.2 (b) Contact Time

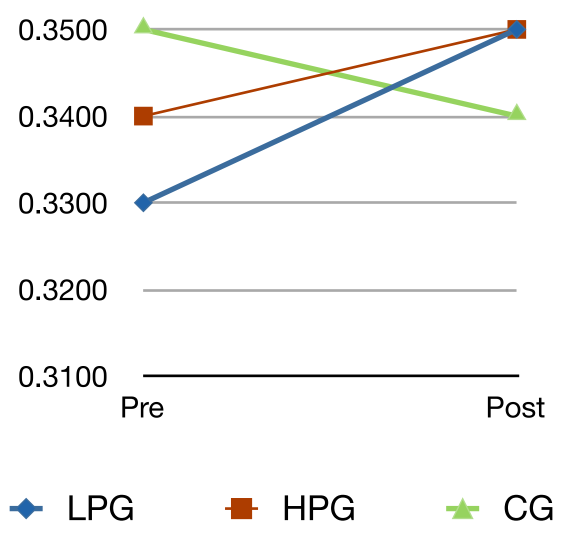

Figure 2.2 (b) Jump Height

It is evident from the above figures that although there is no significant difference reported between the LPG group and HPG group, the percentage difference improvement of the two groups should be noted: LPG - 12.5%, and HPG - 7.2%.

4.3 Leg Stiffness

A between group repeated measures ANOVA [Group (3) x Time (2)] was conducted to explore the impact of a low volume plyometric training programme and a high volume plyometric training programme on leg stiffness. Means (± standard deviations) for leg stiffness for each group are shown in table 5.

Table 5. Mean (±SD) Leg Stiffness Values

	Leg Stiffness (kN .m^{-1})		
Group	Pre	Post	% Diff Means
LPG	35.20±8.62	36.06±5.47	+2.44
HPG	35.44±5.82	38.81±6.63	+9.51
CON	34.54±7.67	35.09±4.59	+1.59

No significant interaction effect between time*group or main effect were observed, although both experimental groups did see an increase in post testing values (F = 1.39, p = .25) with a small effect size demonstrated for measures of time*group and time. Partial Eta Squared measured using Wilk's Lambda = 0.033 and 0.053 respectively.

Chapter Five – Discussion

As identified earlier in the dissertation the aim of the proposed study was to identify whether similar SSC performance benefits are gained from a low volume plyometric programme and a high volume plyometric programme for a specific population, namely collegiate rugby union players. The study found that in terms of RSI both LPG and HPG groups demonstrated a significant difference in relation to the CON group. Although there was no significant difference reported between the LPG and HPG group, the percentage increase of the groups (LPG - 12.5%, and HPG -7.2%) was of note and will be discussed within this chapter. In relation to leg stiffness, neither experimental group reported a significant increase in relation to the CON group, although again the percentage increases in performance were of note (LPG - 2.4%, HPG - 9.7%).

Thave been a plethora of studies which have investigated the effect of plyometric programmes on a range of performance functions including jumping ability (Makaruk, et al 2010; Dodd and Alvar, 2007), sprint times (Ronnestad, et al, 2008), muscle function (Markovic, et al, 2007) running economy (Turner et al, 2003) and agility (Meylan and Malatesta, 2009). However despite the number of studies outlining the effects of plyometric programmes, there is still a lot of confusion in relation to the relevant variables that make up the plyometric training programme and the optimum volume for a plyometric programme still remains unclear.

There are also a range of methods by which the plyometrics programmes are tested with performance outcomes such as vertical jump height, counter movement jump and drop jump amongst the most common (Markovic, et al, 2007; Holcolmb, et al, 1996; Makaruk, Winchester, Sadowski, Czaplicki and Sacewicz, 2011). As plyometric training is a training method which is often used to enhance the development of explosive movements which utilise SSC function, the use of RSI and leg stiffness are both measures which are useful in the identification of SSC capacity, would seem a sensible choice of outcome measure, although current literature which uses them within plyometric training studies is relatively rare.

The aim of the current study was to use leg stiffness and RSI to measure the effects of two different volumes of plyometric training over a six week period. One volume being a high volume group (HPG) and the other a low volume group (LPG). The HPG group carried out a total of 1920 contacts across the six week programme (160 contacts per session, 320 contacts per week). The LPG group carried out a total of 480 contacts across the whole programme (40 contacts per session, 80 contacts per week).

The results of the current study revealed that both HPG and LPG groups demonstrated significant improvements in RSI values when compared to the control group. The results also demonstrated that there was no significant difference between the HPG and LPG group. This suggests that the relevant training programmes significantly improved RSI performance and that the low volume programme was as successful at eliciting improvements in RSI as the high volume programme. Results also revealed that there were no significant differences in leg stiffness values in any of the experimental groups compared to the control group following the plyometric programmes, although results for both experimental groups did demonstrate a trend to increased performance.

5.1 Reactive Strength Index

Results revealed the both the high volume programme and low volume programme were successful at eliciting a significant training effect in relation to the control group. There was no reported significant difference between the training effect of the HPG and the LPG, although it has been noted that the percentage performance increase of both groups is worthy of further discussion. The percentage increase of the LPG was 12.5% as opposed to the 7.2% increase of the HPG group. In terms of performance a further

5% increase in performance would definitely be of note to practitioners, especially when aligned to the SDs for both groups. The LPG group had a smaller SD which suggests that all people in the group were eliciting similar training effects, whilst the larger SD found within the HPG groups suggests that there are larger individual differences within the group. This result suggests that the same or better training effect can be accomplished with a low volume training programme as with a high volume training programme (in this case 480 overall contacts as opposed to 1920 contacts). These data demonstrate a similar result to that of Saez, Saez de Villarreal, et al (2008), who's study indicated that a low (420 total contacts) and moderate (840 contacts) frequency plyometric programme produced greater jumping and sprinting gains than a high (1680 contacts) frequency programme. However it must be identified here that the focus of their study was frequency rather than volume. Also it is of note that within their study, the training programme consisted only of drop jumps.

From the results of the current study, it can be suggested that a low volume plyometric programme produces similar performance enhancements in terms of reactive strength as a high volume programme, yet with a greater efficiency (25% of the total for HPG). The results would also suggest that increasing the number of contacts within a programme would not conceptually be the correct course of action to increase reactive strength capabilities in collegiate rugby players. The results would also support a suggestion by both Saez-Saez de Vaillarreal, et al (2008) and Sankey, et al (2008), who suggest that there may be an minimal training threshold required to gain a significant performance improvement and after which further training is no longer advantageous.

The results are contradictory to another study carried out by a number of the same authors (Saez- Saez de Villarreal, 2009), who carried out a meta- analysis of plyometric training variables to increase jump height. They suggest that in order to maximise the possibility of eliciting significant training effects, programmes should be designed to include volumes of more than 10 weeks, with at least 20 sessions and with at least 50 jumps of a high intensity nature in each session.

The current study would have elicited similar results to those suggested by Saez-Saez de Vaillarreal (2009), with just fewer than 50% of the suggested minimum contacts. This suggests that the results of this study could be of significant practical importance to strength and conditioning coaches, when looking to plan effective and efficient training programmes. It must be remembered, however, that the results from this current study were revealed using a group of collegiate rugby players, and so the results may not be generalisable to other populations, such as elite rugby players or untrained participants.

As the RSI is a measure of SSC capability (Flanagan and Comyns, 2008), it can be proposed that the participants in both the HPG and LPG groups will have developed increased levels of SSC performance. In order to increase SSC performance and be more efficient at overcoming eccentric forces, there are a number of potential contributing factors to this increase in performance. These include; increased neural excitation before the concentric action, giving a greater potentiation effect, increased utilisation of stored elastic energy in the musculotendinous unit, a desensitisation of the Golgi-tendon organ’s inhibitory response and an increase in the reflex contributions of the muscle spindles (Flanagan and Comyns).
The results obtained for RSI would seem to contradict the report of Jeffreys and Turner (2010) who suggest it may take up to 4 months of plyometric training to inhibit the Golgi-tendon organ and utilise the potentiation caused by the activation of muscle spindles.

5.2 Leg Stiffness

Results revealed that there were no significant increases in leg stiffness as a result of the HPG or LPG, although the results did demonstrate increases in performance of 9.51% in the HPG and 2.44% in the LPG. A small effect size demonstrated for both experimental groups, LPG - 0.033 and HPG 0.053 respectively. Although this improvement exists, further analysis of the data reveals that the reaction to the training programmes was found to be individualised with some participants increasing considerably, whilst others demonstrated no improvement and some even showed a decrement in their performance levels. This result is similar to that of Hunter and Smith (2007) cited in De Ste Croix (2012) who whilst using a fatigue protocol, found within their study that some showed improvement whilst others demonstrated no increase or even a decrease in stiffness performance.

It may be seen as somewhat surprising that as leg stiffness is so closely linked to SSC function that participants in both experimental groups saw a significant increase in performance of RSI values whilst no significant increases were detected in leg stiffness. However, there are some contributory factors that may help to explain the lack of significant improvement.

Wilson and Flanagan (2008) warn that when examining scientific literature that care needs to be taken when interpreting results as readers need to be aware that leg stiffness is modulated depending on the specific demands of any particular task. They also point out that movements that differ only slightly may engender significant differences in leg stiffness.

In Hobara's (2010) study of leg stiffness adjustment for a range of hopping frequencies, it was identified that as hopping frequencies increased then leg stiffness increased. Whilst undertaking both the testing and the training programme, all movements were carried out at the preferred frequency of the participant and so they may not have had the opportunity to carry out movements where an increase in leg stiffness was needed.

Within the same study, the authors also identified that the increase in leg stiffness was mainly due to the decrease in vertical displacement of the COM. They propose that as the hopping frequency increases, the stiffness of the spring-mass system increases and the displacement of the COM decreases so that contact time is minimised and the ability is created to bounce off the ground in less time. Within the training programme, whilst participants were encouraged to minimise contact time and jump as high as possible, there was no particular attention paid to the amount of COM displacement and as a result, this may have had an impact on the stiffness developed within the training sessions.

Hobara, et al (2010) also suggest that there was a significant difference in the hip angle when an increase in frequency and a subsequent increase in stiffness was observed. They identified that a stiffer landing was achieved by adopting a more erect posture. Whereas the participants of the study adopted a more erect posture for the hopping test, they did not undertake any specific plyometric exercises where a more erect posture was adopted and it is postulated that again, this may have had an effect on their ability to develop greater levels of leg stiffness.

In Kuitenen, et al’s (2011) study on leg stiffness in hopping, they also allowed the participants to choose their own hopping frequency as in the current study. They suggest that participants accommodate their hopping frequency in order to maintain their leg stiffness despite any increase in hopping intensity. They go on to suggest that adjustments may occur in what seems to be similar hopping conditions and that participants prefer to select an ‘optimal’ leg stiffness which is independent of differences in hopping intensity, where frequency of hopping is not a constraint. This suggests that even within the testing conditions carried out within the present study, participants could select their ‘optimum’ stiffness based on the fact that they were able to hop at their preferred frequency.

Chapter Six – Conclusion

The aim of the proposed study was to identify whether similar SSC performance benefits are gained from a low volume plyometric programme and a high volume plyometric programme for a specific population, namely collegiate rugby union players.

In revisiting the aims, it is possible to see that similar benefits were gained from a low volume plyometric programme and a high volume programme. Measures of RSI and leg stiffness were taken prior to and post a six week programme which was undertaken as part of a periodised plan by a group of collegiate rugby players.

Results revealed that significant increases were gained by both the low volume group and the high volume group in terms of RSI values, when compared to the control group, with no significant differences between the experimental groups. Results revealed that there were no significant differences between the experimental groups for leg stiffness values. Although a trend was evident for increase in leg stiffness values was apparent in both groups, none of these improvements was significant.

It is suggested that the improvements in RSI will be attributed to more efficient SSC function. There are a number of potential contributory factors which include; increased neural excitation before the concentric action, giving a greater potentiation effect, increased utilisation of stored elastic energy in the musculotendinous unit, a desensitisation of the Golgi-tendon organ’s inhibitory response and an increase in the reflex contributions of the muscle spindles.

The results reveal that similar training benefits can be gained from a low volume plyometric training programme as a high volume training programme, as the low volume group undertook a quarter of the contacts that were undertaken by the high volume group. This may have potential benefits for the strength and conditioning professional when designing and implementing a programme that meets the needs of the physiological demands of the game, in terms of the development of strength and power, whilst also carrying out both game related practices and associated metabolic training.

Although it is not possible to identify why no significant gains were made in terms of leg stiffness values, it is possible to postulate that this was due to a number of factors which may include; not enough specificity of movements within the plyometric programme itself, the decision to utilise the subjects' preferred frequency whilst hopping.

6.1 Limitations

When conducting any piece of research it is important to note that there will be limitations to that study which need to be considered before any generalisation of results can be contemplated. Within this study it is worth noting that although it was pleasing to complete a training study over a 6 week period, it needs to be considered that the overall numbers taking part in the study (n = 29) is relatively small, and as such a similar piece of research with larger numbers would be advantageous.

It is also important to consider that the current study looked at differing volume plyometric training programmes with a population of collegiate rugby players, and whilst the results may be of specific relevance to strength and conditioning coaches and practitioners, there needs to be acknowledgement of the fact that different populations may elicit different results.

It is also worth noting that the author utilised a random sampling technique within this study, which resulted in the control group reporting very low on RSI scores. Block randomisation could have been utilised, where the scores from the pre -test can be used, so that the standard of each group is similar before the intervention is put into place. So for example using the scores from the RSI and ranking the participants from

1 - 59, participants could have been grouped using a ABC, BAC, CBA, ACB etc method, this would endure that all groups are of a similar standard.

6.2 Practical Applications

The current study has demonstrated that it is possible to improve reactive strength capabilities to a significant level and leg stiffness to a lesser degree via the use of a low volume plyometric programme. The low volume programme elicited the same or even better (12.5% increase for the LPG group, as opposed to 7.2% increase for the HPG group) performance improvement in RSI values as a high volume programme whilst undertaking only a quarter of the volume. This suggests that strength and conditioning coaches may be able to benefit from the ability to develop more time efficient and effective plyometric programmes. This would also be of potential benefit in developing and maintaining high levels of strength and power, whilst simultaneously completing high volumes of both metabolic training and technical and tactical sessions.

6.3 Implications for further research

In terms of study design the author suggests that further research needs to be carried out in relation to the effects of plyometrics on leg stiffness. When taking into account the findings of this study it is suggested that a plyometric training programme is designed to include more ‘stiffness’ based exercises, which have decreased displacement of COM and are carried out utilising a more upright posture.

The author would also suggest that further research is undertaken whereby testing of leg stiffness involves testing at a range of different frequencies, as this would potentially negate the suggestion of adjustments being made to the frequency to maintain the subjects’ preferred ‘optimal’ stiffness levels.

As the improvements have been made in RSI values within a reasonably short time frame and also benefitting from a low volume plyometric programme, the author would also suggest a study which investigates the detraining effect of the low volume plyometric programme.

As noted earlier, the sample size utilised within this study, although relavant, was still relatively small. It would therefore be useful to carry out a similar study with a larger sample size. The ability to elicit the same or better results to RSI scores with a quarter of the plyometric training volume would be of use to a number of strength and conditioning practitioners working a in a number of sports and so further studies in other sports and with specific populations (recreational or elite) would also be beneficial.

6.4 Hypothesis testing

In relation to the hypotheses identified in the introduction of the dissertation:

Low volume plyometric training will elicit similar significant improvements in reactive strength as high volume plyometric programmes.

Low volume plyometric training will elicit similar significant improvements in leg stiffness as high volume plyometric programmes.

Null Hypotheses

Low volume plyometric training will not elicit similar significant improvements in reactive strength as high volume plyometric programmes.

Low volume plyometric training will not elicit similar significant improvements inleg stiffness as high volume plyometric programmes.

It is evident that the first hypothesis has been confirmed and it is suggested that low volume plyometric volumes may even elicit a better improvement in reactive strength, although further research is needed in this area.

In relation to leg stiffness, it has been the null hypothesis that has been confirmed in this case as the improvements were not statistically significant, although it is noted that both groups did show improvement and again it is suggested that further research is carried out in this area.

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APPENDICES

Participant Information Sheet

1. **Research Project Title:**

An investigation into the effect of varying plyometric volume on Reactive Strength and Leg Stiffness in collegiate rugby players

2. **Invitation paragraph**

You are being invited to take part in a research project. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

3. **What is the purpose of the project?**

a) To what extent do varying plyometric volumes influence reactive strength capability in collegiate rugby players?

b) To what extent do varying plyometric volumes influence leg stiffness in collegiate rugby players?

4. **Why have I been chosen?**

You have been highlighted by someone known to the research team that is playing rugby at an university level

5. **Do I have to take part?**

Taking part in the research is entirely voluntary. If you do decide to take part, you will be given this information sheet to keep (and asked to sign a consent form). If you decide to take part you are still free to withdraw at any time without giving a reason.

6. **What do I have to do?**

All you have to do is take part in a testing session at the beginning and end of a 6 week training programme based around plyometrics.

7. **What are the possible disadvantages and risks of taking part?**

There are very minimal additional risks to your normal coaching practice.

8. **What are the possible benefits of taking part?**

We hope that in examining the findings of our research, you will be able to learn something about your training programmes. For example, we hope to show you the ratio between the amount of plyometrics you undertake and the benefits of that particular volume.

9. **What happens when the research study stops?**

In the very unlikely event that the research has to stop for any reason, we will notify you immediately and explain why this has occurred.

10. **What if something goes wrong?**

Should you feel the need to complain about anything that happens as a result of participating in the research, you should either contact Dr. Rhodri Lloyd(contact details below) or the Faculty's Research Director, Dr. Mark de ste Croix on 01242 715159 or mdestecroix@glos.ac.uk.

11. **Will my taking part in this project be kept confidential?**

All information collected will be kept strictly confidential. Members of the research team will have access to your anonymised data; however, your name will not be able to be linked with the research materials and you will not be identified or identifiable in the report or reports that result from the research.

12. **What will happen to the results of the research project?**

We are hoping that the results of the research project will be presented at a number of conferences in the UK over the next two years. We also hope to publish the findings in at least one academic journal. You will be presented with a copy of the report findings on completion of the project.

13. **Who is organising and funding the research?**

This project is internally funded by the University of Gloucestershire.

14. **Who has reviewed the project?**

The project has been reviewed by the University of Gloucestershire Faculty of Applied Sciences Research Ethics Panel.

15. Contact for further information

Dr. Rhodri Lloyd

Faculty of Applied Sciences

University of Gloucestershire

Oxstalls Campus

Oxstalls Lane

GL2 9HW

Email: rlloyd2@glos.ac.uk

Tel: 01242 715200

Thank you for taking the time to read through this information – we sincerely thank you for considering contributing to our project. We very much hope that you will be able to be a part of the research.

UNIVERSITY OF GLOUCESTERSHIRE

Consent Form

Title of Research Project: An investigation into the effect of varying plyometric volume on Reactive Strength and Leg Stiffness in collegiate rugby players.

Name of Researcher: Mark Jeffreys

Participant Identification Number for this project:

Please initial box

1. I confirm that I have read and understand the information sheet dated 21st October 2011 explaining the above research project and I have had the opportunity to ask questions about the project.

2. I understand that my participation is voluntary and that I am free to withdraw
at any time without giving any reason and without there being any negative consequences. If I wish to withdraw, I can telephone or email the researcher on 01242 715196 or mjeffreys@glos.ac.uk or simply decline in person on the day of any given observation.

3. I understand that my responses will be kept strictly confidential. I understand
that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research.

UNIVERSITY OF GLOUCESTERSHIRE

SPORT AND EXERCISE LABORATORIES

Health Questionnaire

About this questionnaire:

The purpose of this questionnaire is to gather information about your health and lifestyle. We will use this information to decide whether you are eligible to take part in the testing for which you have volunteered. It is important that you answer the questions truthfully. The information you give will be treated in confidence. Your completed form will be stored securely for 5 years and then destroyed.

Section 1, which has been completed by the tester, provides basic information about the testing for which you have volunteered. Sections 2 to 7 are for you to complete: please circle the appropriate response or write your answer in the space provided. Please also complete section 8. Sections 9 and 10 will be completed by the tester, after you have completed sections 2 to 8.

Section 1: The testing *(completed by tester)*

To complete the testing for which you have volunteered you will be required to undertake:

Moderate exercise (i.e., exercise that makes you breathe more heavily than you do at rest but not so heavily that you are unable to maintain a conversation) ☐

Vigorous exercise (i.e., exercise that makes you breath so heavily that you are unable to maintain a conversation) ☐

The testing involves:

Walking	☐	Generating or absorbing high forces through your arms	☐
Running	☐	Generating or absorbing high forces through your shoulders	☐
Cycling	☐	Generating or absorbing high forces through your trunk	☐
Rowing	☐	Generating or absorbing high forces through your hips	☐
Swimming	☐	Generating or absorbing high forces through your legs	☐
Jumping	☐		

Section 2: General information

Name: .... Sex: M F Age:

Height (approx.): ....……..………..   Weight (approx.):

Section 3: Initial considerations

1. Do any of the following apply to you?
No Yes

a) I have HIV, Hepatitis A, Hepatitis B or Hepatitis C
b) I am pregnant
c) I have a muscle or joint problem that could be aggravated by the testing described in section 1
d) I am feeling unwell today
e) I have had a fever in the last 7 days

(If you have answered "Yes" to question 1, go straight to section 8)

Section 4: Habitual physical activity

2a. Do you typically perform moderate exercise (as defined in section 1)

No Yes

for 20 minutes or longer at least twice a week?

2b. Have you performed this type of exercise within the last 10 days?
No Yes

3a. Do you typically perform vigorous exercise (as defined in section 1)

No Yes

at least once a week?

3b. Have you performed this type of exercise within the last 10 days?
No Yes

Section 5: Known medical conditions

4. Do **any** of the following apply to you?
No Yes

a) I have had Type 1 diabetes for more than 15 years
b) I have Type 1 diabetes and am over 30 years old
c) I have Type 2 diabetes and am over 35 years old

5. Have you ever had a stroke?
No Yes

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

7. Do **both** of the following apply to you?
No Yes

a) I take asthma medication
b) I have experienced shortness of breath or difficulty with breathing in the last 4 weeks?

8. Do you have any of the following: cancer, COPD, cystic fibrosis, No Yes
other lung disease, liver disease, kidney disease, mental illness, osteoporosis, severe arthritis, a thyroid problem?

(If you have answered "Yes" to any questions in section 5, go straight to section 8.)

Section 6: Signs and symptoms

9. Do you often have pains in your heart, chest, or the surrounding areas?
No Yes

10. Do you experience shortness of breath, either at rest or with mild exertion?
No Yes

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

12. Have you, in the last 12 months, experienced difficulty with breathing
No Yes
when lying down or been awakened at night by shortness of breath?

13. Do you experience swelling or a build up of fluid in or around your ankles?
No Yes

14. Do you often get the feeling that your heart is racing or skipping
No Yes
beats, either at rest or during exercise?

15. Do you regularly get pains in your calves and lower legs during exercise
No Yes
that are not due to soreness or stiffness?

16. Has your doctor ever told you that you have a heart murmur?
No Yes

17. Do you experience unusual fatigue or shortness of breath during
No Yes
everyday activities?
(If you have answered "Yes" to any questions in section 6, go straight to section 8)

Section 7: Risk factors

18. Does **either** of the following apply to you?
No Yes

a)I smoke cigarettes on a daily basis
b)I stopped smoking cigarettes on a daily basis less than 6 months ago

19. Has your doctor ever told you that you have high blood pressure?
No Yes

20. Has your doctor ever told you that you have high cholesterol? No Yes

21. Has your father or any of your brothers had a heart attack,
No Yes
heart surgery, or a stroke before the age of 55?

22. Has your mother or any of your sisters had a heart attack,
No Yes
heart surgery, or a stroke before the age of 65?

23. Do **any** of the following apply to you?
No Yes

a) I have had Type 1 diabetes for less than 15 years
b) I have Type 1 diabetes and am 30 or younger
c) I have Type 2 diabetes and am 35 or younger

Section 8: Signatures

Participant: ………………………………………………….. Date: ....…….
…….......

Guardian*: ....……………….......... Date: ....………
…........

(*Required only if the participant is under 18 years of age)

Section 9: Additional risk factors (to be completed by the tester if relevant)

24. Is the participant's body mass index >30 kg/m^2?
No Yes

25. Has the participant answered no to questions 2a **and** 3a?
No Yes

Section 10: Eligibility (to be completed by the tester)

26. Is the participant eligible for the testing? No Yes

Name (of tester): ....……….........……………………

Signature: ………………………………………………… Date: ………...……….
…...