MONITORING RECOVERY FROM MUSCLE DAMAGE IN RUGBY UNION
Table of Contents

List of Tables

List of Figures

Acknowledgements

Abstract

CHAPTER ONE

Introduction

CHAPTER TWO

Literature Review

2.1. Demands of Rugby Union

2.1.1. Physiological Demands of Rugby Union Competition

2.1.2. Physical Demands of Rugby Union Competition

2.2. Rugby Union Participation and Muscle Damage

2.2.1. Mechanisms of Muscle Damage

2.2.2. Muscle Damage from Rugby Training

2.2.3. Muscle Damage from Rugby Competition

2.2.4. Consequences of Muscle Damage

2.2.4.1. Athletic Performance

2.2.4.2. Risk of Injury

2.3. Managing Training Load
2.3.1. Importance of Measuring Training Load 14
2.3.2. Quantifying Training Load 15
2.3.3. Monitoring Training Intensity 17
  2.3.3.1. Heart Rate 17
  2.3.3.2. Subjective Assessments 17
  2.3.3.3. Global Positioning Systems 19
2.4. Assessing Recovery From Muscle Damage 20
  2.4.1. Factors Affecting Recovery from Muscle Damage 20
  2.4.2. Accurately Measuring Recovery from Muscle Damage 21
    2.4.2.1. Enzymatic and Hormonal Markers of Recovery from Muscle Damage 21
    2.4.2.2. Physical Performance Measures of Recovery from Muscle Damage 22
2.5. Implications of Accurately Monitoring Recovery From Muscle Damage 24
  2.5.1. Recovery Interventions 24
  2.5.2. Longitudinal Monitoring of Recovery 26
  2.5.3. Practicality of Monitoring Recovery 27

CHAPTER THREE

Methods and Procedures

3.1. Study One – Experimental Study 30
  3.1.1. Participants 30
3.1.2. Research Design 30
3.1.3. Preliminary Testing 31
3.1.4. Weightlifting Loads and Conditions 31

3.2. Study Two – Applied Study 31
3.2.1. Participants 31
3.2.2. Research Design 32
3.2.3. Preliminary Testing 32

3.3. Testing Procedures 33
3.3.1. Experimental Procedures 33
3.3.2. Testing Interventions 34
3.3.3. Measuring Procedures 35
  3.3.3.1. Force Plate Data 35
  3.3.3.2. Muscle Damage 37

3.4. Statistical Analysis 37

CHAPTER FOUR

Results 38

4.1 Experimental Study 38
  4.1.1. Creatine Kinase 38
  4.1.2. Jump Performance 38
  4.1.3. Relationship Between Jump Performance and Creatine Kinase 41

4.2. Applied Study 43
### 4.2.1. Creatine Kinase

43

### 4.2.2. Jump Performance

43

### 4.2.3. Relationship Between Jump Performance and Creatine Kinase

45

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**CHAPTER FIVE**

Discussion and Conclusion

5.1. Study One 46

5.2. Study Two 48

5.3. Inter-Study Comparisons 49

5.4. Limitations of the Study 51

5.4.1. Quantifying Game Load and Collisions 51

5.4.2. Limitations of CK 52

5.5. Practical Applications 52

5.6 Conclusion 52

References 54

Appendices 78
List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 2.1</td>
<td>The 10-Point Rating of Perceived Exertion Scale (Borg et al., 1987)</td>
<td>18</td>
</tr>
<tr>
<td>Table 3.1</td>
<td>Subject Physical Characteristics (n=10)</td>
<td>30</td>
</tr>
<tr>
<td>Table 3.2</td>
<td>Subject Physical Characteristics (n=10)</td>
<td>32</td>
</tr>
<tr>
<td>Table 3.3</td>
<td>Jump Protocol</td>
<td>33</td>
</tr>
<tr>
<td>Table 4.1</td>
<td>Study One Subject CK</td>
<td>38</td>
</tr>
<tr>
<td>Table 4.2</td>
<td>Study One Subject Mean Static Jump Performance</td>
<td>39</td>
</tr>
<tr>
<td>Table 4.3</td>
<td>Study One Subject Mean Dynamic Jump Performance</td>
<td>39</td>
</tr>
<tr>
<td>Table 4.4</td>
<td>Study One Effect Sizes</td>
<td>40</td>
</tr>
<tr>
<td>Table 4.5</td>
<td>Study Two Subject CK</td>
<td>43</td>
</tr>
<tr>
<td>Table 4.6</td>
<td>Study Two Subject Mean Static Jump Performance</td>
<td>43</td>
</tr>
<tr>
<td>Table 4.7</td>
<td>Study Two Subject Mean Dynamic Jump Performance</td>
<td>44</td>
</tr>
<tr>
<td>Table 4.8</td>
<td>Study Two Effect Sizes</td>
<td>44</td>
</tr>
</tbody>
</table>

List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1.1:</td>
<td>The Force Velocity Curve (Adapted from Tilllaar, 2004)</td>
<td>1</td>
</tr>
<tr>
<td>Figure 2.1:</td>
<td>The Force Velocity Curve (Adapted from Tilllaar, 2004)</td>
<td>6</td>
</tr>
</tbody>
</table>
Figure 2.2: Relationship Between the Number of Tackles and Plasma Creatine Kinase Activity (Takarada, 2003)

Figure 3.1: Study One Testing Schedule

Figure 3.2: Study Two Testing Schedule

Figure 3.3: Jump Protocol

Figure 4.1: CK and RSI Results Across all Testing Intervals

Figure 4.2: DJ RSI Percentage Change

Figure 4.3: DJ Flight Time Percentage Change

Figure 4.4: DJ Jump Height Percentage Change
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Abstract

**INTRODUCTION** Acute and long-term decreases in athletic performance as a result of muscle damage from participating in rugby union, are well documented. To date, research designed to measure recovery from muscle damage using jump performance has adopted a wide range of methodologies, often in experimental settings. The purpose of this study was to investigate performance decrements of rugby union players in a variety of jump activities after experiencing muscle damage in an experimental (study 1) and applied (study 2) environment. **METHODS** In both studies subjects recorded a baseline squat jump (SJ), countermovement jump (CMJ), drop jump from 30cm (DJ) and submaximal hop (SH) during which the force (F), power (P), velocity (V), ground contact time (tc) and flight time (tf) were measured alongside baseline creatine kinase (CK) levels. Peak force, peak power output, leg stiffness, reactive strength index (RSI), peak velocity and jump height were recorded for each of the given jumps. All jumps were then retested 4min, 1d, 2d, 3d and 7d post a stimulus designed to cause muscle damage with CK recorded at all intervals excluding the 4min interval. In study one subjects completed five sets of ten repetitions of the lowering portion of a back squat at 95% of their back squat 1-RM with a five second eccentric contraction. In study two subjects participated in a full competitive rugby union match. In both studies jump variables were analysed using separate single-factor repeated-measures analyses of variance and correlation analysis between CK and jump variables was carried out using a Pearson’s correlation. The effect size of the change between intervals was also recorded for each variable measured. **RESULTS** In study one, a very large (ES = 3.53) increase in CK was recorded from 256±158 U/I to 813.8±577 U/I, which although not significant (p>0.05), remained elevated until returning to below baseline levels at 7d post intervention. All jump activities experienced significant decreases in performance (p<0.05) across various intervals with DJ RSI displaying the highest correlation with changes in CK over the seven-day period (r=-.61, p<0.01). In study two a very large, but non-significant (p>0.05, ES = 1.93) peak from baseline CK (257.9±91.2 U/I) was recorded at 24hrs post-competition (434±207.8 U/I), which remained elevated before returning to below baseline levels 7d post competition. No jump activities experienced significant decreases in performance. **CONCLUSION** The results suggest that while jump activities can be used to identify the state of
recovery from muscle damage, particularly the RSI of a 30cm DJ, this is dependent on the stimulus used to instigate muscle damage. It can also be concluded that results obtained from an experimental setting may not be applicable to an applied ‘real world’ environment. Strength and conditioning practitioners therefore must assess whether or not the chosen jump method is suitable to the mechanism of muscle damage experienced by their athletes before implementing a monitoring programme using athletic performance measures.
CHAPTER 1

INTRODUCTION
An athlete participating in rugby union can expect to experience muscle damage, either as a result of training (Twist and Eston, 2005) or from taking part in a competitive match (Higgins et al., 2013a). The detrimental consequences of muscle damage include acute (Barnett, 2006) and long-term decreased athletic performance (Cheung et al., 2003) the most concerning of which is the loss of concentric and eccentric strength at high velocities. Rugby union is a sport that requires players to be able to perform a diverse range of movements at both ends of the force velocity curve, shown in Figure 1.1 below. As a result, the impact of a prolonged decrement in power output caused by muscle damage can have significant implications on rugby performance.

![Figure 1.1: The Force Velocity Curve (Adapted from Van Den Tillaar, 2004)](image)

While blood markers such as creatine kinase are suggested as the most reliable and valid methods for assessing muscular damage, it is often expensive, intrusive and there is a large degree of variation among individuals (Brancaccio et al., 2007) which often has a poor temporal relationship with performance and perceptual changes (Twist and Highton, 2013). As a result, blood borne markers are often combined with physical performance measures, such as jumping, which are suggested to provide an accurate, easy to implement, cost effective method of accurately monitoring the extent to which an athlete has recovered from muscle damage post exercise (Beneka et al., 2013).
Jump activities in particular are a suggested multi-joint performance measure, as they are easy and quick to implement (Nédélec et al., 2012). Furthermore, jumping ability has been linked to rugby union performance directly in that it has been shown to differentiate between playing level and speed abilities of players during competition (Cronin and Hansen, 2005; Hansen et al., 2011).

Given the importance of minimising the detrimental effects of muscle damage, strength and conditioning practitioners have adopted a range of methodologies that attempt to monitor the extent of an athlete’s recovery from muscle damage. However, to date, research across a variety of forms of the game, aiming to assess recovery from muscle damage as a result of rugby participation, has produced mixed results, implementing a wide variety of methodologies (McLean et al., 2010; Johnston et al., 2013, West et al., 2014). Consequently there is a lack of clarity as to which jump activity is most effective at measuring recovery from muscle damage.

Furthermore, the studies mentioned thus far were not performed in a controlled laboratory environment. To establish whether these performance decreases are due to muscle damage or other fatigue inducing mechanisms. Given the contrasting results found when comparing hormonal responses of rugby players in lab-based and applied studies (Elloumi et al., 2003) any future research intending to identify recovery from muscle damage should be conducted in both an applied an experimental setting.

Therefore, the aim of this study is to assess performance decrements in a variety of jump activities as a result of muscle damage in both an applied and laboratory setting. Should an effective measure be identified this would have an impact on athlete monitoring strategies for rugby union and also provide a standardised methodology for future research intending to assess recovery from muscle damage.
2.1. Demands of Rugby Union

2.1.1. Physiological Demands of Rugby Union Competition

The contents of this literature review will be based around research regarding the suitability of methods used to assess the extent of an athletes’ recovery from muscle damage and fatiguing activity. In addition, the terminology used within the review is in relation to the sport of rugby union.

Rugby is a team game involving frequent incidences of physical contact between opponents in which two teams of fifteen players (split into seven backs and eight forwards) will attempt to outscore each other in two 40 minute halves of play. Attempts to quantify the physiological demands of the sport include the use of time motion analysis (Duthie et al., 2005; Deutsch, Kearney and Rehrer, 2007) which is a non-intrusive method of video analysis that involves the quantification of movement patterns involved in sporting situations which provides information such as speeds, durations and distances of various locomotor patterns during the course of a game (Dobson and Keogh, 2007).

Duthie, et al., (2005) identified that high intensity activity accounts for 14% and 6% of game time for forwards and backs, respectively. It is important to note that the frequency and duration of the work and recovery periods can vary significantly depending on the player position (Deutsch, Kearney and Rehrer, 2007). In addition to this the authors also state that movements in rugby union can vary between high force-low velocity (e.g. scrummaging), high velocity-low force (e.g. sprinting) and high force-high velocity (e.g. tackling).

However, time motion analysis, as a means of evaluating the physiological demands of sport is problematic and has a number of limitations including: the time taken to complete analyses, the subjectivity of defining movement categories, parallax error and a lack of reliability (Dobson and Keogh, 2007). In an attempt to account for these discrepancies more recent studies have used global position system (GPS) units to measure the physical demands of team sports allowing for the intensity of activity and physiological loads placed upon players to be monitored in training and game situations (Cunniffe et al., 2009; Coughlan et al., 2011; Cahill et al., 2013).
Cunniffe et al., (2009) tracked one back (fly half) and one forward (Back Row) continuously during a team selection game using GPS software. The data revealed that players covered on average 6,953m during play, of this distance 37% was spent standing and walking, 27% jogging, 10% cruising, 14% striding, 5% high-intensity running and 6% sprinting; with the back performing a greater number of sprints (>20 km.h\(^{-1}\)) than the forward (34 vs 19). Conversely, the forward entered the lower speed zone (6-12 km.h\(^{-1}\)) on a greater number of occasions than the back (315 vs 229) but spent less time standing and walking (66.5% vs. 77.8%). Average distances for each sprint burst were 15.3m and 17.3m for forwards and backs respectively and players exercised at 80-85% of VO\(_{2}\) max during the course of the game with a mean heart rate of 172 beats per minute.

Coughlan et al., (2011) conducted a similar study but also took into account the number of contacts the two players were involved in, in addition to the locomotive data collected in the study presented previously by Cunniffe et al., (2009). The data revealed that the forward was subject to 838 impacts in a game with the back subjected to 573. The load of these impacts, estimated based on the body load of gravitation force experienced during the collision via accelerometer, was also higher for the forward, despite each player experiencing 174 and 30 severe impacts respectively. Similar results were seen in both studies in that the participants both covered greater distances in the second half compared to the first half.

While the information provided by the research of Coughlan et al., (2011) and Cunniffe et al., (2009) provides more accurate descriptions of the types of activity completed during rugby union competition than previous time motion analysis studies, it is suggested that any applied research studies that involve GPS match performance data must combine information from multiple teams to provide a more representative sample of physical match performance (Wisbury et al., 2010; Kempton et al., 2014). As both studies use small participant numbers to quantify rugby union performance, a greater subject and competition range is required to do this with greater accuracy. Cahill et al., (2013) sampled 98 elite players from eight English Premiership Clubs using global positioning systems during 44 competitive matches throughout the 2010/2011 season. Analysis revealed that the game is predominantly played at low speeds with little distance covered sprinting by either the backs (50 ± 76m) or the forwards (37 ± 64m).
The backs travelled greater (p<0.05) absolute and relative distances than the forwards. The scrum half covered the greatest total distance during a match (7098 ± 778m) and the front row the least (5158 ± 200m) with the back row covering the greatest distances at sprinting speed, particularly the number 8 position (77m). In the same year Quarrie et al., (2013) coded 763 payers from video recordings of 90 international matches played by the New Zealand national squad from 2004 to 2010. The authors highlighted that forwards sustained much higher contact loads per match than backs via scrums, rucks, tackles and mauls. Mean distance covered per match ranged between 5400-6300m with backs generally running further than forwards. Again, there were marked differences between positional groups in the amount of distance covered at various speeds. This study also studied distances covered by players at running speeds in excess of 5m/s and suggests that international players cover more distances in this speed range when compared to players competing at lower levels of the professional game.

In summary, rugby union competition involves periods of high intensity running / collision based activity interspersed with lower intensity aerobic activity and rest. It is also important to note that the frequency and duration of the work, severity of collisions and recovery periods can vary significantly depending on player position (Roberts et al., 2008).

2.1.2. Physical Demands of Rugby Union Competition

The diversity of movements that rugby union players are required to produce can be demonstrated using the force velocity curve (presented in Figure 2.1) which demonstrates that as the velocity of movement increases concentrically from zero velocity the force produced is decreased (Kraemer and Looney, 2012). For example, scrummaging is an activity that produces large amounts of force at low velocities (Bevan et al., 2010), the magnitude of which increases as the level of competition improves (Preatoni et al., 2013). However, a player that is required to scrummage will also be required to sprint at a high velocity, over varying distances, during competitive play (Cahill et al., 2013). The same player would also be subject to a large number of collisions throughout the course of the game (Coughlan, 2011), which involves the application of large forces at high velocities (Bevan et al., 2010).
This information highlights that, while this may vary according to position, all rugby union players are required to perform activities across the strength and power continuum, involving maximal strength, power and high velocity movements. From this it is fair to suggest that rugby union players are required to develop their capabilities of performing movements across the full range of the force velocity curve when attempting to optimise performance.

The intermittent nature of rugby union implies that the bioenergetic demands are met through both the anaerobic and aerobic metabolic pathways and that the ability to quickly recover from successful running efforts is critical to performance (Cunniffe et al., 2009; Coughlan et al., 2011; Cahill et al., 2013). This, coupled with the diverse physical stresses experienced during competition, means that training for rugby union must physically prepare players to cater to these demands (Duthie, 2006; Smart and Gill, 2013; Smart et al., 2014).

When reviewing the relationship between physical fitness and game behaviours in rugby union players Smart et al., (2014) state that physical conditioning programmes should be adapted to reflect the importance of speed, repeated sprint ability and body composition in the performance of key game behaviours during competition. Strength training has been shown to improve body composition and force production (Ahtiainen et al., 2003) as well as increasing muscular power (Ignjatovic et al., 2011). Furthermore, maximal strength, specifically, is often related to acceleration, overall movement velocity and jumping ability (Haff, 2012). All of which have been suggested to be key predictors of performance in rugby union (Smart et al., 2014).
The ability to express high rates of force development and high peak power outputs (PPO) is considered to be among the most important sports performance characteristics especially in activities that rely on jumping, change of direction and/or sprinting performance. These activities are central to success in rugby union (Haff & Nimphius, 2012; Kraemer and Looney, 2012), which is supported in the fact that PPO is significantly higher (p<0.001) in elite rugby union players in comparison to elite junior players (Baker, 2001; Hansen et al., 2011). It can therefore be suggested the ability to express muscular strength and PPO would be advantageous for rugby union performance.

2.2. Rugby Union Participation and Muscle Damage

2.2.1. Mechanisms of Muscle Damage

The combative nature of rugby union match play, combined with the intermittent high-intensity activity during competition is synonymous with repeated blunt force trauma, micro damage to skeletal muscle and post exercise muscle soreness (Gill et al., 2006). This soreness is commonly termed ‘delayed onset of muscle soreness’ (DOMS) which has been classified as a sensation of pain or discomfort occurring 1-2 days post exercise (Barnett, 2006) and is associated with: stiffness/swelling, a loss of muscle force generating capacity (Connolly et al., 2003) reduced glycogen resynthesis and increased predisposition to injury (Thompson et al., 1999).

A number of early theories have been proposed to explain the pain stimulus associated with DOMS which include: elevated lactic acid levels, muscle spasm, inflammation, enzyme efflux theories and other proposed models (Cleak and Eston, 1992; Gulick and Kimura, 1996). However, there is a general consensus amongst researchers that a single mechanism cannot explain the onset of DOMS. Cheung et al. (2003), integrate a variety of models in an attempt to provide an overview of such mechanisms of DOMS and how they interrelate, demonstrated below:

1. High tensile forces produced during eccentric muscle activity or trauma cause disruption of structural proteins in muscle fibres, particularly at the weakened z-lines. This is accompanied by excessive strain of the connective tissue at the myotendinous junction and surrounding muscle fibres (connective tissue damage theory and muscle damage theory).
2. Damage to the sarcolemma results in the accumulation of calcium (Ca$^{2+}$) that inhibits cellular respiration. ATP production is hindered and Ca$^{2+}$ homeostasis is disturbed. High Ca$^{2+}$ activates Ca$^{2+}$ dependent proteolytic enzymes that degrade the z-line of sarcomeres, troponin and tropomyosin (enzyme efflux theory).

3. Within a few hours there is a significant elevation in circulating neutrophils (inflammation theory).

4. Monocytes/macrophages peak in number post 48hrs. Upon exposure to the inflammatory environment, macrophages produce prostaglandin (PGE$_2$) that sensitises type III and IV nerve endings to mechanical, chemical or thermal stimulation (inflammation theory).

5. The accumulation of histamine, potassium and kinins from active phagocytosis and cellular necrosis in addition to elevated pressure from tissue oedema and increased local temperature could then activate nociceptors within the muscle fibres and the muscle tendon junction (inflammation theory).

6. These events lead to the sensation of DOMS. Soreness may be increased with movement as the increased intramuscular pressure creates a mechanical stimulus for pain receptors already sensitised by PGE$_2$).

2.2.2. Muscle Damage from Rugby Training

Muscle damage can occur during, concentric, eccentric or isometric muscle action (Clarkson, et al., 1986) however it is has long been established to be most severe after eccentric contraction (Fridén, 1983; Proske and Morgan, 2001). It is widely agreed that there are two prominent signs of damage in a muscle immediately after it has been subjected to a series of eccentric muscle actions: the presence of disrupted sarcomeres in myofibrils and damage to the excitation-contraction coupling system (Proske and Morgan, 2001). Yet, eccentric muscle actions rarely occur in isolation in natural human movement, instead, natural muscle function occurs in a sequence of active eccentric action followed by an active concentric action, known as the stretch-shortening cycle (SSC) (Komi, 2000; Komi, 2003).
The SSC is an eccentric phase of movement or stretch followed by an isometric transitional period (amortisation phase), which leads to an explosive concentric action. The purpose of the SSC is to enhance performance during the final concentric action of a movement when compared with the performance of an isolated concentric action. Aside from an enhanced concentric contraction, efficient usage of the SSC also affords the athlete with a reduction in the metabolic cost of movement (Turner and Jeffreys, 2010). Eccentric actions actively contribute to the SSC and, therefore, it is unsurprising the muscle damage is a common occurrence during prolonged or intense exercise involving the SSC (Byrne et al., 2004). Exercise-induced muscle damage is a common occurrence following activities with a high eccentric component, such as resistance training, plyometrics, distance running and prolonged, intermittent shuttle running (Twist and Eston, 2005).

The research presented within Section 2.1 provides a rationale as to why the completion of resistance training, plyometrics and intermittent shuttle running could be suggested to compliment and improve rugby union performance. Training in rugby union players therefore typically incorporates structured resistance training for hypertrophy, strength, and power; aerobic and anaerobic conditioning; and speed training in conjunction with the skill-based team sessions (Duthie, 2006; Smart and Gill, 2013). There is a body of evidence supporting muscle damage as a by-product of: repeat sprint activity (Thomson et al., 1999), resistance training (Cleak and Eston, 1992; Proske and Morgan, 2001), plyometric activity (Twist and Eston, 2005) and rugby union specific activities completed during training (Ehlers et al., 2002; Takarada, 2003 Smart et al., 2008; Gill et al., 2006; Higgins et al., 2013b). Therefore it can be expected that a player participating in training for rugby union competition will be subject to muscle damage as a result.

While the research presented above justifies the statement that resistance training and repeat sprint activity causes muscle damage when participating in training for rugby union, the information presented in Section 2.1.1 suggests that players sprint very small distances during competition. This suggests that the mechanisms of muscle damage experienced during competitive rugby union, may be different to those experienced during training for competition.
2.2.3. Muscle Damage from Rugby Competition

Muscle damage from participation in rugby union competition is well documented, recently Higgins et al., (2013a) reported large changes in levels of DOMS in comparison to baseline scores after a simulated rugby union competition. Gill et al., (2006) conducted a study using elite players, in a live competitive match using electrosonophoretic transdermal sampling to measure CK scores to be used as a marker to assess the effectiveness of a variety of recovery protocols. Twenty three elite male players were monitored transdermally before, immediately after, 36hrs after and 84hrs after competitive rugby union matches. Again, the study produced significant increases (p<0.01) in interstitial CK concentration from pre- to post-competition with levels of 1023 ± 308 and 2194 ± 834 respectively.

The research of Takarada, (2003) provides further insight as to what aspect of rugby union competition primarily contributes to the increasing levels of CK post rugby union competition demonstrated above. Incidences of muscle damage were measured after two competitive rugby union matches where fifteen amateur players, from a variety of positions, completed venous blood sampling: pre, 0min, 45min, 90min, 24hr, 48hr and 72hr post competition. Alongside this the number of tackles in which each subject was involved and the mean duration of the work and rest periods were investigated by analysing video recordings of the two matches. The number of tackles was defined as the total number of times that the player tackled or was tackled in situations in which the player was tackled from in front. CK levels increased significantly (p<0.05) 24hrs post competition before then rapidly returning to resting levels in an exponential fashion 72hrs post competition. The relationship between the number of tackles and muscle damage was then investigated. Players completed an average of 14 tackles throughout the study (7.4 per game) with the maximum number of tackles recorded being 35. This information was correlated with levels of CK 24hrs after the match. Positive and significant correlations (p<0.01) were observed between both, as shown in Figure 2.4 overleaf.
However, while it is acceptable to suggest that both collisions and high intensity exercise bouts contribute to muscle damage in rugby, there is limited research examining the relationship between physical impact and CK response, with specific respect to rugby. As a result, CK could act as an indicator of either: the amount of intense exercise bouts performed by a player, the number and intensity of impacts experienced or both of these measures. This observation suggests that, without further analysis of the relationship between CK and collisions, the association presented by Takarada (2003) cannot be directly associated to the impacts, despite the pleasing correlation.

Smart *et al.* (2008), aimed to investigate the relationship between the pre to post game changes in the CK concentration and impact-related game statistics in elite rugby union players. Twenty three elite male rugby union players volunteered to participate in the study drawn from a squad of players selected to play in the New Zealand National Provincial Championship. Each player provided interstitial fluid samples obtained via electrosonophoresis 210 mins before and within 30 mins after up to five rugby union games. Specific game statistics that were deemed to be important in determining the relationship between impact and CK were obtained for each individual player. Game time and time defending were significantly (p<0.05) correlated to CK concentration with forwards experiencing significantly higher levels of muscle damage (p<0.01) when compared to backs (1439±677 IU and 545±341 IU respectively).
This pattern of muscle damage is also consistent at international level. A more recent study (Cunniffe et al., 2010) also found significant correlations ($r=0.78-0.86$) between serum CK activity and player involvement in tackles and game contact events when taking blood samples from players on entry to a training camp, morning of a game, immediately after a game and 14hrs and 38hrs into a passive recovery period.

2.2.4. Consequences of Muscle Damage

2.2.4.1. Athletic Performance

It has long been documented (Cleak and Eston, 1992), that the impairment of muscle function associated with the stresses of training and competition can impair an athlete’s performance - either temporarily (minutes to hours post activity) (Barnett, 2006) or over a prolonged period of time (up to several days) (Cheung et al., 2003).

Muscle damage can be classified into three distinct categories based on specific clinical changes. A type I injury refers to exercise-induced muscle damage that is associated with muscle swelling, stiffness and DOMS occurring 24hrs to 48hrs after exercise, a type II injury includes specific tearing of muscle fibres and a type III muscle injury refers to muscle soreness and/or cramps that occur during or immediately after exercise (Hamlin and Quigley, 2001). The major concern for rugby union performance is, if a selective loss of concentric and eccentric strength at high angular velocities of movement occurs, as has been suggested (Golden and Dudley, 1992; Eston et al., 1996), it would render the affected muscles markedly less powerful at the velocities of movements required during competition.

Byrne and Eston, (2002a) assessed the effect of exercise induced muscle damage on knee extensor muscle strength and VJ performance. After completing a bout of muscle damaging exercise (10x10 squats at 70% of body mass load), participant: CK, Squat Jump (SJ), Countermovement Jump (CMJ), and Drop Jump (DJ), alongside knee extensor muscle strength during concentric, eccentric and isometric actions were evaluated. Performance was reduced for four days ($p<0.05$) independent of the muscle action being performed, highlighting that the movement across the full spectrum of the force velocity may well be compromised by muscle damage.
The association between muscle damage and reduced athletic performance is supported further in the work of Twist and Eston, (2005) who aimed to assess the effects of exercise induced muscle damage on maximal intermittent sprint performance – a key movement requirement of rugby union participation (Smart et al., 2014). Ten male participants performed a bout of 10x6s cycle ergometer sprints, interspersed with 24 s recovery against a load corresponding to 0.10 kp/kg and 10x10 m sprints from a standing start, each with 12 s active (walking) recovery.

All variables were measured immediately before and at 30min, 24, 48, and 72h following a plyometric exercise protocol comprising of 10x10 maximal CMJ. CK was significantly elevated (p<0.05) at 24h, 48h and 72h when compared to baseline. The rate of fatigue over the ten cycling sprints was reduced compared to baseline, with the greatest reduction of 47% occurring at 48h (p<0.01). This was largely attributed to the lower PPO in the initial repetitions resulting in a lower starting point for the rate of fatigue and sprint times over 10m were higher (p<0.05) at 30min, 24h, and 48h compared to baseline. All values returned to baseline by 72h. These results highlight that following a plyometric muscle damaging exercise protocol (as can be expected as a result of participation in rugby union training/competition) the ability of the muscle to generate power is reduced for at least three days. This is also manifested by a small, but statistically significant reduction in very short-term intermittent sprint running performance.

However, it is important to note that the studies used university students from a wide variety of backgrounds that were either untrained (Byrne and Eston, 2002a) or trained once weekly (Twist and Eston, 2005) with no reference to type of training completed. As a result, the results produced from this study cannot be applied to professional rugby players completing high levels of resistance and rugby training in a normal week. Furthermore it cannot be assumed that 10x10 squats at 70% of bodyweight and 10x10 maximal CMJ efforts will have the same effect on muscle damage when prescribed to a sample of professional rugby players.
2.2.4.2. Risk of Injury

Muscular injury can often be characterised by the presence of muscle dysfunction, a term used to describe unusual patterns of muscle recruitment during a prescribed set of movements (Edgerton et al., 1996). Injury to the muscle or connective tissue during eccentric exercise can result in changes to recruitment patterns or the temporal sequencing of muscle activation patterns. A reduction in force output by an injured part of a muscle may lead to compensatory recruitment from an uninjured area of muscle, which may place unaccustomed strain on muscle, ligaments and tendons during functional activity (Cheung et al., 2003).

The reduction in strength and power during muscle soreness, identified in Section 2.2.4.1, may lead to an individual having to work at a higher intensity than is normally required to achieve a consistent level of performance (Smith, 1992). For instance, if an athlete is prescribed a pre-determined intensity of training during DOMS, the intensity will be relatively higher as a result of loss of function in damaged and weakened muscle fibres. Furthermore, an increased incidence of injury may also be observed if reduced force output or unusual patterns of muscle recruitment from DOMS leads to an alteration in the strength ratio of agonist and antagonist muscle groups (Yeung et al., 2009).

2.3. Managing Training Load

2.3.1. Importance of Measuring Training Load

From the information provided above it could be justified to suggest that participation in rugby union competition and training will result in some degree of muscle damage, which has significant impacts on an athlete’s physical performance and wellbeing. The weekly activity during modern rugby union competition includes a competitive game and then a period of relative rest before training for the next competitive game is recommenced. In professional rugby, the training week usually consists of four field sessions including: skills, unit skills (scrums, line-outs and backline moves), conditioning sessions, team run-throughs and 2-3 resistance training sessions (Higgins et al., 2013b).
This cyclic activity may result in players accumulating muscle damage as the season progresses because the quick turnaround between training and competition may not provide sufficient time for players to fully recover (Reilly and Ekblom, 2005) and, while an increase in training volume may lead to improvements in the fitness and skills of individual players as well as improved team performances, increased training volume may also be accompanied by an increase in the number and injuries sustained by players. This is demonstrated in the research of Brooks et al., (2008) which found that players subjected to higher training volumes suffered an increased severity of match injuries particularly during the second half of competition. However, a more detailed analysis of the results presented within the study indicates that injury incidence in programmes recording the highest volume of training (>9.2hrs/wk.) was no different to the lowest volume programmes (<5hrs/wk.) both presenting 2.05 and 2.08 injuries/1000hrs respectively. Furthermore, the severity of injuries sustained during moderate volume programmes (5-6.3 and 6.3-7.3hrs/wk.) was actually more severe than those experienced in the highest volume programmes.

As a result there is a requirement for the strength and conditioning coach to be responsible for monitoring and adjusting the training load of the players involved in their programme (Corcoran and Bird, 2009) in order to avoid injury and the performance decrements associated with the accumulation of muscle damage (Twist and Highton, 2014).

2.3.2. Quantifying Training Load

Training volume, training intensity and training load are the primary training variables that a coach may manipulate in order to control training stress. Coutts et al., (2004) provide a general overview of these important variables:

*Training Volume:* The duration of training, generally interpreted in terms of time (e.g minutes per day or hours per week) or distances covered (e.g 80km/week for a distance runner and 300km/week for a cyclist).
Training Intensity: Intensity refers to how hard the training session is.

Most coaches manipulate both training intensity and volume in their training programmes. Therefore, taking measures of volume and intensity independently to measure training may not truly reflect the training stress imposed on the athletes. It is suggested, therefore, that the training stress be measured using the training load calculation. This is often referred to as the internal training load.

Training Load: Training load is simply the function of external training loads and internal training loads and can be expressed by the following formula:

\[
\text{Training Load} = \text{Training Volume} \times \text{Training Intensity}
\]

The internal training load imposed on the athlete ultimately determines the stimulus for training adaptation (Viru and Viru, 2000), this is of particular importance in rugby union as the planned external load is often similar for each team member as the extensive use of group exercises such as conditioned games squad training sessions (Impellizzeri et al., 2004). This is demonstrated in the fact that soccer players with higher VO2 max tend to exercise at a lower percentage of VO2 max during small sided games exercises which suggest that group training sessions may not provide consistent stimuli between squad members (Hoff et al., 2002). In addition to fitness level, other factors such as injury, illness, weather conditions, match schedule problems, and athlete psychological status can influence the internal training load and is of paramount importance that, in order to guarantee each athlete receives an adequate training stimulus, internal training loads are accurately measured (Impellizzeri et al., 2004). Therefore having a reliable and valid measure of internal training loads (intensity) is required to monitor and control training volume.
2.3.3. Monitoring Training Intensity

2.3.3.1. Heart Rate

One of the most widely accepted methods of evaluating internal training intensity in endurance athletes uses heart rate (HR) as a measure of exercise intensity (Wallace et al., 2008). However, a meta-analysis of HR as a marker of training load concluded that the clinical usefulness of HR was limited and that the small to moderate amplitude of alterations in HR may fall within the day to day variability of markers and any interpretation of HR fluctuations during the training process requires the comparison of other signs of overtraining to be meaningful (Bosquet et al., 2008).

Furthermore, heart rate as a measure of intensity of rugby union performance has limitations as heart rate response is a relatively poor method for evaluating high intensity exercise activities such as: load, interval and plyometric training (Foster et al., 2001). Section 2.2 demonstrated that these types of high intensity training sessions are common in a typical rugby union training programme. This, combined with the problems associated with HR monitoring such as: the technical expertise required, time consuming process of collecting data of all team players every training session, legality of match day use, and the cost of numerous HR telemetric systems (Impellizzeri et al., 2004), limit the usefulness of HR as a monitoring tool of internal training load for rugby.

2.3.3.2. Subjective Assessments

Using session ratings of perceived exertion (RPE) is a simple system for monitoring internal training load in athletes. The most widely used instrument to measure perceived exertion or exercise intensity is Borg’s RPE scale and, since the unveiling of the original scale over 50 years ago, the CR-10 RPE scale has since become a standard validated method to evaluate perceived exertion in exercise testing, training and rehabilitation (Day et al., 2004). This protocol for measuring exercise intensity requires the athlete to subjectively rate the intensity of the entire training session according to the category ratio scale (CR 10-scale) of Borg et al., (1987) which is illustrated in Table 2.1.
The athlete will provide an RPE score for an exercise session, along with a measure of training time, which is then combined to calculate a measure of session intensity using the formula below:

\[
\text{Training Load} = \text{Session RPE} \times \text{Duration (minutes)} \quad \text{(Coutts et al., 2004)}.
\]

A major advantage of quantifying training load using session RPE compared with other reported methods is that it is simple and relatively easy to interpret. Furthermore, studies have shown session RPE to compare favourably with more complicated methods of quantifying training load in endurance (Foster, 2001), team sports (Coutts et al., 2003; Impellizzeri et al., 2004) and resistance training (Day et al., 2004).

**Table 2.1:** The 10-Point Rating of Perceived Exertion Scale (Borg et al., 1987).

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Rest</td>
</tr>
<tr>
<td>1</td>
<td>Very, Very Easy</td>
</tr>
<tr>
<td>2</td>
<td>Easy</td>
</tr>
<tr>
<td>3</td>
<td>Moderate</td>
</tr>
<tr>
<td>4</td>
<td>Somewhat Hard</td>
</tr>
<tr>
<td>5</td>
<td>Hard</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Very Hard</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Maximal</td>
</tr>
</tbody>
</table>

While RPE scales have been shown to be effective in assessing training loads in team sports similar to rugby union (Coutts et al., 2003) the literature related to Borg’s RPE scale has revealed inconsistencies about the strength of the relationship between RPE and various physiological criterion measures, for example, heart rate and blood lactate concentration (Chen, et al., 2002). Furthermore, the physiological variables suggested as criterion measures used in research on RPE are confounded by the presence of potential psychological variables such as mood or affect, exercise history and physiological condition, all of which may undermine the relationships between RPE and physiological indicators of exercise intensity (Chen et al., 2002).
A large-scale meta-analysis to determine the strength of the relationship between RPE scores and seven physiological variables (participant sex, participant fitness, type of RPE scale used, type of exercise, exercise protocol, RPE mode, study quality) was conducted by Chen et al., (2002). The findings suggest that, although Borg’s RPE scale has been shown to be a valid measure of exercise intensity, its validity may not be as high as previously thought (r= 0.8-0.9).

### 2.3.3.3. Global Positioning Systems

Given the subjective nature of RPE scores negatively impacting the accuracy of quantifying intensity, a more objective measure may be seen as a more suitable method of measuring the intensity of training and competition. GPS units have been shown to gauge the movement patterns and physiological demands of rugby union competition and training in a more objective, quantifiable measure than provided by session RPE (Cunniff et al., 2009). While these units have been shown to produce valid and reliable data (Varley et al., 2012; Cummins et al., 2013) their use is often limited as each player is required to wear an individual unit which can be costly and time consuming when analysing data. This is demonstrated in a recent study by Bradley et al., (2015) which involved the monitoring of 45 elite European rugby union players with only 17 players being able to wear a unit at one time due to a lack of equipment.

There is a need to monitor training load and levels of muscle damage when attempting to optimise the performance of rugby union players. However, it is difficult to accurately monitor training load given the challenge of precisely assessing individual internal training loads within a team of athletes (Hoff et al., 2002; Impellizzeri et al., 2004; Bradley et al., 2015). A useful and more direct approach may be to assess the athlete’s level of recovery post muscle damaging activity as opposed to attempting to predict this through manipulation of subjective training variables.
2.4. Assessing Recovery From Muscle Damage

2.4.1. Factors Affecting Recovery from Muscle Damage

Recovery is a multi-faceted process. For example, poor nutritional strategies can lead to increased muscle damage post activity as a positive muscle protein balance is required to repair exercise induced muscle damage post exercise (Ivy, 2004). If an inadequate protein intake occurs post training a negative net protein balance will occur which will lead to muscle protein breakdown (Bowtell et al., 1998). Furthermore, the addition of post-exercise protein and carbohydrate feedings can reduce muscle soreness and decrease CK concentrations (Cockburn et al., 2008). Alcohol consumption post activity has been shown to aggravate and exacerbate eccentric-exercise induced losses in performance (Barnes et al., 2010a; Barnes et al., 2010b). Sleep quality can also have an impact on a player’s ability to recover from physical activity as theories of sleep function propose that sleep repays the neural and metabolic cost of waking (Frank, 2006). Extensive sleep loss (30hrs sleep deprivation) is associated with reductions in muscle glycogen content (Skein et al., 2011) and chronic sleep restriction (50% of the habitual time over 12 days) may contribute to amplifications of soreness (Haack and Mullington, 2005). There is also an ever-growing body of literature from diverse fields implicating psychological stress as a factor that modulates physiological recovery, demonstrated in a detailed meta-analysis conducted by Walburn et al., (2009). A recent study identified that in all analyses, higher stress was associated with worse recovery. Stress, whether assessed as life event stress or perceived stress, moderated the recovery trajectories of muscular function and somatic sensations in a 96-hour period after strenuous resistance exercise (Stults-Kolehmainen, 2014).

The previous demonstrates that a wide range of factors influence an athlete’s ability to recover from physical activity and, while it is beyond the scope of this literature review to comprehensively review the full array of these factors, the strength and conditioning practitioner must consider all of these when attempting to optimise the readiness and wellbeing of the players under their control.
2.4.2. Accurately Measuring Recovery From Muscle Damage

2.4.2.1. Enzymatic and Hormonal Markers of Recovery from Muscle Damage

Previously muscle biopsy has been used to assess the extent of damage caused by muscle trauma; however this method cannot be guaranteed to identify the area where the greatest damage occurred. It has become increasingly common, therefore, to use the appearance of muscle proteins in blood as indicators of muscle damage following exercise such as Creatine Kinase (CK) the primary enzyme regulating anaerobic metabolism (Thompson et al., 1999; Ehlers, et al, 2002). Checking for increases in blood serum levels of CK is one of the most valid and reliable methods for assessing muscular damage because a high percentage of the body's CK is present in skeletal muscle tissue (Epstein, 1995; Brancaccio et al., 2007) and has been commonplace for more than four decades in studies investigating muscular damage (Dawson and Fine, 1967). While the exact mechanism by which CK enters the general blood circulation is still under dispute, it is hypothesised that when acute damage occurs to the muscle cell structure, CK leaks into the interstitial fluid and is picked up by the lymphatic system. CK then travels through the lymphatic system and is eventually emptied back into general blood circulations resulting in increased serum CK (Ehlers et al., 2002).

In athletes, the study of CK at rest and after exercise could be an important tool for coaches and practitioners however muscle recovery cannot be evaluated by changes in serum CK levels alone, as there is no correlation between serum enzyme leakage and muscular performance impairment after exercise (Margaritis et al., 1999). There is also considerable variability among individuals. Some athletes are low responders to physical training, with chronically low CK serum levels, whereas as some are high responders, with higher values of enzyme (Brancaccio et al., 2007) which suggests that the use of hormonal markers alone as a measure of recovery may be limited.
In presenting a system for monitoring training stress and recovery in high school athletes Jeffreys (2004) suggests subjective scaled records as a simple, effective, low-cost tool to monitor training loads when dealing with large teams or groups. However, as previously stated, subjective scales are limited as they cannot measure a number of important aspects of training volume and stress such as hormonal balances: prompting the suggestion that they should be used along with performance data (Jeffreys, 2004). This is supported by the fact that not everyone undergoing eccentric exercise demonstrates muscular soreness. Observations from the research of Sayers et al., (2001) have indicated that 30-35% of subjects do not demonstrate at least moderate soreness during the hours of peak soreness after eccentric exercise which may affect the accuracy of participants' recordings, if muscle soreness is to be used as a marker of muscle damage.

Hormonal markers such as the testosterone to cortisol ratio have also traditionally been suggested as a useful tool in the early detection of overtraining and as a measure of recovery from intensive physical activity as result of their potential impact on physical sporting performance (Gaviglio and Cook, 2014). However the reliability of using hormonal analysis alone as objective measures of recovery from muscle damage is limited (Brancaccio, et al., 2007; Gaviglio and Cook, 2014), due to the complexity of the multiple mechanisms associated with their production.

As the impact of muscle damage on physical performance is heavily supported from the research presented within Section 2.2.4 it is acceptable to suggest that a physical athletic performance measure, when combined with CK responses, may provide an accurate, easy to implement, cost effective method of accurately monitoring the extent to which an athlete has recovered from muscle damage post training.

2.4.2.2. Physical Performance Measures of Recovery from Muscle Damage

Early studies using physical measures to assess recovery have shown decrements in the power generating abilities of muscle under conditions of muscle damage (Sherman et al., 1984; Sargeant and Dolan 1987; Miles et al., 1997) highlighting the potential sensitivity of performance measures for monitoring recovery from muscle damage.
However, these studies have relatively small sample sizes and use isolated, single-joint, muscle actions as a performance measure when muscle actions rarely occur in isolation in natural human movement (Komi, 2003). In addition to this, the practicality of implementing these performance measures on a large scale regularly for a rugby union team is compromised due to the cost, time and availability of equipment. Jumping activities can be suggested as a suitable multi-joint performance measure as they are easy and quick to implement (Nédélec et al., 2012) and jumping ability has been linked to rugby union directly in that it can differentiate between playing level (Hansen et al., 2011) and have been shown to predict speed abilities of rugby union players during competition (Cronin and Hansen, 2005). As a result a number of studies have looked at jumping performance as an indicator of recovery.

Byrne and Eston (2002a) conducted a study intending to assess the effect of exercise induced muscle damage on CK, knee extensor muscle strength during isometric, concentric and eccentric actions; and VJ performance in the SJ, CMJ and DJ. These variables were measured before, 1hr, and 1,2,3,4 and 7 days after a bout of muscle damaging exercise (10x10 back squat at 70% body mass load). CK was elevated (p<0.05) above baseline 1 hour after exercise and remained significantly elevated for three days. While strength was significantly reduced for four days (p<0.05) no significant differences (p>0.05) were apparent in the magnitude or rate of recovery of strength between isometric, concentric and eccentric muscle actions. On the contrary, while all VJ performances decreased (p<0.05) the overall decline in VJ performance was dependent on jump method with SJ being affected to a greater extent than CMJ (91.6 ± 1.1% vs 95.2 ± 1.3% of pre exercise values) and DJ (95.2 ± 1.4% p<0.05) performance. This research indicates that, while strength loss after muscle damage was independent of the muscle action being performed, the impairment of muscle function was attenuated when the SSC was used in VJ performance.
More recently Beneka et al., (2013) assessed performance responses after an acute bout of plyometrics combined with high and low intensity weight training. Changes in performance were monitored by measuring CMJ and SJ and strength performance was assessed through isometric and isokinetic testing of knee extensors at two different velocities. The muscle damaging intervention consisted of 50 hurdle bounds and 50 drop jumps from a 50cm box. Additionally, each group performed a combination of leg presses and leg extensions (90-95% of 1RM for the high intensity group and 60% of 1RM for the low intensity group). Squat Jump decreased significantly (p<0.001) for both experimental groups immediately after exercise but also at 24hrs of recovery and remained below baseline at 48hrs, 72hrs and 96hrs of recovery. Similar changes in performance were found in the CMJ but the differences between experimental groups were not significant (p>0.01). However because there was no measure of muscle damage (CK) as part of this study it impossible to assess whether or not these changes in performance came as a result of muscle damage impairing performance. Furthermore, the participants, again, had not been exposed to weightlifting and resistance training for 6 months prior to the assessment, which further limits the application of these results for professional rugby athletes.

2.5. Implications of Accurately Monitoring Recovery From Muscle Damage

2.5.1. Recovery Interventions

It can be argued that accelerating recovery may be the most important part of the yearly training programme as it is one of the main bridges between training and improved performance (Greener, 2013). A summary study by Reilly and Ekblom (2005) suggests: warm downs, deep water running, restoration of energy, and rehydration as suitable methods of speeding up recovery. Barnett (2006) further identifies massage, active recovery, cryotherapy, contrast bathing, compression garments, stretching and non-steroidal anti-inflammatory drugs as potential modalities to improve recovery. However research assessing the effectiveness of various recovery modalities is often conflicting.
Gill et al., (2006) examined the effectiveness of four interventions on the rate and extent of muscle damage recovery with CK as a measure. Twenty three elite rugby union players were monitored before and: immediately, 36hrs and 84hrs post competitive rugby union matches, before being randomly assigned to one of four post match strategies: contrast bathing, compression garments, active recovery and passive recovery. They found significant increases in CK activity as a result of the rugby union competition (p<0.01) and that the magnitude of recovery in the passive recovery intervention group was significantly worse at the 36 and 84 hour time points (p<0.05) when compared to the compression garment, contrast bathing and active recovery groups.

In spite of this, a recent study by Higgins et al., (2013b) evaluated hydrotherapy by conducting both passive and power-based tests across a cyclic week of competitive rugby. Twenty-four experienced male rugby union players were randomly divided into three groups: cold water immersion, contrast bathing and a control group. The two forms of hydrotherapy were administered immediately after a simulated rugby union game, the content of which was unspecified. The results from all tests were inconclusive in determining whether cold water immersion or passive recovery effectively attenuated fatigue, indicating that contrast baths have little benefit in enhancing recovery during a cyclic week of rugby union competition.

Duffield et al., (2010) also presented data that differs from the findings of Gill et al., (2006). They compared the effects of compression garments on recovery following fatiguing exercise. Eleven club/regional standard rugby union players performed two sessions separated at seven-day intervals; with and without lower-body compression garments during and 24hrs post exercise. Blood samples and physical measures (20m sprint and 10 plyometric bounds) were completed before, following, two hours and 24hrs post exercise. No differences (p=0.4-0.8) were present between conditions for CK leading to the conclusion that the effects of compression garments on voluntary performance and recovery were minimal.
The research presented above indicates some inconsistency in the findings of research aimed at assessing the effectiveness of various recovery modalities. This may be a result of the wide variation in methodological designs, combined with the differences in timing and duration of intervention, exercise modality and training status of the populations investigated (Hill et al., 2013). The ability of coaches to quantify increases in physical training loads with appropriate recovery is of critical importance for optimising athletic performance (Smith, 2003). In reviewing the information presented in Sections 2.5.1 and 2.5.2 it is demonstrated that recovery is a multifactorial process and it is difficult to prescribe recovery interventions accurately given the conflicting nature of research findings.

As a result of the inconsistency presented regarding the effectiveness of recovery modalities, the strength and conditioning practitioner cannot confidently implement such interventions without having an accurate method of measuring the extent to which an athlete has recovered from muscle damage post training.

2.5.2. Longitudinal Monitoring of Recovery

Section 2.4. demonstrates that physical performance measures react to a change in levels of muscle damage sensitively enough to identify muscle damage in a single lab based training stimulus. However, rugby union is a demanding sport that required extensive in-season training which may mean more frequent testing of recovery may be required in order to promote optimal performance over the course of a competitive season.

Zody et al., (2011) examined the performance characteristics and in-season recovery of female basketball players using drop jump characteristics and recovery-stress conditions. Fourteen NCAA Division 1 female basketball players filled out the REST-Q Sport questionnaire, which assesses self-perceived stress and recovery, prior to performing two 30cm DJ on two force plates sampling at 1000Hz. Participants were assessed fortnightly over a month of preseason training and on four occasions throughout the season. Total recovery, stress score global recovery score and global stress score were also calculated throughout the season. The results revealed significant differences in: flight time, jump height and reactive strength index (p<0.05).
These results showed that DJ characteristics declined throughout the course of a basketball season, which were accompanied by abnormally high stress scores and low recovery scores. This information justifies the use of simple performance tests to help strength and conditioning practitioners monitor information regarding recovery of athletes over a course of a season.

2.5.3. Practicality of Monitoring Recovery

The research presented thus far highlights that participation in rugby union training and competition will cause the athlete involved to experience some degree of muscle damage, which negatively impacts athletic performance and injury predisposition. Monitoring training volume and hormonal responses have been suggested as appropriate methods of monitoring exposure to muscle damage, however a more time and cost effective method could be to use change in a physical performance marker, such as jumping, to establish the extent of recovery from muscle damage.

While the work of Byrne and Eston (2002a) has demonstrated the ability of jump activity to identify a lack of recovery from muscle damage; advances in technology suggest that, for measurement accuracy, jump tests must be conducted using a portable force plate with standardised testing procedures (Owen et al., 2014). All jumps in Byrne and Eston’s (2002a) study were performed on an electronic timing mat which has been suggested as an inferior method of assessment as it does not provide the level of quantitative data on the numerous variables associated with jumping activity as a force platform would (Nédélec et al., 2012).

A further limitation of laboratory-based studies of recovery from muscle damage, like that of Byrne and Eston (2002a), is that hormonal responses of rugby union players have been shown to contrast when comparing laboratory based to applied studies (Elloumi et al., 2003). So, if muscle damage was culminated from a single intervention stimulus in the laboratory environment, the practical application of the information provided by non-applied research into a working rugby union environment is limited. Despite this, lab based studies are important for the establishment of a standardised protocol for the criterion method of measuring recovery from muscle damage, which has not yet been established.
It is paramount, therefore, that in order for the strength and conditioning practitioner to carry out longitudinal, in-season, testing data and assess the effectiveness of any recovery strategies implemented, the most appropriate method for monitoring recovery must be established. The assortment of studies presented in this literature review have utilised a range of methodologies to monitor recovery from muscle damage including differing: jump types, testing intervals, muscle damaging interventions and laboratory or applied experimental settings. However, no studies to date have tested a consistent protocol across both an experimental and applied muscle-damaging stimulus and the most effective jump activity as a tool of recovery is still not clear if indeed it exists at all.

In order to address this issue further it is important that the effectiveness of a variety of suggested methods of monitoring recovery from muscle damage are assessed using the same experimental methodology across both an applied and experimental setting.
CHAPTER 3

Methods and Procedures
3.1. Study One - Experimental Study

3.1.1. Participants

Twelve (12) male rugby union players volunteered to participate in this study, all of which were currently engaged in regional and age-grade international level rugby, for which recovery from a high intensity volume of training is essential. All recruited participants had completed regular strength training for 2 or more years and were capable of performing single repetitions in the back squat exercise with sound technique and who play a high standard of rugby. The study was approved by the Human Ethics Committee of Cardiff Metropolitan University. Prior to commencement of the study all participants / guardians of the participants were informed of the experimental procedures before signing an informed consent/assent form as required. An example of the informed consent and participant/guardian information forms are given within the appendix.

All participants completed the protocol to voluntary failure, or in full (dependent on which came first) averaging 46 ± 7 reps of the full 50-repetition protocol. Two subjects were removed during testing due to injury and training commitments. Table 3.1 provides the descriptive physical characteristics of the 10 subjects that completed the full testing battery.

<table>
<thead>
<tr>
<th>Table 3.1: Subject Physical Characteristics (n=10).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Years)</td>
</tr>
<tr>
<td>17.59 ± 0.73</td>
</tr>
</tbody>
</table>

3.1.2. Research Design

Participants in the study visited the laboratory on six occasions. Prior to the commencement of the main experimental trial, the initial visit was used to ensure the participants were fully familiarised with the assessment protocol for the jumping techniques and participants’ one repetition maximum (1-RM) in the back squat was established. The subsequent visits were used to assess the effects of a training protocol designed to cause high levels of muscle damage on the participants’ performances in a variety of jump protocols. The full testing schedule is presented in Figure 3.1 overleaf.
3.1.3. Preliminary Testing

Participants age was recorded along with stature (m) determined using a Harpenden Stadiometer (Holtain Limited, Crymych, UK); body mass (kg) was measured using 875 flat series calibrated scales (Seca, Kent, UK). Participants were then required to record a 1-RM back squat effort after reporting their previous 1-RM load in order to minimise the number of attempts required to determine the 1-RM.

3.1.4. Weightlifting Loads and Conditions

A standard 20-kg Olympic barbell and calibrated weight discs (Ivanko, Sweden) were used for all load assessments and subsequent experimental protocols. All weight lifting was performed within the confines of a weightlifting safety cage with appropriate squat safety bars. Participants were permitted to use weightlifting shoes, as they required. The use of support knee wraps, weightlifting body suits and weightlifting belts were not permitted for use in this study. On all 1-RM attempts a lift was deemed to be successful if the subjects could lower the body until the hip axis was below the knee axis in relation to the horizontal and recover at will to an upright position with the knees locked as per the International Powerlifting Federation Rules (International Powerlifting Federation, 2009).

3.2. Study Two - Applied Study

3.2.1. Participants

Ten (10) male rugby union players volunteered to participate in this study, all of which were currently engaged in regional and age-grade international level rugby, for which recovery from a high intensity volume of training is essential. The study was approved by the Human Ethics Committee of Cardiff Metropolitan University. Prior to commencement of the study all participants / guardians of the participants were informed of the experimental procedures before signing an informed consent/assent form as required. An example of the informed consent and participant/guardian information forms are given within the appendix.

Figure 3.1: Study One Testing Schedule.
Table 3.2 provides the descriptive physical characteristics of the 10 subjects that completed the full testing battery.

**Table 3.2:** Subject Physical Characteristics (n=10).

<table>
<thead>
<tr>
<th>Age (Years)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.27 ± 1.00</td>
<td>182.93 ± 5.71</td>
<td>94.77 ± 8.69</td>
</tr>
</tbody>
</table>

### 3.2.2. Research Design

Participants in the study visited the laboratory on five occasions. Prior to the commencement of the main experimental trial, the initial visit was used to ensure the participants were fully familiarised with the assessment protocol for the jumping techniques. The subsequent visits were used to assess the effects of participating in a single match of rugby union on the participants’ performances in the jump protocols. The full testing schedule is presented in Figure 3.2.

![Figure 3.2: Study Two Testing Schedule.](image-url)

### 3.2.3. Preliminary Testing

Participants age was recorded along with stature (m) determined using a Harpenden stadiometer (Holtain Limited, Crymych, UK); body mass (kg) was measured using 875 flat series scales (Seca, Kent, UK).
3.3. Testing Procedures

3.3.1. Experimental Procedures

Participants reported to testing having refrained from any strenuous exercise and having abstained from alcohol and caffeine for 48hrs prior to testing. After the measurement of each participant’s body mass and baseline levels of CK participants underwent a standardised warm-up, which comprised of progressive functional movement with players performing dynamic mobility exercise at set intervals throughout the warm-up with an emphasis on warming-up the musculature associated with jumping.

Post completion of the warm up protocol, the participants performed the jumping procedure demonstrated in Table 3.3 on an accupower portable force platform (AMTI, Massachusetts, USA) during which their force (F), power (P), velocity (V) ground contact time (tc) and flight time (tf) were measured. The participants were actively encouraged to jump as high as possible and spend as little time in contact with the ground during each jump and were given a two minute rest between completing each jump. Subjects were given two attempts to record a score for each jump excluding the submaximal hopping where subjects completed one set of hops.

<table>
<thead>
<tr>
<th>Table 3.3: Jump Protocol.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Submaximal Hopping</td>
</tr>
<tr>
<td>2 – Squat Jump</td>
</tr>
<tr>
<td>3 – Countermovement Jump</td>
</tr>
<tr>
<td>4 – Drop Jump from 30cm</td>
</tr>
</tbody>
</table>

After completing the baseline jumping protocols each participant was then required to fully complete the fatiguing stimulus for the given study, presented in Section 3.3.2. The participants were then required to repeat the jumping protocols at 4m, 24hr, 48hr, 72hr and 7 days post completion of the intervention. During this time the participants completed no additional resistance or rugby union training but participated in rehabilitation programmes on a needs only basis.
The extent of the participants’ muscle damage was also recorded before each post intervention jumping session. Participants were permitted consumption of water during the testing as per their individual requirements. Room temperature was maintained throughout. Verbal encouragement was provided to maximise performance.

3.3.2. Testing Interventions

In Study One, participants completed a training session designed to cause neuromuscular fatigue and muscle damage. The session consisted of five sets of ten repetitions of the lowering portion of a back squat at a load of 95% of their 1-RM with a five second eccentric contraction which was measured using a metronome. Similar methods have been shown to produce muscle damage in previous research (Byrne and Eston, 2002a; Byrne and Eston, 2002b). At the base of the lift the bar was unloaded onto the safety bars of the squat rack and assistance was given returning the weight to the correct starting position. Each player was given a two-minute rest between sets. Due to the strenuous nature of the weightlifting activity the participants were permitted to perform a number of sub-maximal repetitions in the back squat in the build-up to the training session. Using the calculations of Baechle and Earl (2008) the participants performed a maximum set of 8 repetitions at 50% of 1-RM, 4 repetitions at 70% of 1-RM, 2 repetitions at 80% 1-RM and 1 repetition at 90% 1-RM.

In Study Two, the study participants partook in a full (80 minute) competitive rugby union match. Each individuals length of involvement was subject to the requirement of the head coach, however all players completed a minimum of fifty minutes of competitive play.
3.3.3. Measuring Procedures

3.3.3.1. Force Plate Data

A number of different methodologies are available when measuring force, velocity and power output from jumping activities. Despite the variety of methodologies, it has been suggested that these variables, measured directly or calculated from GRF-time data recorded from a force platform, provide the most accurate way to assess strength qualities during a vertical jump (Hori et al., 2006; Walsh et al., 2006; Hori et al., 2009).

SJ: The squat jump was performed from a squat position with the knees flexed to approximately ninety degrees. The participants were asked to hold this position for three seconds and then, upon the verbal command ‘go’, the participant jumped vertically to maximum height. It was imperative that no countermovement was made at the start of the jump. Participants were not permitted to use their arms and placed their hands on their hips to reinforce this. Peak force, peak velocity, peak power output and jump height were recorded during each squat jump. SJ have previously shown to be a reliable method ($\alpha=0.97$) (Markovic et al., 2004) and this methodology was adapted from Byrne and Eston (2002a).

CMJ: The participants started from an erect standing position with knees fully extended. Upon the verbal command ‘Go’, the participant made a downward countermovement to a self-selected depth and then jumped vertically for maximum height in one continuous movement. Participants were not permitted to use their arms and placed their hands on their hips to reinforce this. Peak force, peak velocity, peak power output and jump height were recorded during each countermovement jump. CMJ have previously shown to be a reliable method ($\alpha=0.98$) (Markovic et al., 2004) and this methodology was adapted from Byrne and Eston (2002a).
The participants were instructed to drop from a 30cm platform onto the floor and then jump vertically for maximum height as soon as possible after landing, with minimal ground contact. As a measure of reactive strength, the jump is associated with very high muscle forces, very high power output around the knee joint and very high angular velocities of movement (Byrne and Eston, 2002a). The height was selected based on the previous exposure to drop jumping techniques and with consideration of the state of fatigue the participants would be in when completing the activity. DJ heights of 30cm have been recommended previously and are thought to be safe heights for such assessments (Cronin et al., 2004).

The DJ has previously shown to be a reliable method of measuring RSI ($\alpha=0.99$), Jump Height ($\alpha=0.99$) and Contact time ($\alpha=0.98$) (Flanagan et al., 2008) and this methodology was adapted from Byrne and Eston (2002a). Participants were not permitted to use their arms and placed their hands on their hips to reinforce this. Jump height, ground contact time and flight time were recorded during each drop jump. From this information reactive strength index was calculated using the equation of Flanagan and Comyns (2008).

$$\text{Jump Height (mm) / Ground Contact Time (ms)}$$

$SH$. Participants began started from an erect standing position with hands on hips and were instructed to hop, maintaining a minimal ground contact time, for 20 seconds with both feet landing at a frequency of 2.5 Hz (150bpm), to ensure movement patterns were reflective of typical spring-mass model behaviour (Lloyd et al., 2009) which was indicated via metronome. The first ten hops in each trial were discounted and the flight time and ground contact time of the five subsequent hops was recorded. Submaximal hopping has previously shown to be a reliable method of assessing leg stiffness (Dalleau et al., 2004) and this methodology was adapted from Lloyd et al., 2012).
This data was then used to calculate absolute and relative leg stiffness based on the equation proposed by Dalleau et al., (2004). With 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.

$$K_n = \frac{[M\pi(T_f + T_c)]/T_c}{[(T_f + T_c/\pi) - (T_f/4)]}$$

3.3.3.2. Muscle Damage

Plasma CK activity was determined from fingertip capillary blood samples. A warm fingertip was cleaned with a sterile alcohol swab and allowed to dry. Capillary puncture was made with a softclix lancet (Accu-Chek, UK) and a sample of whole fresh blood (32ml) was pipetted from a capillary tube onto the test strip and analysed for CK activity using an automated reagent test strip analyser (Reflotron Plys Analyser, Bio stat Ltd. Stockport, UK). This system uses a plasma separation principle, which is incorporated in the reagent carrier on the test strip.

3.4. Statistical Analysis

Jump variables identified in Section 3.3.1. were analysed using separate single-factor repeated-measures analyses of variance. The assumption of sphericity was tested by the Mauchly test of sphericity. Violations of this assumption were corrected using the Greenhouse-Geisser adjustment to raise the critical value of $F$ as indicated by (GG). The Bonferonni correction technique was used to eliminate the problem of an inflated Type 1 error risk by adjusting alpha depending on the number of pairwise comparisons. Correlation analysis between CK and jump variables was carried out by linear regression, and the Pearson’s correlation coefficient ($r$) was calculated.

Given the applied nature of this research, in order to practically assess the real-world importance of an effect, effect sizes were measured by using the formula below and were quantified as: small ($>0.2$), moderate ($>0.6$), large ($>1.2$), very large ($>2.0$) and extremely large ($>4.0$) as recommended by Hopkins et al., (2009).

$$\text{Effect Size} = \frac{\text{Change from Baseline Score}}{\text{Baseline Standard Deviation}}$$
CHAPTER 4

Results
4.1. Experimental Study

4.1.1. Creatine Kinase

Table 4.1 presents the change in CK across all testing intervals; one participant presented anomalous CK scores and, as a result, was removed from any data sets involving CK including the table below. No significant change was recorded at any testing interval (p>0.05). A peak from baseline levels of CK (256U/l) to 813.8U/l at 24hrs post-intervention, was observed which remained elevated until the 72hr testing interval. By the seven-day interval, CK levels had returned to below baseline recordings. Despite increasing by over 3 times the original measure, no changes in CK were considered statistically significant. Despite a lack of statistical significance however, the effect sizes reported demonstrate that the change in CK presented can be considered ‘very large’ (ES=3.53) and ‘large’ (ES=1.48) at 24hrs and 48hrs post intervention respectively using the thresholds suggested by Hopkins et al., (2009).

<table>
<thead>
<tr>
<th>Interval</th>
<th>Pre</th>
<th>24</th>
<th>48</th>
<th>72</th>
<th>7d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean CK</td>
<td>256</td>
<td>813.8</td>
<td>489</td>
<td>317.1</td>
<td>202</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>157.9</td>
<td>577</td>
<td>482.2</td>
<td>362.4</td>
<td>82.7</td>
</tr>
<tr>
<td>Effect Size</td>
<td>0</td>
<td>3.53</td>
<td>1.48</td>
<td>0.39</td>
<td>-0.34</td>
</tr>
</tbody>
</table>

4.1.2. Jump Performance

Table 4.2 displays mean group jump performance, plus standard deviations, across all measured variables at each testing interval for both CMJ and SJ and highlights that CMJ peak force decreased significantly (p<0.05) immediately and 24hrs post intervention while PPO decreased significantly (p<0.05) at only the 48hr interval. SJ performance decreased significantly across all variables immediately post intervention (p<0.05 and p<0.01), however presented inconsistent significant (p<0.05) change in jump height at 72hrs, and peak power at both 48hrs and 72hrs intervals post intervention.
and Jump height (p<0.05).

levels 72hrs post intervention significantly impaired (p<0.01) immediately and 24hrs post intervention. DJ RSI decreased significantly (p<0.05) immediately post, 48hrs and 72hrs post intervention. DJ RSI decreased significantly (p<0.05) immediately post, 48hrs and 72hrs post intervention. DJ RSI decreased significantly (p<0.05) immediately post, 48hrs and 72hrs post intervention. DJ RSI decreased significantly (p<0.05) immediately post, 48hrs and 72hrs post intervention.

Table 4.3 highlights SH absolute leg stiffness decreased significantly (p<0.05) immediately post and 72hrs post intervention, while relative stiffness decreased significantly (p<0.05) immediately post, 48hrs and 72hrs post intervention. DJ RSI decreased significantly (p<0.01) immediately and 24hrs post-intervention, remaining less significantly impaired (p<0.05) 48hrs post-intervention before returning to baseline levels 72hrs post-intervention. Similar responses were recorded in Jump Flight Time and Jump height (p<0.05).

Table 4.3 displays mean group jump performance, plus standard deviations, across all measured variables at each testing interval for both DJ and SH. Table 4.3 highlights SH absolute leg stiffness decreased significantly (p<0.05) immediately post and 72hrs post intervention, while relative stiffness decreased significantly (p<0.05) immediately post, 48hrs and 72hrs post intervention. DJ RSI decreased significantly (p<0.01) immediately and 24hrs post-intervention, remaining less significantly impaired (p<0.05) 48hrs post-intervention before returning to baseline levels 72hrs post-intervention. Similar responses were recorded in Jump Flight Time and Jump height (p<0.05).

**Table 4.2:** Study One Subject Mean Non-Plyometric Jump Performance.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre</th>
<th>Post</th>
<th>24hrs</th>
<th>48hrs</th>
<th>72hrs</th>
<th>7d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ Jump Height (cm)</td>
<td>39.84 ± 4.70</td>
<td>31.40 ± 5.23</td>
<td>36.00 ± 4.05</td>
<td>35.56 ± 3.18</td>
<td>37.65 ± 4.23</td>
<td>39.15 ± 3.00</td>
</tr>
<tr>
<td>CMJ Peak Force (N)</td>
<td>2174 ± 358</td>
<td>1941** ± 241</td>
<td>1999** ± 285</td>
<td>2002 ± 256</td>
<td>2035 ± 286</td>
<td>2100 ± 360</td>
</tr>
<tr>
<td>CMJ Peak Velocity (m/s)</td>
<td>2.79 ± 0.16</td>
<td>2.48 ± 0.21</td>
<td>2.65 ± 0.15</td>
<td>2.64 ± 0.12</td>
<td>2.75 ± 0.15</td>
<td>2.77 ± 0.11</td>
</tr>
<tr>
<td>CMJ PPO (W)</td>
<td>4750 ± 728</td>
<td>4038 ± 484</td>
<td>4385 ± 560</td>
<td>4389** ± 596</td>
<td>4461 ± 606</td>
<td>4514 ± 578</td>
</tr>
</tbody>
</table>

**Table 4.2** shows study one subject mean non-plyometric jump performance. Table 4.2 includes variable: CMJ Jump Height (cm), CMJ Peak Force (N), CMJ Peak Velocity (m/s), CMJ PPO (W), SJ Jump Height (cm), SJ Peak Force (N), SJ Peak Velocity (m/s), SJ PPO (W), DJ Ground Contact Time (s), DJ Flight Time (s), DJ Jump Height (cm), DJ Peak Landing Force (N), DJ RSI, SH Absolute Leg Stiffness, SH Mean Contact Time (s), SH Mean Flight Time (s), SH Relative Stiffness.

**Table 4.3:** Study One Subject Mean Plyometric Jump Performance.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre</th>
<th>Post</th>
<th>24hrs</th>
<th>48hrs</th>
<th>72hrs</th>
<th>7d</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJ Ground Contact Time (s)</td>
<td>0.195 ± 0.03</td>
<td>0.242 ± 0.06</td>
<td>0.206 ± 0.03</td>
<td>0.206 ± 0.03</td>
<td>0.198 ± 0.03</td>
<td>0.181 ± 0.02</td>
</tr>
<tr>
<td>DJ Flight Time (s)</td>
<td>0.461 ± 0.05</td>
<td>0.357** ± 0.06</td>
<td>0.397** ± 0.03</td>
<td>0.404* ± 0.04</td>
<td>0.426 ± 0.04</td>
<td>0.429 ± 0.04</td>
</tr>
<tr>
<td>DJ Jump Height (cm)</td>
<td>26.13 ± 0.28</td>
<td>15.98** ± 0.48</td>
<td>19.45** ± 0.33</td>
<td>20.17* ± 0.37</td>
<td>22.44 ± 0.43</td>
<td>22.78 ± 0.46</td>
</tr>
<tr>
<td>DJ Peak Landing Force (N)</td>
<td>5077 ± 1082</td>
<td>4189 ± 901</td>
<td>4555 ± 605</td>
<td>4518 ± 875</td>
<td>4656 ± 808</td>
<td>4837 ± 537</td>
</tr>
<tr>
<td>DJ RSI</td>
<td>1.349 ± 0.14</td>
<td>0.729** ± 0.35</td>
<td>0.959** ± 0.21</td>
<td>1.001* ± 0.25</td>
<td>1.146 ± 0.25</td>
<td>1.172 ± 0.30</td>
</tr>
<tr>
<td>SH Absolute Leg Stiffness</td>
<td>43.87 ± 8.83</td>
<td>33.81* ± 4.83</td>
<td>34.10 ± 6.47</td>
<td>34.21 ± 5.76</td>
<td>33.66* ± 6.33</td>
<td>37.81 ± 7.29</td>
</tr>
<tr>
<td>SH Mean Contact Time (s)</td>
<td>0.178 ± 0.02</td>
<td>0.211 ± 0.03</td>
<td>0.214 ± 0.04</td>
<td>0.213 ± 0.03</td>
<td>0.216 ± 0.04</td>
<td>0.199 ± 0.04</td>
</tr>
<tr>
<td>SH Mean Flight Time (s)</td>
<td>0.215 ± 0.02</td>
<td>0.184 ± 0.03</td>
<td>0.187 ± 0.04</td>
<td>0.186 ± 0.04</td>
<td>0.183 ± 0.03</td>
<td>0.198 ± 0.04</td>
</tr>
<tr>
<td>SH Relative Stiffness</td>
<td>0.499 ± 0.07</td>
<td>0.390* ± 0.06</td>
<td>0.393 ± 0.10</td>
<td>0.394* ± 0.08</td>
<td>0.389* ± 0.08</td>
<td>0.437 ± 0.09</td>
</tr>
</tbody>
</table>

**Table 4.3** includes variable: DJ = Drop Jump, SH = Sub-Maximal Hopping. Change from baseline significant at *p<0.05, **p<0.01.
Table 4.4 presents the change in effect size from baseline for all jump measures during Study 1. Using the scoring system employed extremely large increases in CK were recorded at the 24hr testing interval, remaining largely increased at 48hrs, before fluctuating between baseline levels at the 72hr and 7d interval. DJ demonstrated the greatest decreases in performance at the post, 24hr and 48hr testing intervals with RSI presenting the largest decrements in performance.

### Table 4.4: Study One Effect Sizes

<table>
<thead>
<tr>
<th>Variable</th>
<th>Post</th>
<th>24hrs</th>
<th>48hrs</th>
<th>72hrs</th>
<th>7d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ Jump Height</td>
<td>-1.80</td>
<td>-0.82</td>
<td>-0.91</td>
<td>-0.47</td>
<td>-0.15</td>
</tr>
<tr>
<td>CMJ Peak Force</td>
<td>-0.65</td>
<td>-0.49</td>
<td>-0.48</td>
<td>-0.39</td>
<td>-0.21</td>
</tr>
<tr>
<td>CMJ Peak Velocity</td>
<td>-1.94</td>
<td>-0.88</td>
<td>-0.94</td>
<td>-0.25</td>
<td>-0.13</td>
</tr>
<tr>
<td>CMJ PPO</td>
<td>-0.98</td>
<td>-0.50</td>
<td>-0.50</td>
<td>-0.40</td>
<td>-0.32</td>
</tr>
<tr>
<td>SJ Jump Height</td>
<td>-2.45</td>
<td>-1.07</td>
<td>-1.28</td>
<td>-0.89</td>
<td>-0.54</td>
</tr>
<tr>
<td>SJ Peak Force</td>
<td>-0.64</td>
<td>-0.17</td>
<td>-0.19</td>
<td>0.03</td>
<td>-0.19</td>
</tr>
<tr>
<td>SJ Peak Velocity</td>
<td>-2.62</td>
<td>-1.15</td>
<td>-1.31</td>
<td>-0.92</td>
<td>-0.54</td>
</tr>
<tr>
<td>SJ PPO</td>
<td>-1.70</td>
<td>-0.66</td>
<td>-0.76</td>
<td>-0.46</td>
<td>-0.45</td>
</tr>
<tr>
<td>DJ Ground Contact Time</td>
<td>1.57</td>
<td>0.37</td>
<td>0.37</td>
<td>0.10</td>
<td>-0.47</td>
</tr>
<tr>
<td>DJ Flight Time</td>
<td>-2.08</td>
<td>-1.28</td>
<td>-1.14</td>
<td>-0.70</td>
<td>-0.64</td>
</tr>
<tr>
<td>DJ Jump Height</td>
<td>-3.63</td>
<td>-2.39</td>
<td>-2.13</td>
<td>-1.32</td>
<td>-1.20</td>
</tr>
<tr>
<td>DJ Peak Landing Force</td>
<td>-0.82</td>
<td>-0.48</td>
<td>-0.52</td>
<td>-0.39</td>
<td>-0.22</td>
</tr>
<tr>
<td>DJ RSI</td>
<td>-4.43</td>
<td>-2.79</td>
<td>-2.49</td>
<td>-1.45</td>
<td>-0.55</td>
</tr>
<tr>
<td>Hops Absolute Leg Stiffness</td>
<td>-1.14</td>
<td>-1.11</td>
<td>-1.09</td>
<td>-1.16</td>
<td>-0.69</td>
</tr>
<tr>
<td>Hops Mean Contact Time</td>
<td>1.65</td>
<td>1.80</td>
<td>1.75</td>
<td>1.90</td>
<td>1.05</td>
</tr>
<tr>
<td>Hops Mean Flight Time</td>
<td>-1.55</td>
<td>-1.40</td>
<td>-1.45</td>
<td>-1.60</td>
<td>-0.85</td>
</tr>
<tr>
<td>Hops Relative Stiffness</td>
<td>-1.56</td>
<td>-1.51</td>
<td>-1.50</td>
<td>-1.57</td>
<td>-0.89</td>
</tr>
<tr>
<td>CK</td>
<td>-</td>
<td>3.53</td>
<td>1.48</td>
<td>0.39</td>
<td>-0.34</td>
</tr>
</tbody>
</table>

**Key**

- Small (ES >0.2)
- Moderate (ES >0.6)
- Large (ES >1.2)
- Very Large (ES > 2)
- Extremely Large (ES > 4)
4.1.3. Relationship Between Jump Performance and Creatine Kinase

Significant correlations ($p<0.05$) were recorded between changes in CK and: CMJ PPO, SJ Peak Force, SH relative stiffness, SH mean contact time and SH mean flight time. However all DJ variables recorded stronger correlations with CK ($p<0.01$) with RSI recording the strongest correlation ($r=-.610$). Figure 4.1 presents each individual RSI measure and the CK for the athlete at the time of measuring to demonstrate this correlation.

Furthermore, the percentage decrement of the variables measured during DJ performance not only displayed the highest correlations with changes in CK, but also presented the largest performance decrements of all recorded jump variables. Again, RSI recorded the greatest decreases in performance. Figures 4.1, 4.2 and 4.3 display the percentage change and standard deviations of all DJ variables to have shown significant change from pre levels ($^*p<0.05$ and $^{**}p<0.01$) over the course of the testing protocol.

![Figure 4.1: CK and RSI Results for All Subjects](image)
Figure 4.2: DJ RSI Percentage Change

Figure 4.3: DJ Flight Time Percentage Change

Figure 4.4: DJ Jump Height Percentage Change
4.2. Applied Study

4.2.1 Creatine Kinase

Table 4.5 presents the change in CK across all testing intervals. Baseline levels of CK were recorded as 257.9U/I peaking to 434U/I at 24hrs post-competition and remained elevated before returning to normal levels at the 72hrs testing interval. Despite a large increase at the 24hrs interval, no changes in CK were considered statistically significant. Despite a lack of statistical significance however, the change in CK presented can be considered ‘large’ (ES=1.93) and ‘small’ (ES=.47) at 24hrs and 48hrs post intervention respectively using the thresholds suggested by Hopkins et al., (2009).

<table>
<thead>
<tr>
<th>Interval</th>
<th>Pre</th>
<th>24</th>
<th>48</th>
<th>72</th>
<th>7d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean CK</td>
<td>257.9</td>
<td>434</td>
<td>300.5</td>
<td>232.6</td>
<td>391.5</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>91.2</td>
<td>207.8</td>
<td>149.6</td>
<td>163.9</td>
<td>230</td>
</tr>
<tr>
<td>Effect Size</td>
<td>0</td>
<td>1.93</td>
<td>0.467</td>
<td>-0.28</td>
<td>1.47</td>
</tr>
</tbody>
</table>

4.2.2. Jump Performance

Tables 4.6 and 4.7 display mean group jump performance, plus standard deviations, across all measured variables at each testing intervals. Table 4.6 highlights that CMJ and SJ peak force and jump height did not decrease significantly (p>0.05) when comparing baseline scores to scores recorded at any of the prescribed testing intervals.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre</th>
<th>24hrs</th>
<th>48hrs</th>
<th>72hrs</th>
<th>7days</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ Jump Height (cm)</td>
<td>38.41 ± 4.51</td>
<td>36.1 ± 4.77</td>
<td>37.91 ± 3.81</td>
<td>38.04 ± 4.63</td>
<td>38.41 ± 4.51</td>
</tr>
<tr>
<td>CMJ Peak Force (N)</td>
<td>2295 ± 218</td>
<td>2313 ± 374</td>
<td>2385 ± 340</td>
<td>2466 ± 335</td>
<td>2354 ± 240</td>
</tr>
<tr>
<td>SJ Jump Height (cm)</td>
<td>30.87 ± 3.56</td>
<td>28.59 ± 3.66</td>
<td>30.75 ± 3.73</td>
<td>30.85 ± 2.64</td>
<td>32.10 ± 2.48</td>
</tr>
<tr>
<td>SJ Peak Force (N)</td>
<td>2099 ± 197</td>
<td>2051 ± 211</td>
<td>2025 ± 192</td>
<td>2104 ± 218</td>
<td>2084 ± 237</td>
</tr>
</tbody>
</table>

CMJ = Countermovement Jump, SJ =Squat Jump. Change from baseline Significant at *p<0.05
Table 4.7 highlights that variables recorded during SH and DJ performance also did not present significant (p>0.05) performance decrements at any stage of the testing protocol.

Table 4.7: Study Two Subject Mean Plyometric Jump Performance.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Pre</th>
<th>24hrs</th>
<th>48hrs</th>
<th>72hrs</th>
<th>7d</th>
</tr>
</thead>
<tbody>
<tr>
<td>DJ Ground Contact Time (s)</td>
<td>0.184±0.02</td>
<td>0.185±0.02</td>
<td>0.180±0.15</td>
<td>0.173±0.02</td>
<td>0.182±0.01</td>
</tr>
<tr>
<td>DJ Flight Time (s)</td>
<td>0.405±0.03</td>
<td>0.402±0.06</td>
<td>0.392±0.04</td>
<td>0.400±0.06</td>
<td>0.406±0.05</td>
</tr>
<tr>
<td>DJ Jump Height (cm)</td>
<td>20.24±9.3</td>
<td>20.19±5.7</td>
<td>19.03±4.1</td>
<td>20.08±6.1</td>
<td>20.48±5.1</td>
</tr>
<tr>
<td>DJ Peak Landing Force (N)</td>
<td>566±1204</td>
<td>527±1014</td>
<td>570±1141</td>
<td>565±911</td>
<td>518±855</td>
</tr>
<tr>
<td>DJ RSI</td>
<td>1.109±0.19</td>
<td>1.104±0.32</td>
<td>1.066±0.24</td>
<td>1.181±0.38</td>
<td>1.128±0.28</td>
</tr>
<tr>
<td>SH Absolute Leg Stiffness</td>
<td>43.43±6.99</td>
<td>40.92±5.12</td>
<td>41.11±4.00</td>
<td>43.09±4.50</td>
<td>42.93±5.19</td>
</tr>
<tr>
<td>SH Mean Contact Time (s)</td>
<td>0.184±0.02</td>
<td>0.192±0.02</td>
<td>0.188±0.02</td>
<td>0.183±0.02</td>
<td>0.183±0.02</td>
</tr>
<tr>
<td>SH Mean Flight Time (s)</td>
<td>0.216±0.03</td>
<td>0.208±0.02</td>
<td>0.209±0.02</td>
<td>0.214±0.01</td>
<td>0.219±0.02</td>
</tr>
<tr>
<td>SH Relative Stiffness</td>
<td>0.470±0.09</td>
<td>0.444±0.06</td>
<td>0.451±0.06</td>
<td>0.468±0.06</td>
<td>0.466±0.07</td>
</tr>
</tbody>
</table>

DJ = Drop Jump, SH = Sub-maximal Hops
Change from baseline Significant at *p<0.05

Table 4.8 presents the change in effect size from baseline for all jump measures during study 2. Very large increases in CK were recorded at the 24hr testing interval, remaining moderately raised at 48hrs and 72hrs, before again experiencing a very large increase from baseline scores at the 7d interval. SJ height showed a moderate reduction 24hrs post test, while all other performance variables showed trivial or small changes across all times.

Table 4.8: Test Two Effect Sizes

<table>
<thead>
<tr>
<th>Variable</th>
<th>24hrs</th>
<th>48hrs</th>
<th>72hrs</th>
<th>7d</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMJ Jump Height</td>
<td>-0.47</td>
<td>-0.51</td>
<td>-0.11</td>
<td>-0.08</td>
</tr>
<tr>
<td>CMJ Peak Force</td>
<td>0.08</td>
<td>0.41</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>SJ Jump Height</td>
<td>-0.64</td>
<td>-0.03</td>
<td>-0.01</td>
<td>0.35</td>
</tr>
<tr>
<td>SJ Peak Force</td>
<td>-0.24</td>
<td>-0.38</td>
<td>0.03</td>
<td>-0.08</td>
</tr>
<tr>
<td>DJ Ground Contact Time (s)</td>
<td>0.05</td>
<td>-0.20</td>
<td>-0.55</td>
<td>-0.10</td>
</tr>
<tr>
<td>DJ Flight Time</td>
<td>-0.10</td>
<td>-0.43</td>
<td>-0.17</td>
<td>0.03</td>
</tr>
<tr>
<td>DJ Jump Height</td>
<td>-0.01</td>
<td>-0.36</td>
<td>-0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>DJ Peak Landing Force (N)</td>
<td>-0.32</td>
<td>0.04</td>
<td>-0.01</td>
<td>-0.40</td>
</tr>
<tr>
<td>DJ RSI</td>
<td>-0.03</td>
<td>-0.23</td>
<td>0.38</td>
<td>0.10</td>
</tr>
<tr>
<td>Hops Absolute Leg Stiffness</td>
<td>-0.36</td>
<td>-0.33</td>
<td>-0.05</td>
<td>-0.07</td>
</tr>
<tr>
<td>Hops Mean Contact Time</td>
<td>0.40</td>
<td>0.20</td>
<td>-0.05</td>
<td>-0.05</td>
</tr>
<tr>
<td>Hops Mean Flight Time</td>
<td>-0.27</td>
<td>-0.23</td>
<td>-0.07</td>
<td>0.10</td>
</tr>
<tr>
<td>Hops Relative Stiffness</td>
<td>-0.29</td>
<td>-0.21</td>
<td>-0.02</td>
<td>-0.04</td>
</tr>
<tr>
<td>CK</td>
<td>1.93</td>
<td>0.47</td>
<td>-0.28</td>
<td>1.46</td>
</tr>
</tbody>
</table>

Key

- **Small** (ES >0.2)
- **Moderate** (ES >0.6)
- **Large** (ES >1.2)
- **Very Large** (ES >2)
- **Extremely Large** (ES >4)
4.2.3. Relationship Between Jump Performance and Creatine Kinase

Significant correlations ($p<0.05$) were recorded between changes in CK and DJ ground contact time. Stronger correlations ($p<0.01$) were recorded in DJ peak landing force and CMJ peak force with CMJ peak force recording the strongest correlation ($r=-.514$). However, in contrast to study one, the variables that correlated significantly with changes in CK did not record significant changes at any of the testing time points.
CHAPTER 5

Discussion and

Conclusion
5.1. Study One

The aim of this study was to identify the method of jump performance that was most sensitively affected by muscle damage as a result of a controlled training stimulus designed specifically to cause muscle damage. From the results presented in Section 4.1 all jumps presented statistically significant and substantial decreases in performance in the first three days post eccentric training. In particular DJ height and RSI displayed very large (ES=3.53) reductions in performance in the three days post stimulus, while changes in DJ RSI significantly correlated with changes in CK.

CK increased from baseline levels post intervention and remained before returning to baseline levels at the 72hr mark. A prolonged raise of CK would be expected given the high eccentric volume of the fatiguing stimulus and the increased muscle damage experienced from this particular type of muscle contraction (Prosko and Morgan, 2001; Brancaccio et al., 2007). However, the increase in CK was not considered significant (p>0.05) despite presenting increases that were classed as ‘very large’ (ES=-3.53) and ‘large’ (ES=-1.48) at 24hrs and 48hrs post intervention, respectively. This may come as a result of the increase in standard deviation experienced between 24hrs (+577 U/I) 48hrs (+482.2 U/I) and 72hrs (+362 U/I) post intervention from baseline levels (+158 U/I) and this individual variability has been suggested as a limitation of hormonal measures alone to identify recovery from muscle damage (Brancaccio et al., 2007). The results of this study further support this assumption, in that, while the mean CK for the group increased after a training stimulus, the range of these rises between subjects was much broader than those presented at baseline, so much so that it may have affected the statistical significance of these increases. As a result, it appears that CK measures alone cannot be used to identify recovery from muscle damage in athletes undergoing high volumes of eccentric loading and that athletic performance measures may be required to further confirm the information presented from these tests.
All jumps presented significant (p<0.05, p<0.01) reductions in performance across at least one variable when tested immediately post intervention, with SJ experiencing significant decreases across all variables measured 4 minutes post intervention. Cheung et al., (2003) support this pattern in their integrated model of muscle damage in stating that the high tensile forces produced during the eccentric testing protocol will have disrupted the structural proteins in muscle fibres. However, SJ and submaximal hopping performance returned to levels similar to baseline at the 24hr testing interval before experiencing irregular reductions in performance across the remaining 7 day-testing period. DOMS is classified as occurring 1-2 days post exercise and is associated with a loss of muscle force generating capabilities (Conolly et al., 2003; Barnett, 2006). Given that CK, an indicator of muscle damage (Brancaccio et al. 2007), was at its highest during the 24hr and 48hr testing intervals it is assumed that any reduction in jump performance that comes as a result of muscle damage would be expected to demonstrate impairment, consistently, over a prolonged period of time, of up to 48-72hrs.

In contrast to the jumps above, CMJ and DJ presented variables that remained significantly reduced for an extended period of time. CMJ peak force remained consistently significantly (p<0.05) impaired until the 48hr interval, with DJ flight time; jump height and RSI remaining consistently significantly (p<0.05, p<0.01) impaired until the 72hr interval. While both methods demonstrate the potential ability of jump activities to highlight muscle damage through decreased physical performance, there is a difference between methods with regards to the sensitivity of this measure. When comparing the effect sizes of both jumps, CMJ peak force experienced small to moderate performance decrements. In comparison DJ experienced ‘extremely’ and ‘very’ large initial reductions in performance that slowly returned to trivial changes at the 7d testing interval with DJ RSI presenting the most significant (p<0.01) and largest changes. This information suggests that certain jump activities may be more suitable than others in assessing recovery from muscle damage, caused by a resistance training stimulus, and that DJ RSI, jump height or flight time, may be the most suitable variables to measure.
In order to state with full confidence that jump performance decreased as a result of muscle damage, the relationship between those variables presenting significant change and CK must be observed. Interestingly, CMJ peak force did not correlate significantly with changes in CK, which further supports the suggestion that this may not be an accurate measure of muscle damage when combined with the trivial effect sizes reported over the 7 day protocol. However, when comparing DJ RSI, flight time and jump height, RSI presented the largest percentage decrements and effect sizes of all variables measured throughout the study. In addition to this, RSI also displayed the highest correlation with changes in CK (p<0.01, r=-.610) and, as mentioned above, remained impaired for a prolonged period of time, in line with accepted models of the mechanisms of muscle damage (Cheung et al., 2003). From this information it can be considered fair to state that the RSI of a 30cm DJ provides the most sensitive method of accurately assessing performance decreases as a result of muscle damage, of the methods used in this study.

5.2. Study Two

The aim of this study was to identify the method of jump performance that was most sensitively affected by muscle damage as a result of a live competitive rugby union competition. From the results presented in section 4.2 it is evident that no jumps experienced significant change as a result of the muscle-damaging competition stimulus, despite a large increase in CK.

CK increased from baseline levels and remained elevated for an extended period of time before returning to near baseline levels at the 48 hr mark. This increase is in agreement with previous research, which suggests high impact collisions (Smart et al., 2006; Cunniffe et al., 2010) combined with periods of high intensity running (Thompson, 1999) as the predominant causes of muscle damage during rugby union competition. However, the increase in CK was, again, not considered significant (p>0.05) despite presenting large increases (ES=-1.93) at 24hrs post intervention. In similar fashion to study one, the standard deviation of CK increased considerably post intervention. This supports, once more, that the use of CK alone as an accurate measure of recovery from muscle damage caused during rugby union competition may be limited, without an additional supporting measures such as jump performance.
In contrast to study one, no jumps experienced significant reductions in performance across any measured variable throughout the duration of the testing protocol. In addition to this, despite some variables correlating significantly with CK (p<0.05, p<0.01), all jump performance variables showed trivial or small changes in effect size across all testing intervals excluding a moderate effect on SJ height at the 24hr testing interval (ES=-0.64). However, a detailed needs analysis of rugby union shows that players cover very small distances sprinting at high velocities during competition (Cahill et al., 2013) and as a result it is fair to suggest that the increases in muscle damage recorded in this study are as a result of impacts and collisions. If this is the case, the increases in CK presented may come as a result of damage to the shoulders, trunk and other appendages, and not exclusively the muscle of the lower limb more associated with sprinting performance. As a result, these results can be suggested to demonstrate that jump activities previously suggested as accurate methods of measuring recovery from muscle damage, may not be suitable for measuring damage acquired during participation in live rugby union competition.

5.3. Inter-Study Comparisons

Both studies present large spikes in CK post-intervention with sizeable inter-participant variability and, while neither study presented significant differences in CK, the effect sizes suggest that the stimulus used in study one (ES=3.53) caused greater levels of muscle damage when compared with study two (ES=1.93). The intervention in study one relied on high repetitions of a heavily loaded eccentric squat as a means of causing muscle damage whereas study 2 relied on participation in rugby union competition and, while research supports both interventions as mechanisms of muscle damage, it has long been accepted that eccentric exercise results in the most severe muscle damage in comparison to concentric and eccentric exercise (Fridén, 1983; Proske and Morgan, 2001). This is further supported by the fact that muscle damage remained largely increased for 72 hours in study one, in comparison the 48hrs presented in study two.
However, there are notable differences in the responses of jump activities to this damage when comparing between studies. Study one presents a number of variables that were significantly impaired post intervention whereas study two presented no significant change in any of the jumps measured. In addition to this, the effect size of the change from baseline measures was far greater in study one when compared with study two. Both studies adopted a consistent methodology with regards to the methods of assessing jump performance, as well as the intervals at which this testing was conducted, and the only difference between studies was the stimulus used to initiate muscle damage. An explanation for these sizeable differences in results therefore could be revealed by closely comparing the two interventions. While both studies present large increases in CK following a muscle-damaging stimulus, CK is measured from a blood sample and does not differentiate between global and localised damage as apposed to other proposed methods such as muscle biopsy (Ehlers, et al, 2002; Thompson et al., 1999; Brancaccio et al., 2007). The damage experienced during squatting specifically targets the muscles associated with extension of the hip, knee and ankle, as required during jumping where, in contrast, research suggests that the muscle damage experienced in study two came as a result of the impact of game collisions, which have a more global spread of damage in comparison to the stimulus of study one. These observations could explain the large differences in jump performance between studies.

A jump performed after explicitly damaging the lower limb in isolation, would be expected to present decreased performance and during study one DJ experienced the largest performance decrements post-intervention of all methods tested, with DJ RSI displaying the highest correlation with changes in CK (r=-.610). The DJ is a SSC activity, two important mechanisms of which are pre-activation and variable activation of the muscle preceding the functional phase of the given movement. These mechanisms are put under severe stress during fatigue and a DJ performed under these conditions will experience increases in contact time and reduced jump height (the two components of RSI) as a result of decreased strength, reflex activity and initial stiffness (Komi, 2000).
Alternatively, during study two, where muscle damage was not confined specifically to the lower limb, the DJ was not impaired significantly further supporting the suggestion that, while the stimulus of a live rugby union competition can induce large levels of muscle damage, this damage does not impact the musculature associated with jumping significantly enough to act a measure of recovery when compared from a controlled, eccentric training protocol.

These results suggest that, while physical performance markers, particularly DJ RSI, may be able to identify the extent of recovery from fatigue induced by muscle damage, the mechanism of damage must have a considerable enough impact on the musculature associated with the performance marker in order for this to be clearly apparent. Furthermore, in comparing the results of these studies it is apparent that results collected during experimental studies may not always be reflected in an applied setting.

5.4. Limitations of the Study

5.4.1. Quantifying Game Load and Collisions

The testing intervention of study two relies on, collisions and the work during rugby competition as the mechanisms of muscle damage which has been supported in previous research (Takarda, 2003; Smart et al., 2006). While participation time was consistent for all subjects, the extent of involvement can vary for each player depending on their position and the involvement required during the competition (Cahill et al., 2013). In this study no data is provided to quantify the extent of each players involvement in the match other than standardising game time for each player. Tools such accelerometers could provide quantifiable measures of the impact each player was subjected to during the competition (Cunniffe et al., 2009) and the use of GPS units could accurately measure the extent of each players involvement during the match (Varley et al., 2012; Cummins et al., 2013) however, these units are costly and were unavailable during the study. Any future research in this field should aim to utilise GPS or accelerometer data during competition to allow comparisons to further validate these claims.
5.4.2. Limitations of CK

Throughout this piece of research the individual variability of CK measures is referenced as a limitation of its use which is supported in the results of the both studies. It is important to note that, while this may be a limitation, the same study that suggests these limitations still supports that CK measures are still the most reliable and valid methods for assessing muscular damage (Brancaccio et al., 2007) in athletes.

5.5. Practical Applications

From the information presented above DJ RSI can be considered an effective measure of recovery from eccentric resistance training or exercise that specifically causes damage to the lower extremities. As a result strength and conditioning practitioners aiming to assess the recovery of their athletes from muscle damage should perform a DJ from 30cm.

However, while jump activities can be considered suitable for identifying a lack of recovery from muscle damage, it is important to note that it cannot be assumed that methods suggested as accurate during experimental research are precise as jump performance is dependent on the stimulus use to cause said damage. Before implementing a longitudinal monitoring programme utilising jump activities, as a marker of recovery from training and match participation in rugby union, the strength and conditioning practitioner must first determine whether or not the chosen jump responds accurately to the mechanism of muscle damage experienced by their athletes.

5.6. Conclusion

Within this study a rationale for the necessity of assessing recovery from muscle damage in rugby union is presented. Players participating in rugby union can be expected to accumulate muscle damage and fatigue as a result of both training and match play, both of which can have negative impacts on performance and susceptibility to injury. As a result, strength and conditioning practitioners have adopted a number of methods in an attempt to quantify the extent of recovery from muscle damaging activities including subjective measures (close monitoring of training volumes through RPS’s), objective hormone measures (monitoring CK levels
and testosterone:cortisol) and physical performance measures (jumping). Physical performance measures, such as jumping, are often implemented practically in rugby union as a result of their ease of application (Nédélec et al., 2012) and correlation with rugby performance (Cronin and Hansen, 2005; Hansen et al., 2011) and have been supported as suitable measures of recovery in research (Byrne and Eston, 2002a; Beneka et al., 2013). While the use of jump activities to assess recovery is common, there is a large degree of variety in research with regards to choice of jump and how this jump is measured and no research to date has attempted to compare the effectiveness of a variety of jumping activities against each other in both an experimental and practical environment.

To summarise the findings of these studies, DJ RSI is the most effective jump method measure to assess performance decrements of muscle damage produced during eccentric resistance training as a result of its correlations to changes in CK (r=-.610) and significant (p<0.01) reductions in performance post intervention. However, this result is not replicated in an applied rugby setting as study two presented no significant (p>0.05) decrements in any jump variables measured. It can be concluded from these results that, while jump activities can be used to identify the state of recovery from muscle damage, with RSI from a 30m DJ being the most effective measure, the success of these measures is dependent on the stimulus used to cause muscle damage. In addition to this it is fair to suggest, given the different studies, that results recorded in an experimental laboratory cannot be assumed to be representative of an applied, live environment. Further research is required to identify whether this method of jump is sensitive over a longer period of time with multiple muscle damaging interventions.
Reference List


Appendices
Appendix A: Participant Information Sheet

Title of Project: Monitoring Recovery From Muscle Damage in Rugby Union

Participant Information Sheet

The Background of This Study.

This study is an attempt to understand the impact of participation in rugby union training and competition on player recovery. It is being undertaken by Sam Dodge as a MPhil project and has been granted ethical approval by the ethics board of the University of Wales Institute, Cardiff.

In brief, this study is concerned with performance in a variety of jump based measures of performance and recovery, which will be taken at various intervals post a competition or training intervention, and requires training techniques that you will be familiar with through your participation in Cardiff Blues Academy programme organised by the WRU. There are two areas the study will examine:

(i) To understand the sensitivity of force plate data derived from various jump tests to identify the extent of recovery from fatigue produced during a controlled bout of training exercise.

(ii) To assess the effectiveness of various jump performances ability to identify the extent of recovery from fatigue produced during rugby union competition.

Why you?

You are being asked because you are a member of the Cardiff Blues Academy, also as part of my role as strength and conditioning coach for the programme I have opportunity to adjust your training itinerary accordingly.

What will happen?

The study will require you to complete a number of jumping activities prior to and after completing a competitive game and a training session designed to cause muscle damage and fatigue. The procedure involves countermovement, squat, and depth jumps, sub maximal hopping and finger capillary blood pricks to monitor creatine kinase.

Do I have to?

No, you don’t. No-one is forcing you. And if you start and decide you don’t want to carry on with the study, that’s fine. There’s no problem, just let me know.
What do we do?

When the information has been collected it will be analysed and presented in my findings as part of my masters degree. This is a field that hasn’t been extensively studied yet and if the results are significant it has a good chance of being published in an academic journal. The results will be presented and stored in such a way that your identity will remain anonymous.

Have you got any questions?

If you have any questions about the research or how I intend to conduct the study, please do not hesitate to contact me on the details below.

Sam Dodge

📞 07446936561
✉️ sadodge@cardiffmet.ac.uk

Thank you for your time.
Appendix B: Participant Information Sheet

Title of Project: Monitoring Recovery From Muscle Damage in Rugby Union

Parent / Guardian Information Sheet

Background

This study is an attempt to understand the impact of participation in rugby union training and competition on player recovery. It is being undertaken by Sam Dodge as a MPhil project and has been granted ethical approval by the ethics board of Cardiff Metropolitan University.

In brief, this study is concerned with performance in a variety of jump based measures of performance and recovery, which will be taken at various intervals post competition or training. You will be using training techniques that you will be familiar with through your participation in the Cardiff Blues Academy strength and conditioning programme organised by the WRU. There are two areas the study will examine:

(i) To understand the sensitivity of physical performance data derived from various jump tests in assessing the extent of recovery from fatigue produced during a controlled bout of training exercise.
(ii) To assess the effectiveness of various jump protocols to identify the extent of recovery from fatigue produced during rugby union competition.

Your child’s participation in the research project

Why your child has been asked

Your child has been invited to take part in the study because he is a member of the Cardiff Blues Academy. One of the requirements of the study is that the players have experience in weightlifting techniques and participate in rugby union. I have been granted access to the players as I am currently working as a strength and conditioning coach with the academy.

What would happen if you agree for your child to take part in the study?

If you agree for your child to join the study they will be required to complete a number of jumping activities prior to and after completing a competitive game and a training session designed to cause muscular fatigue. The procedure involves a range of jumping and rebounding protocols. All of these activities are common exercises/tests used as part of physical conditioning for rugby union and will not place your child under any unnecessary risk. Additionally we will be collecting small blood samples taken from finger pricks, which will be collected by an experienced researcher.
**Are there any risks?**

We do not think there are any significant risks to your child from taking part in the study. As stated above the training is very similar to what your child will have experienced before and their suitability to take part in sessions will be evaluated by the strength and conditioning staff within the academy.

**Your rights**

You have the right to withdraw your child from the study at any time and to deny their participation outright should you be unhappy with any aspect of the study.

**What happens to the results?**

When the information has been collected it will be analysed and presented in my findings as part of my masters degree. The results will be presented and stored, for a period of up to 7 years, in such a way that your identification will remain anonymous.

**Are there any benefits from taking part?**

Yes. If the study does highlight improvements to the training they are currently completing it could lead to more success when representing Cardiff Blues and their country.

**What happens next?**

With this letter you’ll find an information sheet for your child. There are also two forms to complete. The first is for you to give permission for your child to be involved in the study. The second is a different form for your child to complete to confirm that he is willing to take part. If you are willing for your child to participate, and he is too, these forms should be completed and returned to Rhodri Williams or myself.

**How we protect your privacy:**

As you can see, everyone working on the study will respect your privacy. We have taken very careful steps to make sure that you cannot be identified from any of the information that we have about you.
All the information about you and your child will be stored securely away from the consent and assent forms. At the end of the evaluation study we will destroy the information we have gathered about you and your child. We will only keep the consent and assent forms with your name and address. We keep these for ten years because we are required to do so by Cardiff Metropolitan University.

**Further information**

If you have any questions about the research or how we intend to conduct the study, please contact myself or Rhodri Williams.

Sam Dodge

📞 07446936561

✉️ sadodge@cardiffmet.ac.uk

Thank you for your time.
# CARDIFF MET 18+ PARTICIPANT CONSENT FORM

**Title of Project:** Monitoring Recovery From Muscle Damage in Rugby Union

**Name of Researcher:** Sam Dodge

---

**Participant to complete this section:**

Please initial each box.

1. I confirm that I have read and understand the information sheet dated ……… for this evaluation study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that my participation is voluntary and that it is possible to stop taking part at any time, without giving a reason.

3. I also understand that if this happens, our relationships with the WRU, the Cardiff Blues, with Cardiff Met University, or my legal rights, will not be affected.

4. I understand that information from the study may be used for reporting purposes, but that I will not be identified.

5. I agree to take part in this study.

---

**Name of Participant**

________________________________             ___________________

**Signature of Participant**          **Date**

---

* When completed, one copy for participant and one copy for researcher's files.
Appendix D: Child Subject Informed Assent Form

CARDIFF MET u18 PARTICIPANT ASSENT FORM

Title of Project: Monitoring Recovery From Muscle Damage in Rugby Union

Name of Researcher: Sam Dodge

Participant to complete this section: Please initial each box.

1. I understand that my parents/guardian have given permission for me to take part in a project about recovery from rugby training under the direction of Sam Dodge.

2. I confirm that I have read and understand the information sheet dated .......... for this evaluation study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

3. I understand my participation in this project is voluntary and I have been told that I may stop my participation in this study at any time without penalty and loss of benefit to myself.

4. I understand that information from the study may be used for reporting purposes, but that I will not be identified.

5. I agree to take part in this study.

________________________________________________________
Name of Participant

_____________________

Signature of Participant

_____________________
Date

• When completed, one copy for participant and one copy for researcher’s files.
Appendix E: Parent / Guardian Informed Consent Form

CARDIFF MET PARENT / GUARDIAN
CONSENT FORM

Title of Project: Monitoring Recovery From Muscle Damage in Rugby Union

Name of Researcher: Sam Dodge

Parent/Guardian to complete this section: Please initial each box.

1. I confirm that I have read and understand the information sheet dated .......... for this evaluation study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily.

2. I understand that the participation of my child is voluntary and that it is possible to stop taking part at any time, without giving a reason.

3. I also understand that if this happens, our relationships with the Cardiff Blues, the WRU, Cardiff Met University, or our legal rights, will not be affected.

4. I understand that information from the study may be used for reporting purposes, but that my child will not be identified.

5. I agree for my child to take part in this study.

__________________________________________                     ______________________
Name of Child                                              Name of Parent / Guardian

__________________________________________                     ______________________
Signature of Parent / Guardian                              Date

__________________________________________                     ______________________
Name Of Participant                                         Date

Signature of participant

* When completed, one copy for participant and one copy for researcher’s files.