**INJURY RISK MANAGEMENT IN
PROFESSIONAL RUGBY PLAYERS –
APPLICATION OF GPS TECHNOLOGY,
FUNCTIONAL MOVEMENT SCREENING
AND PERCEPTUAL FATIGUE
MEASURES**

A thesis submitted to the Faculty of Health Sciences, University of
Johannesburg, in fulfilment of the requirements for the degree of
Doctor of Philosophy: Sport Science

Jason Cameron Tee
(Student number: 920204725)

Supervisor : Prof. Y. Coopoo
Co-supervisor: Prof. M.I. Lambert

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For my loving and supportive wife,
Monique Clare Tee,

I couldn't have finished without you.

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DECLARATION

PhD THESIS TITLE:

**INJURY RISK MANAGEMENT IN PROFESSIONAL RUGBY PLAYERS –
APPLICATION OF GPS TECHNOLOGY, FUNCTIONAL MOVEMENT SCREENING
AND PERCEPTUAL FATIGUE MEASURES**

I, Jason Cameron Tee, hereby declare that this thesis is my own unaided work, both in concept and execution, and I have received no assistance apart from the normal guidance of my supervisors. Neither the whole, nor any part of this thesis has been, is being, or is to be submitted for another degree in this or any other university. The originality of this thesis document has been confirmed via submission to “TURNITIN” (Appendix 4).

I am now presenting the thesis for examination for the degree of PhD.

Signature:

31 August 2015

ABSTRACT

Background: Rugby union is a team sport played in professional leagues worldwide. Injuries occur frequently in professional rugby union, at a rate of 81 injuries per 1000 playing hours (95% CI 63 - 105) (Williams *et al.*, 2013). The frequency of injury within the professional game affects player wellbeing, as well as the overall performance of teams. As such it is necessary to develop strategies that will assist in minimizing the risk of injury to professional rugby union players.

Methods: A previously established injury risk management model (Fuller, 2007c) was applied within a professional rugby union team environment to determine the effect of various risk factors on injuries. Specifically, the risk factors assessed were the results of a pre-season functional movement screen (FMS), training volume and intensity and in-match player fatigue. Following risk factor assessment, global positioning system (GPS) monitoring was used to optimize training to match play.

Results: It was determined that a low score (≤ 13) in the FMS test is a risk factor for injury. Furthermore, very high and low training volumes and high training intensities were also established as injury risk factors. GPS analysis established the typical match play requirements of professional players. A comparison between these match play requirements and typical rugby union training activities determined that training was sub-optimal due to a lack of positional specificity. It was further determined that there are positional differences in the occurrence of fatigue during matches, and that differing management approaches would be required.

Conclusions: The injury risk management model identified a number of target areas for the reduction of injury risk among professional rugby union players. These include identifying “high-risk” players through pre-season movement screening; monitoring training volume and intensity and player fatigue; improving the specificity of training for players in different positional groups and increased awareness of the injury risk associated with in-match player fatigue.

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Tee, J.C., Klingbiel, J.F.G., Collins, R., Lambert, M.I. and Coopoo, Y., Functional Movement Screen predicts severe contact and non-contact injuries in professional rugby union players, *J Strength Cond Res.*, (in review)

Tee, J.C., Lambert, M.I. and Coopoo, Y., The impact of fatigue on rugby union movement patterns, *Int J Sports Physiol Perform.*, (in review)

Conference presentations

World Rugby Science Network Conference, 15-16th September 2015, Cape Town, South Africa. Invited speaker on the topic of “*Applications of GPS in rugby union matches and practice.*”

20th Annual Congress of the European College of Sports Sciences (ECSS), 24-27th June 2015, Malmö, Sweden. Oral presentation “*Rugby union movement patterns: The impact of fatigue and substitute players*”

South African Sports and Recreation Conference (SASReCon), 6-8th October 2014, Potchefstroom, South Africa. Oral presentations *“Movement and impact characteristics of South African professional rugby players”* and *“Functional Movement Screen predicts severe injuries in professional rugby players”*

TERMS, DEFINITIONS AND ABBREVIATIONS

Coefficient of variation (CV)

CV is calculated standard deviation of a measurement as a percentage of the mean. It is an important indicator of the reliability of a measure. A measure would be considered to have acceptable reliability of the CV is less than 5% (Hopkins, 1997).

Countermovement jump (CMJ)

CMJ is commonly performed assessment of neuromuscular power. The test typically requires participants to stand, before bending their hips and knees to a self selected depth, and then explode upwards in an attempt to achieve maximal height (Cormack *et al.*, 2008).

Effect size (ES)

ES is a measure of the magnitude of the standardized difference between two means. Jacob Cohen determined that this standardized difference, known as *Cohen's d*, can be calculated by determining the difference between two means divided by their pooled standard deviation (Hopkins, 2015).

$$d = \frac{\bar{x}_1 - \bar{x}_2}{s}$$

The effect sizes of <0.2, 0.5, 0.8 and 1.2 correspond to trivial, small, medium, large and very large differences respectively.

Functional Movement Screen (FMS)

The FMS is a comprehensive pre-participation and pre-season screen, that consists of seven tests/movements which challenge an individual's ability to perform basic movement patterns that reflect combinations of muscle strength,

flexibility, range of motion, coordination, balance and proprioception (Cook, Burton & Hoogenboom, 2006a, b).

Global positioning system (GPS)

Global positioning system (GPS) is a satellite-based navigational technology. The development of portable GPS units has permitted the application of this technology in sports settings (Cummins *et al.*, 2013). Positional data are determined by comparing the signal travel time of radio frequency signals sent from the orbiting satellite and a GPS receiver worn by a player/athlete. The distance to the satellite is then calculated by multiplying the signal travel time with the speed of light. By calculating the distance to at least 4 satellites, the exact position can be trigonometrically determined. Changes in speed (velocity) are usually determined via the Doppler shift method, that is, measurements of the changes in signal frequency due to movement of the receiver (Larsson, 2003).

Range of motion (ROM)

ROM is the measurement of movement around a specific joint or body part. Reduced ROM in is a risk factor for muscular strain type injuries in sports (Bradley and Portas, 2007).

Time-motion analysis (TMA)

TMA is a method of quantifying the type, duration, and frequency of discrete movements making up the intermittent activity patterns in team sports (Roberts, *et al.* 2008). Historically, TMA has been conducted through the application of either notational or video analysis, but more recently GPS technology has been utilized.

CHAPTER 1 - INTRODUCTION

1.1 Introduction

Rugby union is a global game, played in 120 countries and played by over 7.23 million players worldwide (World Rugby, 2015a). It is physically demanding game with an intermittent activity profile. The game is characterized by frequent bouts of high-intensity activities like running and sprinting and physical collisions such as tackling, scrummaging, rucking and mauling (Deutsch, Kearney & Rehrer, 2007; Duthie, Pyne & Hooper, 2005; Roberts *et al.*, 2008). Between these high-intensity exertions, players are engaged in low intensity movements, such as walking and jogging (Cahill *et al.*, 2013; Deutsch *et al.*, 2007; Duthie *et al.*, 2005; Roberts *et al.*, 2008). The frequent and intense collisions in professional rugby union result in substantial risk of injury among players (Williams *et al.*, 2013). Recently, it was revealed that 55% of players sustained a time-loss injury during elite professional competition (Schwellnus *et al.*, 2014). These injuries have negative consequences for individual players in terms of physical trauma and the financial and emotional cost of rehabilitation, and for teams in terms of reduced performance (Orchard, 2009).

Responsible management principles dictate that in any organization, internal controls should be present to “help manage and control risk appropriately” (Internal Control Working Party of the Institute of Chartered Accountants in England & Wales, 1999). In line with this, an established injury risk management model (Fuller, 2007c) was applied within a professional rugby union team setting with the aim of managing and controlling injury risk among the players. It should be appreciated that the objective of the risk management process is not to reduce risks to zero, but to control them within acceptable levels and then to ensure that players, coaches and medical staff are made aware of the residual risks (Fuller, Junge & Dvorak, 2012).

The risk management model is discussed in depth in Chapter 2. The process followed within this research thesis was to conduct a “risk evaluation” in the form of an injury audit to measure the current injury risk within the team, and compare that with previously reported rugby union epidemiological research. This investigation showed that the level of risk within the team studied was higher than in other professional rugby union teams.

Consequently, research was conducted into risk factors that may have been responsible for the increased injury risk, and into methods of risk mitigation. A novel risk factor for injury identified in this study was a low score (≤ 13) in a pre-season functional movement screen (FMS) (Cook, Burton & Hoogenboom, 2006a,b). Further injury risk factors identified were fatigue in various forms (activity-related, short-term and prolonged) (Twist & Highton, 2015). It was demonstrated that training volume and intensity affected injury incidence and severity within the player group.

In order to mitigate the risk presented by inappropriate training loads, time-motion analysis (TMA) utilizing global positioning systems (GPS) was conducted into match play and training. The objectives of this investigation were to determine the physical requirements of match participation for players in different positions, and then determine how specific training practices are to these match requirements. The outcome of this investigation was that the training practices of the team were largely non-specific for individual positional requirements, and that improving training practices would better prepare players for the demands of competition and may consequently reduce injury risk.

Further to this analysis, activity-related fatigue was identified as an injury risk factor based on literature review. Further GPS analysis was conducted to determine the nature of activity-related fatigue within match play and how this

could be best managed through the use of monitoring and substitutes. These risks were communicated to coaching and medical staff to facilitate improved management of these “high-risk” players.

1.2 Statement of the Problem

The game of rugby union has increased in intensity in recent years, with players covering more distance, performing a greater number of sprints, being involved in more collisions and having shorter rest periods during match play (Austin, Gabbett & Jenkins, 2011a,b). This increased intensity necessitates increased training loads for rugby union players. There are associations between increased training load and injury in rugby league (Gabbett & Jenkins, 2011c) and increased training volume and injury severity in rugby union (Brooks *et al.*, 2008a). This suggests that the more rugby players train, the more likely they are to become injured (Gabbett *et al.*, 2011c). In contrast to this assertion, research has also shown that rugby league players with well-developed physical qualities are at a reduced risk of injury (Gabbett, Ullah & Finch, 2012a). Based on the above information it becomes clear that coaches and trainers of rugby players have a difficult job. They must balance the need for improved fitness levels with the increased risk of injury associated with increased training loads.

1.3 Purpose of the study

The purpose of this study was to assess the application and impact of an injury risk management model within a professional rugby union team setting. The process followed was to determine the risk that the players within the team were exposed to, and then identify which risk factors could be managed or modified to mitigate injury risk. A key component within this process was the evaluation of the dose response relationship of training to injury incidence. It was necessary to determine what training load elicits sufficient physical adaptation for players to cope with the demands of the game, without subjecting players to an unreasonable risk of injury. This objective was complicated by the

fact that the physical attributes and movement patterns required of players in different positions in rugby union are highly varied (Deutsch *et al.*, 2007; Roberts *et al.*, 2008). There is a broad range of body mass, body composition, strength, power, and endurance characteristics between players in a typical professional squad (Duthie, Pyne & Hooper, 2003). Therefore, any training or match stimulus would be perceived differently among the members of the squad. Furthermore, forward positions are exposed to a greater number of contact events (tackle, ruck, maul, scrum) during match play (Deutsch *et al.*, 2007; Roberts *et al.*, 2008), increasing the potential for muscle damage (Johnston *et al.*, 2014c). It is, therefore, essential that training be individualized to cater for the differences in physical characteristics and demands of the playing positions. Prescribing the same training load to an entire squad will risk undertraining or over-training the players and also increasing the risk of injury. The purpose of this study, therefore, is to determine the movement and impact profiles of players participating in professional rugby union competition and based on this determination, optimize training and reduce injuries in a practically viable professional team setting.

1.4 Study Objectives

The translation of sports science research into high performance practice is often poor because sports science findings can be difficult to implement in a practical setting (Bishop, 2008). Researchers should consider how their findings would be applied and adopted in the actual sport setting with the limited resources and staff available (Bishop, 2008). The aim of this thesis was to describe the application of an injury risk management model within a rugby union team competing in South Africa's premier professional competitions. The ultimate aim of this intervention was to develop practically relevant methods of monitoring player fatigue and injury risk factors, to reduce injury incidence and improve performance. Figure 1.1 details how the chapters of this thesis were set out in order to attain the study objectives.

Background

Original investigations

Conclusion

Figure 1.1 – Overview of thesis chapters

1.5 Research Questions

Chapter	Research questions	Outcomes
2. Theoretical Framework and literature review	<ol style="list-style-type: none"> 1. What is injury risk management? 2. What is known regarding injury epidemiology and risk factors within rugby union? 	<ol style="list-style-type: none"> 1. Determine best practice for injury risk management within professional team sport. 2. Determine injury risk factors to be managed.
3. Injury risk estimation in a professional rugby union team	<ol style="list-style-type: none"> 1. What is the current level of injury risk within this team? 2. How does this compare with expected risk? 	<ol style="list-style-type: none"> 1. Determine whether current level of risk is acceptable. 2. Identify target areas for injury risk mitigation.
4. Pre-season functional movement screen as a predictor of injury in professional rugby union players	Can FMS predict injury within professional rugby union players?	Improved identification and management of "high risk" players
5. Monitoring training and fatigue within a professional rugby union team	<ol style="list-style-type: none"> 1. What is the relationship between training load and injuries? 2. How is this relationship best monitored? 	<ol style="list-style-type: none"> 1. Recommendations regarding training volume and intensity to minimize injury risk. 2. Evaluation of training monitoring protocols.
6. Match play movement and impact characteristics of professional rugby union players	What are the physical match play requirements of players in different positions?	Understanding of what players need to be able to do leads to production of position specific training programmes
7. Specificity of rugby union training activities for players in different positions	Are contemporary rugby union training activities specific to the match play requirements of players in different positions?	Improved specificity of training will ensure that players are better prepared.
8. Determining acute-fatigue during match play in professional rugby union	<ol style="list-style-type: none"> 1. What are the signs of player fatigue within professional rugby union match play? 2. Is the fatigue profile of players in various positions different? 	Know when player injury risk increases through activity-related fatigue and improve management thereof.

Figure 1.2 – Diagram indicating the steps followed during the application of an injury risk management model within a professional rugby union team. Each step answered a specific research question and forms a chapter within this thesis.

Each chapter within this thesis corresponds to a different step within the risk management process followed. Figure 1.2 describes the contents of each chapter and how these relate to the overall risk management process. Each chapter is presented as a self-contained research question that corresponds to a step within the injury risk management process, with its own rationale, context, methods and results.

1.6 Hypotheses

The following hypotheses are tested in this dissertation –

1. The injury risk of players within the professional team studied is higher than in similar player groups (Chapter 3).
2. A low score on the functional movement screen is a risk factor for injury in professional rugby union players (Chapter 4).
3. There is an inversely proportionate relationship between training volume and intensity and injury incidence and severity (Chapter 5).
4. Individual response to training can be measured through the use of simple assessments of psychophysiological stress (Chapter 5).
5. Readiness to train following match participation can be assessed using a counter movement jump test (Chapter 5).
6. Readiness to train following match participation can be assessed using simple range of motion (ROM) tests (Chapter 5).
7. Failure to recover, as assessed by readiness to train tests, is a risk factor for injury in professional rugby union players (Chapter 5).
8. The movement and impact profiles of players in different positions are different (Chapter 6).
9. Contemporary rugby union training activities are not specific to the match play requirements of players in different positions (Chapter 7).
10. Fatigue in professional rugby union players is represented by a decrease in total and high-intensity running distance during match play (Chapter 8).
11. The fatigue profile of players in different positions is different (Chapter 8).

CHAPTER 2 - THEORETICAL FRAMEWORK AND LITERATURE REVIEW: INJURY RISK MANAGEMENT IN PROFESSIONAL RUGBY UNION

In this section, the theory related to the framework of the study will be described using existing literature, motivating the research path of this study.

2.1 Injury Risk Management

Risk management is a term used in business to describe the identification, assessment, and prioritization of risks, followed by coordinated and economical application of resources to minimize, monitor, and control the probability and/or impact of unfortunate events (Hubbard, 2009). The presence of a well-established risk management system is a benchmark of good governance in both public and private enterprises (Internal Control Working Party of the Institute of Chartered Accountants in England & Wales, 1999).

Generally, sport and exercise are considered to have long-term health benefits for participants; however, all physical activity carries risks that participants will sustain an injury as a result of participation (Fuller & Ward, 2008a). Injuries are a relatively common occurrence in professional sports participants (van Mechelen, Hlobil & Kemper, 1992) and have negative health and financial implications for the individuals involved. In particular rugby union has one of the highest injury incidence of any global team sport (Williams *et al.*, 2013). Beyond the negative consequences for the individual involved, injuries also affect teams in terms of performance and final league placing (Meir, Diesel & Archer, 2007; Orchard, 2009), which has serious implications in terms of lost revenue.

An injury risk management model for sport has previously been described, (Fuller & Drawer, 2004a; Fuller, 2007c) and successfully been applied within football (figure 2.1) (Fuller *et al.*, 2012). This framework provides a structure within which sporting organisations can identify, classify and investigate risks using a logical and transparent protocol. It is important to note at this point that risk management processes will never reduce risks to zero, but assist to control them within acceptable levels (Fuller *et al.*, 2012).

Figure 2.1 – Injury risk management model reproduced from Fuller *et al.* (2012)

Table 2.1 provides brief definitions to provide clarity to the terms used within this model. Briefly, the central premise of the injury risk management model is the identification of intrinsic and extrinsic risk factors affecting participants followed by the estimation and evaluation of the level of risk associated with these factors in a process collectively known as ‘risk assessment’ (Fuller *et al.*, 2012). These risks should be reported to the various stakeholders (players, coaches, medical staff, team management, etc.). When the total level of risk, or the risk associated with any individual risk factor is considered to be too high then risk mitigation strategies should be considered. Risk mitigation strategies may aim to either reduce the incidence of injury (preventative interventions) or reduce injury severity (therapeutic interventions) (Fuller *et al.*, 2012).

Table 2.1 – Core definitions associated with injury risk management protocol. Reproduced from Fuller *et al.* (2012).

Term	Definition
Risk	A combined measure of the probability of occurrence and the consequences of an injury event
Risk factor	A condition or situation that predisposes an individual to injury
Intrinsic risk factor	Risk factors related directly to the participant such as age, level of experience, previous injury and training load
Extrinsic risk factor	Risk factors external to the participant such as playing surface, equipment and environmental conditions
Risk estimation	A quantitative or qualitative measurement of the risk associated with specific risk factors
Risk evaluation	The comparison of measured or perceived risks against an organizational, national or international standard of an acceptable level of risk
Risk assessment	The combined processes of risk estimation and risk evaluation
Risk mitigation	The introduction of measures to reduce the level of individual or organizational risk arising from specific risk factors

2.2 Injury risk factors

A key process within the injury risk management model for the reduction of injury risk is the identification of injury risk factors. In order to understand how individual risk factors affect overall injury risk, it is important to understand how these risk factors relate to the causation of injury. Meeuwisse (1994) developed a sports injury causation model that explains the influence of intrinsic and extrinsic risk factors on injury occurrence (figure 2.2). This model proposes that the occurrence of injury is multifactorial in nature, with intrinsic and extrinsic risk factors combining to predispose athletes to injury before an inciting event can take place (figure 2.2) (Meeuwisse, 1994). The inciting event for injuries involves the physical loading of body tissues, and the inability of the tissue to tolerate that particular load (McIntosh, 2005). Load and load tolerance are influenced by intrinsic and extrinsic risk factors as well as the injury event itself (Bahr & Krosshaug, 2005). Repeated cycles of exposure to sport participation may have the effect of modifying injury risk factors based on the adaptation/maladaptation of the participant and should be taken into account (Meeuwisse *et al.*, 2007).

Figure 2.2 – Complex interaction between internal and external risk factors leading to an inciting event and resulting in injury (Meeuwisse, 1994).

2.3 Risk assessment and mitigation

The overall process of risk assessment refers to the identification of injury risk factors, followed by the estimation and evaluation of those factors. Risk estimation is carried out through epidemiological studies and risk evaluation is completed by comparing the results of these studies to other populations or to the perception of acceptable risk. Following risk evaluation, if the risk associated with any of the potential risk factors is considered too high, risk mitigation strategies should be employed. Further epidemiological studies are then used to assess the effect of the mitigation strategy employed. The final step in the risk management process should be to communicate residual risks (following mitigation) to all of the affected stakeholders (players, coaches, strength and condition and medical staff) so that informed decisions regarding the risks can be made (Fuller *et al.*, 2004a; Fuller *et al.*, 2012; Fuller, 2007c).

There are two general ways in which the risk of injury from a particular risk factor can be mitigated (Fuller & Vassie, 2004b), either through risk acceptance (e.g. self-insurance, organisational acceptance) or through risk reduction (e.g. control, elimination). Typically, professional sports teams manage injury risk through a combination of “risk acceptance” and “risk reduction” approaches. Risk acceptance, is a risk management strategy where an organisation sets aside resources as insurance to protect against a probable loss (Hubbard, 2009). With regard to injury risk, this approach dictates that teams accept that injuries will occur during the season and that “spare” players are required to replace first choice players as they become injured. In contrast to this approach, “risk reduction” strategies involve the use of preventative strategies to reduce injury incidence and therapeutic strategies to improve return to play time following injury. Practically speaking, professional teams need to employ both risk acceptance and risk reduction strategies. Teams must retain the services of enough players to meet the playing demands, but should also be actively involved in reducing player injury risk. Economically, there is a greater incentive

to invest in the risk reduction approach, as this reduces reliance on large player numbers. This reduces the wage bill or alternatively increases the wage per player that a team can afford.

2.4 Review of related literature: Management of players to reduce injury in professional rugby union

The following section will discuss previous research in regard to the physical requirements and typical injury profile within professional rugby union. Thereafter, various injury risk factors will be discussed as well as contemporary practices in terms of managing these risks.

2.4.1 Physical requirements of rugby union

Rugby union is a global collision sport played in 120 countries worldwide (World Rugby, 2015a). The sport is characterized by frequent bouts of high-intensity exercise (e.g. sprinting, tackling and grappling) interspersed by periods of lower intensity activity (e.g. standing, walking and jogging) (Deutsch *et al.*, 2007; Duthie *et al.*, 2005; Roberts *et al.*, 2008). Players cover ≈ 5000 to 7000m during match play depending on their position (Cahill *et al.*, 2013). The mean movement demands of match play are relatively low ($\approx 68\text{ m}\cdot\text{min}^{-1}$) in comparison to other global team sports (Cahill *et al.*, 2013), but the demands of the game are significantly increased by the frequency of physical collisions that occur (Gabbett, 2015a). Players are typically involved in 10-22 tackles per game (Quarrie *et al.*, 2012). In addition to the involvement in physical collisions, rugby union players are regularly exposed to 7 to 17 repeated high-intensity effort bouts (three or more sprints, scrums/rucks/mauls or tackle efforts with less than twenty-one seconds between efforts) per game (Austin *et al.*, 2011b).

Analysis of physical attributes of rugby union players indicates that increased body mass and stature, and reduce body fat percentage and sprint time are all associated with higher playing levels within rugby union (Duthie *et al.*, 2003).

Furthermore, lower-body strength (3RM squat) and power (counter movement jump height), upper body strength (3RM bench press and chin up) and endurance (body-mass maximum repetition bench press), and prolonged high-intensity intermittent running ability (Yo-Yo intermittent recovery test, level 1) were associated with selection for higher levels of competition in rugby league (Gabbett & Seibold, 2013a). In addition, lower body strength was associated with distance run and repeated high-intensity efforts performed during match play (Gabbett *et al.*, 2013a). Ball-carrying ability (Waldron *et al.*, 2014) and tackling ability (Gabbett, Jenkins & Abernethy, 2011a) are positively associated with acceleration (10m sprint) and lower body power. Well-developed upper body strength and prolonged high-intensity intermittent running ability (8 x 12 second shuttle sprints on a 48 second cycle) have been associated with reduced injury incidence in professional rugby league players (Gabbett *et al.*, 2012a). Collectively, these results suggest that specific anthropometric and fitness qualities are associated with elite performance in rugby union.

2.4.2 Injury incidence and severity in rugby union

The nature of match injuries in professional rugby union is well researched, and players can expect an average injury incidence of 81 injuries per 1000 playing hours (95% CI 63 - 105) (Williams *et al.*, 2013). Injury incidence in rugby union tends to increase with the level of play, with the highest injury incidence being recorded in international competition (123 injuries per 1000 playing hours, 95% CI 85 – 177) (Williams *et al.*, 2013). The average severity of injuries in professional rugby union, defined as the number for days that the player cannot train, is 20 days (95% CI 14-27). It has been estimated that, on average, a professional club will have 18% of their playing squad unavailable due to injuries sustained in matches (Brooks *et al.*, 2005a).

The body regions most commonly injured during matches are the lower limbs (incidence 47 injuries per 1000 playing hours, 95% CI 26-84; severity 19 days,

95% CI 13-26), followed by the upper limbs (incidence 14 injuries per 1000 playing hours, 95% CI 8-25; severity 32 days, 95% CI 26-38), head (incidence 13 injuries per 1000 playing hours, 95% CI 7-23; severity 12 days, 95% CI 6-18) and then trunk (incidence 9 injuries per 1000 playing hours, 95% CI 5-16; severity 16 days, 95% CI 9-22) (Williams *et al.*, 2013). Contact events, such as tackling, being tackled, scrumming and ruck/maul involvement account for approximately 80% of all match injuries (Williams *et al.*, 2013).

The epidemiology of training injuries is less clearly defined. Meta-analysis indicates that the incidence of training injuries for professional rugby players are 3 injuries per 1000 training hours (95% CI 2 - 4) (Williams *et al.*, 2013). The mean severity of training injuries tends to be greater than that of match injuries (Brooks *et al.*, 2005b; Fuller *et al.*, 2008b; Fuller, Sheerin & Targett, 2013). Data from Rugby World Cup competitions indicates that the majority of training injuries occur during contact training sessions (Fuller *et al.*, 2008b; Fuller *et al.*, 2013). In contrast, other researchers have indicated that running is the predominant cause of training injuries (Brooks *et al.*, 2005b; Kemp *et al.*, 2012). This difference may be because teams do not expose themselves to high running loads during World Cup tournaments.

As in match play, the lower limb is the body location most likely to be injured during training (Brooks *et al.*, 2005b; Fuller *et al.*, 2008b; Fuller *et al.*, 2013). The England Rugby Premiership Injury and Training Audit 2010-2011 indicated that hamstring injuries have been the most common and highest risk (days lost) training injury from 2002 to 2011 (Kemp *et al.*, 2012). Overall, it is estimated that on average 5% of professional club players will be unavailable for selection due to training injuries (Brooks *et al.*, 2005b).

Despite the wealth of information regarding the incidence, severity and cause of injuries in professional rugby union, relatively little is known about specific injury

risk factors in rugby union (Gabbett *et al.*, 2012a). In addition, very little is known about how increased training loads relate to injury incidence in rugby union. The training load injury dose response relationship is well established in rugby league (Gabbett *et al.*, 2011c; Gabbett, 2010b), yet similar investigations have not taken place in rugby union. The aim of this review is to report on the known risk factors for injury in rugby union and how they would be optimally managed. Furthermore, based on research in other sports, we aim to identify novel risk factors for rugby union that can be managed to further improve any injury risk management programme.

2.4.3 Movement screens

Many injury management programmes centre on the quantity of physical exertion that players are exposed to, and how best to manage those loads (Gabbett *et al.*, 2011c; Gabbett, 2010b; Rogalski *et al.*, 2013). However, an important and often neglected consideration is the quality of movement that a player is capable of. Asymmetries in muscular strength and flexibility are known risk factors for injury in athletes (Knapik *et al.*, 1991), and poor ROM predisposes team sport players to muscular strain injuries (Bradley & Portas, 2007). Therefore, musculoskeletal screening of players should be conducted prior to the start of the season to identify players at risk for injury (Bradley *et al.*, 2007). These players should be placed on a pre-habilitation programme designed to address the imbalances identified.

Dysfunctional movement patterns may affect the rate of accumulation of fatigue over the course of a season. If two players perform the same training session, but one player is more efficient in the movements he performs, the inefficient player will have worked relatively harder and experience a greater training load than his more efficient counterpart. This is a further reason for continually monitoring the training response.

An overwhelming variety of musculoskeletal assessments exist, which can make pre-season screenings exceedingly time consuming in a team sport environment. Practitioners should aim to utilize screening tests that are quick to administer and have predictive value in terms of determining players at risk of injury (Meeuwisse & Fowler, 1988). The Functional Movement Screen™ (FMS) is a promising screening tool because it assesses balance, core strength and range of motion simultaneously to provide an integrative assessment of movement quality (Cook *et al.*, 2006a, b). The test takes only a few minutes to administer and is reliable between raters of varied experience (Minick *et al.*, 2010). Importantly, the test has been shown to predict injury in contact sport athletes (American football) (Kiesel, Butler & Plisky, 2014; Kiesel, Plisky & Voight, 2007), but has yet to be tested in rugby union. Better performances in the FMS test has also been associated with longitudinal improvements in track and field performance, possibly because these athletes suffer less lost training time due to injury (Chapman, Laymon & Arnold, 2014).

2.4.4 Fatigue and recovery

Participation in a professional rugby union match is known to reduce muscle function for up to 36 hours after a match and results in both hormonal and mood disturbances (West *et al.*, 2013), suggesting that tissue damage and fatigue are present in the days after a match (Twist & Highton, 2015). The magnitude of fatigue experienced by players will depend on the duration of match involvement, and the movement and contact demands placed on the players (Twist & Highton, 2015). Typically, all symptoms of fatigue are recovered within 60 hours (West *et al.*, 2013) following a match, but large match or training loads and poor recovery practices may extend the time course of recovery. Figure 2.3 illustrates this complex interaction between training stimulus, fatigue and recovery.

Black Line represents well-managed player showing a short-term fatigue response to match/training and the typical course of recovery time. Dotted grey line represents a player experiencing higher match/training load followed by greater short-term fatigue response and slower recovery. Dashed grey line shows fatigue response when under-recovered player is exposed to additional fatiguing activity, leading to increased risk of prolonged and potentially chronic fatigue. Key factors contributing to player fatigue response are indicated above.

Figure 2.3 – Factors influencing fatigue and recovery of players during and after rugby-related activity. Reproduced from Twist et al. (2015)

Figure 2.3 shows how training in the context of incomplete recovery could lead to reduced performance and susceptibility to injury (Twist & Highton, 2015). Based on this information, three types of fatigue; activity-related, short-term and prolonged; are typically experienced in rugby union. All three types of fatigue are likely risk factors for injury.

Activity-related fatigue

The risk of activity-related fatigue is demonstrated by the fact that less injuries occur in the first, than in the second, third and fourth quarters of matches (Williams *et al.*, 2013), and the highest injury incidence among starting players is in the fourth quarter (Brooks *et al.*, 2005a). This suggests that as players begin to suffer higher levels of activity-related fatigue, their injury risk increases.

The tackle is the inciting event responsible for the largest proportion of injuries in rugby union. Tackling is a high-coordination skill where a player must make contact with and pull to ground an opposing player trying to avoid being tackled and often moving at high speed (Hendricks & Lambert, 2010). A possible mechanism for the increased risk of injury during the latter period of matches may be reduced tackle skill as a result of fatigue (Hendricks & Lambert, 2014c).

Tackles result in the most injuries in rugby union because they are the contact event that occurs most frequently however, the relative risk of tackling is low compared to other rugby activities (scrumping, collisions) (Fuller *et al.*, 2007b). This suggests that if players can perform tackles with a high degree of competency the risk of injury is not unduly high. It has been demonstrated that tackling technique becomes worse when players are fatigued (Gabbett, 2008b). A link between tackling proficiency and injury incidence has not yet been demonstrated (Gabbett & Ryan, 2009), but recently published models of tackling injury risk suggests that fatigue is a key risk factor in tackling injury (Hendricks *et al.*, 2014b; Usman, McIntosh & Fréchède, 2011). Well-developed physical qualities (1RM weighted pull up and prolonged high-intensity intermittent running ability) are associated with reduced contact injury risk (Gabbett *et al.*, 2012a), possibly because these qualities delay the onset of fatigue. Players should be physically well-conditioned to cope with the demands of the game to minimize fatigue related injury risk. Furthermore, players should be closely

monitored during match play to determine when they are fatigued and, whenever possible, fatigued players should be substituted to prevent injury.

Short-term fatigue

Short-term fatigue following participation in a rugby union match is characterized by reductions in neuromuscular function, hormonal and mood disturbances, all of which, should return to baseline levels within 60 hours (West *et al.*, 2013). Although short-term fatigue could also occur following a training session, general practice in professional rugby union is to ensure recovery from a match and then enter a training micro-cycle to prepare for the following match (typically 6 to 7 days) (Higgins, Climstein & Cameron, 2013). Within a team of players participating in the same match there will be large variations in the physical load experienced, due to differences in movement demands (Twist *et al.*, 2012) and contact loads experienced (Johnston *et al.*, 2014c). Furthermore, individual variation in response to exercise stimulus dictates that there would be a range of fatigue responses following match play, even if the playing demands were similar for all players (Mann, Lamberts & Lambert, 2014).

Therefore, the time course of recovery will not be the same for all players, and should be monitored to optimize when players should return to full training. Figure 2.3 demonstrates how training in the presence of incomplete recovery may result in a prolonged fatigue response (Twist & Highton, 2015). Incomplete recovery leads to reductions in physical performance parameters such as high-speed running, maximal accelerations and tackling ability (Johnston, Gabbett & Jenkins, 2013), and may lead to increased match injury rates (Dellal *et al.*, 2013). For these reasons, recovery from short-term (match) fatigue should be carefully monitored.

Prolonged fatigue

In a typical one-week training micro-cycle in rugby union, the match represents the greatest physical exertion. The rest of the training cycle is structured to ensure an adequate training stimulus is received, but most importantly that full recovery has occurred before the following match is played (Higgins *et al.*, 2013). There is a delicate balance between training load and recovery required to sustain high performance.

Research in professional rugby league players has shown that greater training loads are associated with higher injury rates both in-season (Gabbett *et al.*, 2011c; Gabbett, 2010b), and during pre-season (Killen, Gabbett & Jenkins, 2010). Rugby union research has shown that increased training volume is positively associated with injury severity (Brooks *et al.*, 2008a). These findings would seem to indicate that the harder the rugby players train, the more likely they are to sustain injuries. Repeated practice training loads that are larger than required likely lead to incomplete recovery and may cause a prolonged fatigue effect, which is a risk factor for injury. On the other hand, certain physical qualities such as lower body strength and prolonged high-intensity intermittent running ability must be developed to ensure success in match play (Gabbett *et al.*, 2013a). Strength and conditioning coaches are, therefore, under pressure to develop all of these physical qualities within their players.

Based on these two arguments, it is prudent to carefully monitor player training loads to ensure that adequate training stimulus is received to maintain or improve physical performance, but also that the training load is not so large that recovery cannot be achieved between training sessions. Dellal *et al.* (2013) has shown that the match injury rate increases in intense periods playing periods with reduced recovery time in soccer. In addition, it has been demonstrated that results in a mid-season perceptual-fatigue questionnaire were associated with burnout at the end of the season. Meeuwisse *et al.* (2007) has demonstrated

that repeated cycles of training modify the effect of internal and external injury risk factors. This means that training loads that were easily tolerable in the early part of the season may become risk factors later in the season based on the interaction of a number of other season variables. Indeed, Gabbett *et al.* (2010b) demonstrated that the injury response to a similar training load was higher in the late-competition than the early-competition phase. These findings demonstrate why the response to training should be continually monitored throughout the season.

2.4.5 Individual variation among rugby union players

A major challenge for practitioners in rugby union is the broad differences in the physical attributes and abilities of players in different positions. Various researchers have documented the differences in movement patterns and physical requirements of players in different positions and have called for individualized training programmes reflecting these differences (Austin *et al.*, 2011a; Cahill *et al.*, 2013; Deutsch *et al.*, 2007; Roberts *et al.*, 2008). For example, professional tight forwards were reported to run 5408 ± 702 m ($\approx 8\%$ high-intensity running), while outside backs ran 6190 ± 929 m ($\approx 12\%$ high-intensity running) during English Premiership match play (Roberts *et al.*, 2008). In this study, outside backs ran 15% further and covered 56% more distance in high-intensity running than tight forwards did. Tight forwards are known to be heavier than outside backs (Duthie *et al.*, 2003), which likely influences their rate of fatigue resulting in reduced running distance. Regardless, a running training session pitched between these two extremes may under prepare outside backs, but be overly challenging for tight forwards. The time course of recovery for these players exposed to the same training session could be drastically different, based on differences in the physical profiles of the players and on individual variation in response to training (Mann *et al.*, 2014). This may reveal why the largest proportion of training injuries occur during traditional conditioning training (running without the ball) (Brooks *et al.*, 2005a; Brooks *et al.*, 2005b;

Gabbett & Godbolt, 2010d), as the running loads may not be differentiated by position.

2.4.6 Monitoring training loads and training response in rugby union

Monitoring the training load of athletes is important to determine whether an athlete is adapting to the training programme and to minimize the risk of non-functional overreaching (fatigue lasting weeks to months), injury, and illness (Halsen, 2014). Training should be titrated against individual fatigue responses to be appropriate for various competition phases (e.g. pre-season or in-season) (Halsen, 2014). A number of methods are available for monitoring both training load, and response to those training loads within the realm of professional competition. Halsen (2014) has performed an extensive review of these measures, and only the ones available for use within this research project are further explored here.

When monitoring training load, measures can be thought of as either internal or external. External load is generally measured in term of the actual physical load completed by an athlete (e.g. distance run, weight lifted or power output). In contrast, internal load estimates the relative physiological or psychological stress imposed by a given training load (Halsen, 2014). Dissociation between external and internal training loads (e.g. a higher than normal stress response to a given training session), is indicative of fatigue in an athlete (Pyne & Martin, 2011).

External load monitoring

Global positioning systems (GPS)

Modern GPS player tracking systems are able to provide accurate, non-invasive, real-time movement analysis within team sport match play and practice environments (Aughey, 2011). GPS units are able to measure total distance, maximum speed, and speed within arbitrarily defined speed zones (e.g. walking, jogging, sprinting, etc.) (Aughey, 2011). Speed zones can be set using absolute

speed thresholds, or relative thresholds based on a players individual peak velocity (Gabbett, 2015b). The use of individualized speed zones tends to increase the amount of high-speed running apportioned to slower players, and decrease the amount apportioned to faster players (Gabbett, 2015b). The reliability of GPS measurements improves with increased sampling rate (Varley, Fairweather & Aughey, 2012). Reliability of measurement is somewhat reduced at the highest velocities and during rapid change of direction tasks (Aughey, 2011).

Various brands of GPS tracking devices are available within the market. The GPS devices used in this research thesis were SPI-Pro units (GPSports, Canberra), which sample positioning data at a frequency of 5Hz. The validity and reliability of these units has been previously established (Coutts & Duffield, 2010; Petersen *et al.*, 2009; Waldron *et al.*, 2011). In particular, the validity for speed zones walking (SEE $1.0 \pm 0.4\%$), jogging (SEE $3.7 \pm 1.4\%$) and striding (SEE $3.0 \pm 1.1\%$) is strong (Petersen *et al.*, 2009). The validity of distance measures in sprint zones ($>5\text{m}\cdot\text{s}^{-1}$) is less accurate (SEE $10.5 \pm 3.9\%$), typically underestimates sprint distance and should be interpreted carefully (Petersen *et al.*, 2009). SPI-Pro GPS units reliably measure peak velocity (CV 2.3 90%CI 2.1-6.6) (Coutts *et al.*, 2010). Despite concerns over the validity of distance measures in sprint zones, these units have previously been used in other rugby related research studies (Cahill *et al.*, 2013; Granatelli *et al.*, 2013; Kempton *et al.*, 2013; McLellan & Lovell, 2012).

One concern regarding the use of GPS tracking, is that the units are unable to quantify the load of actions such as kicking, jumping and tackling (Aughey, 2011). For this reason, manufacturers have included a tri-axial accelerometer in the design in an attempt to quantify collisions (Gabbett, 2012c). Previous research utilizing the SPI-Pro GPS units has demonstrated that there is no association between contact events (tackles, rucks, etc.) and high-intensity impacts recorded by the accelerometer (Gabbett, 2012c; McLellan, Lovell & Gass, 2011a).

Accelerometer measures do however correlate with creatine kinase concentrations (McLellan *et al.*, 2011a), and reductions in measures of neuromuscular function (McLellan *et al.*, 2012) following match play. This information suggests that while they are unrelated to the occurrence of actual contact events, accelerometer measures are associated with the occurrence of muscle damage.

There are a number of potential applications of GPS technology within an injury risk management framework. These are:

1. providing match play norms for movement characteristics including extreme values and expected variability
2. determining whether players match exertions exceed the norm and additional recovery may be required.
3. monitoring running distances and intensities during training.
4. determining the specificity of training activities to match play demands.
This technique has already been successfully applied within rugby league (Gabbett, Jenkins & Abernethy, 2012b).
5. live monitoring of players during matches to determine the onset of fatigue.

A number of these applications are explored within this research thesis.

Internal load monitoring

Session-RPE

A convenient method of monitoring daily training load is the session-RPE method (Foster *et al.*, 2001). Each player's reported rating of perceived exertion (RPE) for a training session is multiplied by the session duration (in minutes) to provide an approximation of the overall internal training load experienced. This method was developed to eliminate the need to utilize heart rate monitors to measure exercise intensity (Halsen, 2014). Session-RPE measures correlate well with exercise heart rate ($r = 0.89$) and blood lactate concentration ($r = 0.86$) during

rugby league training (Gabbett *et al.*, 2011c). Studies in rugby league (Gabbett *et al.*, 2011c; Gabbett, 2010b) and Australian Rules football (Rogalski *et al.*, 2013) have all linked higher training loads based on the session-RPE method with increased injury risk. No research has yet been published describing the training load injury relationship in rugby union.

Monitoring training response

The previous section addressed some methods with which the actual load of training can be quantified. However, within the context of variable individual responses to training (Mann *et al.*, 2014), it is prudent to regularly assess how athletes are responding to the training loads they are being subjected to. Accessible and cost-effective methods for assessment of recovery training response include questionnaires and subjective assessments of fatigue, neuromuscular function and performance tests (Twist & Highton, 2015).

Monitoring training response – external methods

Performance tests

A key consideration in the use of performance tests to assess fatigue status is that the test should not result in additional fatigue for an already under-recovered player (Nédélec *et al.*, 2012). As such, performance tests should be limited to submaximal protocols such as the HIMS test (Lamberts *et al.*, 2004), short maximal speed (10m sprint) or strength and power (1-3RM) tests (Coutts *et al.*, 2007a) that will not result in residual fatigue. For submaximal tests, fatigue will be expressed as an increase in heart rate and/or rating of perceived exertion (RPE) at set exercise intensity (Lamberts *et al.*, 2004). Wherever possible, performance tests should be integrated with regular training (Twist & Highton, 2015). Submaximal tests can be performed as part of warm-up, while maximal speed and strength can be monitored during training through the use of GPS and commercially available power monitoring systems (Twist & Highton, 2015). Players who are unable to reproduce previous standards of performance for

maximal tests, or have increased heart rate or RPE during submaximal tests, are not fully recovered and should not be exposed to high-intensity training until full recovery has occurred.

Neuromuscular function

Assessments of neuromuscular function such as jump tests or sprint performance, are popular within team sport environments because they are simple to administer and do not cause additional fatigue (Twist & Highton, 2013). Assessing neuromuscular function through jump tests has shown impaired jump ability for 24-36 hours following participation in rugby match play (McLellan, Lovell & Gass, 2011b; Twist *et al.*, 2012; West *et al.*, 2013). While the use of a force platform is desirable, cheaper contact mats that assess only flight time can be reliably used to assess jump ability (Twist & Highton, 2015). Jump ability, therefore, produces a “readiness for activity” measure. It can be assumed that once a player’s jump ability has returned to normal, he is no longer experiencing the fatigue of a previous exercise bout, and is ready to resume training at full intensity.

Range of motion

Joint range of motion (ROM) is reduced in response to exercise-induced muscle damage and generally resolves within 48 hours (Eston & Peters, 1999). Players with poor ROM have a higher risk of muscle strain type injury (Bradley *et al.*, 2007), and may suffer greater symptoms of muscle damage and take longer to recover than more flexible players (McHugh *et al.*, 1999). For these reasons, some professional rugby teams have adopted the approach of using regular ROM tests to assess player readiness to train (Rugby Strength Coach Podcast, 2015). A ROM test battery may include sit-and-reach, knee to wall ankle dorsiflexion, shoulder internal rotation and adductor squeeze tests (Rugby Strength Coach Podcast, 2015). A reduction in a player’s range of motion may indicate that muscle damage is still present and the player is not fully recovered.

Monitoring training response – internal methods

Questionnaires and subjective assessments of fatigue

A variety of perceptual fatigue measures (POMS, DALDA, REST-Q and the Total Quality Recovery Scale) are available for coaches to monitor psychophysiological fatigue (Twist & Highton, 2015), and are currently being used in high-performance sports programmes (Taylor *et al.*, 2012). The length of these questionnaires has lead many practitioners to develop shortened custom-designed questionnaires (Gastin, Meyer & Robinson, 2013). These shortened, subjective fatigue questionnaires are sensitive to fatigue following training stress (Coutts *et al.*, 2007b). The time course of perceptual fatigue recovery from rugby match play is ≈ 4 days, which is longer than that of neuromuscular and hormonal changes (McLean *et al.*, 2010; Twist *et al.*, 2012). A perceptual fatigue response that is disproportional to the training load experienced is an early marker of overreaching maladaptation to training (Coutts *et al.*, 2007b). Perceptual fatigue questionnaires are regularly criticized for being easily manipulated by players (Nédélec *et al.*, 2012), and should be corroborated with some form of physiological data (Halsen, 2014).

Interpreting fatigue data

Decision making regarding whether an intervention is required for a player who scores sub-optimally in one of the recovery tests is challenging. One must determine whether a “real” change has actually occurred, or whether the observed change falls within the natural variability of the measurement (Twist & Highton, 2015; Twist *et al.*, 2013). A real change has occurred if the change is greater than the individualized co-efficient of variation (CV) of that measurement (calculated as $SD/mean \times 100$) (Hopkins *et al.*, 2009). The magnitude of the effect can be determined as small, moderate or large depending on whether the measure is 0.3, 0.9 or 1.6 times the CV respectively (Hopkins *et al.*, 2009). This approach is not valid for perceptual fatigue measures as they typically only vary in increments of one. Twist *et al.* (2015) suggest that changes in perceptual

fatigue in the order of one to two points, especially in conjunction with meaningful changes in other fatigue measures, would necessitate the initiation of a rest or recovery strategy.

Failure to recover from short-term fatigue is a risk factor for injury. It follows that decreases in perceptual fatigue, neuromuscular function, physical performance and range of motion following match participation are all risk factors for injury. These should all be carefully monitored following every game to identify players at risk and allow opportunities for intervention to prevent injury.

2.4.7 Conclusion

The aim of this thesis is to utilize an injury risk management model to reduce the effect of injuries in a professional rugby union team. Player fatigue has been identified as a key risk factor associated with injury within professional players. The nature of three different forms of fatigue (activity-related, short-term and prolonged) within rugby players has been reviewed. Methods of quantifying both training loads and the response to training have been discussed to provide a model explaining how rugby players can be best managed in the context of a professional team with limited resources.

CHAPTER 3 – INJURY RISK ESTIMATION AND EVALUATION IN A PROFESSIONAL RUGBY UNION TEAM

3.1 Introduction

The process of risk management should be implemented as part of a best practice management system within sports organisations (Fuller *et al.*, 2004a). Epidemiological studies are often the first step in the implementation of injury risk management programmes. Epidemiological studies provide information that initially allows for evidence-based decisions to be made about risk levels participants are exposed to, and later the efficacy of preventative and therapeutic interventions made (Fuller *et al.*, 2004a).

Prospective epidemiological studies are more accurate than retrospective studies due to poor recall of injured players (Brooks & Fuller, 2006). In addition, the results of epidemiological reports can often be difficult to interpret due to variations in the injury definitions and/or methods of data collection used (Brooks *et al.*, 2006). In the sport of rugby union, a consensus statement on injury definitions and data collection procedures was published by the International Rugby Board (IRB) in 2007 (Fuller *et al.*, 2007a), which has led to the publication of number of high quality epidemiological studies (Fuller *et al.*, 2007b; Fuller *et al.*, 2008b; Fuller *et al.*, 2009; Fuller *et al.*, 2013; Schwellnus *et al.*, 2014; Williams *et al.*, 2013). These studies are excellent resources for rugby union researchers, and were reported on in detail in Chapter 2 (pg. 13 to 15).

The initial step in this research thesis was to conduct a one-year epidemiological study in a professional rugby union team. As per the framework for risk management in sport (Fuller *et al.*, 2004a), this epidemiological study serves two purposes; to allow the identification of injury risk factors, and to estimate the injury risk that team players are exposed to. Following the risk estimation

process, the injury risk will be evaluated by comparison with other epidemiological studies in professional rugby union.

Determining the acceptability of levels of risk within sport is complicated because there are no defined acceptable risk levels in sport. Instead, acceptable levels of risk in sport are mostly determined more by the risk perceptions of the participants and other stakeholders such as coaches and administrators (Fuller *et al.*, 2004a). It has previously been estimated that in professional football the injury risk is 1000 times greater than that present in high-risk occupations such as construction and agriculture. Injury incidence in professional rugby union is far greater than in professional football (Brooks & Kemp, 2008b). Players voluntarily accept these risks through their participation, but it is questionable how well these risks are communicated to them (Fuller *et al.*, 2004a). Both players and team management have vested interests in minimising injury occurrences (Meir *et al.*, 2007; Orchard, 2009), so it would be expected that following the risk evaluation procedure these stakeholders would aim to mitigate rather than accept risks.

The findings of this initial cohort investigation, as well as the associated risk assessment process, will be used to guide interventions in subsequent years of the study. Continuing injury data collection and comparison with the original investigation will allow for the further determination of injury risk factors, as well as assessment of the efficacy of various injury mitigation strategies implemented.

3.2 Methods

3.2.1 Experimental approach to the problem

This research was conducted in conjunction with a professional South African Rugby Union team that competes in the Super 15, Currie Cup and Vodacom Cup competitions. A longitudinal, prospective approach was used to determine the

injury profile of this team in two separate seasons (2012 and 2013), as well as cumulatively for both seasons. The results of the 2012 season injury audit would be used to estimate the level of risk (injury incidence and severity) that players are exposed to. A risk evaluation process would compare these results with those from other recent epidemiological studies in rugby union. These results would be reported to players, coaches and medical staff. If the risk assessment indicated that injury risk was too high within the team, risk mitigation strategies would be implemented for the 2013 season. The effectiveness of these mitigation strategies would be assessed through a subsequent injury audit for the 2013 season.

3.2.2 Participants

Professional players contracted to the same South African rugby union team were recruited to participate in this study. Team management endorsed the research project and coaches and medical staff encouraged the players to take part. Due to the observational nature of this research no exertions in addition to the daily requirements of team membership were required of the players, and the ethical review board of the University of Johannesburg approved all experimental procedures. All participants received a clear explanation of the study, including the risks and benefits of participation, and written consent was obtained from all team players. The study was conducted in accordance with the Declaration of Helsinki (World Medical Association, 2013). Data from contracted players who did not represent the first team in either of the 2012 or 2013 seasons were later removed from the overall data set. Data regarding the physical attributes and playing experience (senior provincial games played) of the players was recorded from official match day programmes.

3.2.3 Injury, competition and training exposure data

The team doctor recorded all injuries sustained by team members for the duration of the 2012 and 2013 rugby seasons, including the preceding pre-

season training periods. All injury data were recorded in accordance with the IRB consensus statement on injury definitions and data collection procedures (Fuller *et al.*, 2007a). The primary injury definition used was: *'Any physical complaint sustained by a player during a match or training session that prevented the player from taking a full part in all training activities or match play for more than 1 day following the day of injury'* (Fuller *et al.*, 2007a). Absence from training or competition due to illness or other medical conditions were excluded from the study. Injuries were designated "contact" if they were the result of contact with another players or object (eg. tackles, collisions or scrums), or "non-contact" if they occurred in the absence of physical contact with another player or object. Data were not recorded as to whether injuries were new or recurrent. Injury severity was defined as the total number of days that a player was unavailable for full training or competition following an injury. Injury burden was calculated as the sum total number of days that any players were unavailable for across a whole season.

Match exposures were calculated based on 15 players being exposed for 100 min during games (analysis showed it takes 100 min to complete an 80 min game due to stoppages). Match results and player participation were verified using match reports downloaded from www.sarugby.net, the official website of the South African Rugby Union (SARU). Training exposure time was calculated based on the number of players attending each training session, and the reported (by strength and conditioning coach) length of the training session.

3.2.4 Season Comparison

Unforeseen circumstances lead to the team being removed from the Super 15 competition at the end of the 2012 season. In 2013 the team arranged to play in alternative competitions to Super 15 comprised of the Lions Challenge, the Vodacom Cup and a Super 15 promotion relegation series. Comparisons between the two years must be considered in the context of significant changes to both

the coaching and playing staff, and differing competition demands on the players.

3.2.5 Statistical Analysis

Difference between seasons

Due to this team being excluded from Super Rugby in 2013 it was necessary to perform analysis to determine differences between the 2012 and 2013 rugby seasons. Physical profile of players (age, stature and body mass) and playing experience of players representing the team in 2012, 2013 or in both seasons were compared using a one-way ANOVA and *Tukey's post hoc* test. Differences in team performance (mean points for, points against and points difference) across the two seasons were tested using independent samples T-tests. The team's win rates per season were compared using a z-test. Wherever possible, Cohen's d effect sizes were calculated to allow for magnitude based inferences to be made. Effect sizes of 0.2, 0.5, 0.8 and 1.2 were considered *small, medium, large and very large* respectively (Hopkins *et al.*, 2009).

Injury data

Injury incidence is reported collectively, and separately for matches and training, as the number of injuries/1000 player-hours (95% Confidence interval) of exposure. The z-test was used to determine differences in proportional injury incidence, circumstance and mechanism between seasons. Injury severity (days) was reported as mean $\pm$ SD. Mann-Whitney tests were used to determine differences in injury severity between seasons.

Statistical significance was set at $p < 0.05$ for all analyses. Medcalc statistical software for biomedical research (version 15.2.2, Medcalc, Belgium) was used to calculate injury incidence, 95% confidence intervals and perform z-tests. SPSS statistics software (version 22, IBM Inc.) was used to perform t-tests, ANOVA and Mann-Whitney U tests. Effect sizes were calculated using an excel spreadsheet

designed for this purpose (retrieved from www.cem.org/effect-size-calculator Nov 23 2014).

3.3 Results

3.1.1 Season Comparison

Table 3.1 presents a comparison of the players who represented the team in the 2012 season only, the 2013 season only, and in both seasons. There were *small*, non-significant differences in the physical characteristics of the players who represented the team in the two seasons. There was a *large* significant difference in experience between players who represented the team in 2012 only and in 2013 only (2012 season: 63 ± 60 vs. 2013 season: 20 ± 42 caps, ES = *Large*). This indicates that while of a similar physical profile, the player who replaced those who left at the end of the 2012 season were significantly less experienced.

Table 3.1 – Physical attributes and playing experience of players that represented the team in the 2012 and 2013, and of players who represented the team in both years.

	N	Age (years)	Stature (cm)	Body mass (kg)	Experience (games)
2012	18	26 ± 4	188 ± 8	105.6 ± 11.7	63 ± 60
2013	24	24 ± 2 (<i>Medium</i>)	186 ± 8 (<i>Small</i>)	100.0 ± 12.7 (<i>Small</i>)	$20 \pm 42^*$ (<i>Large</i>)
Both seasons	24	25 ± 3 (<i>Small</i>)	186 ± 7 (<i>Small</i>)	102.9 ± 12.3 (<i>Small</i>)	47 ± 44 (<i>Small</i>)

Data are presented as mean $\pm$ SD (Effect size). * indicates a significant difference between 2012 and 2013. Effect sizes are based on comparison to 2012. Data on players who represented the team in both seasons is reported as at the start of the 2012 season. These players on average earned 14 ± 5 caps during the 2012 season

Table 3.2 presents a comparison of the team performance in the 2012 and 2013 seasons. The team won just 30% of their matches in 2012 compared with 70% in 2013. Overall, the team scored more and conceded fewer points in 2013 than in 2012. The team performed substantially better in the alternative competitions than in the Super 15. There were no significant differences in the team's performance in Currie Cup competition between the two seasons. These results indicate that there was likely a large difference in competitive standard between Super Rugby and the alternative competition entered in 2013.

Table 3.2 – Comparison of team results from the 2012 and 2013 seasons.

Year	Comp.	Matches (win %)	Points for	Points against	Points Diff	Season results
2012	Overall	27 (30%)	23 ± 10	28 ± 8	-5 ± 13	
	Super 15	16 (19%)	21 ± 10	28 ± 6	-7 ± 10	15 th on log
	Currie Cup	11 (55%)	27 ± 9	27 ± 12	0 ± 15	2 nd on log, lost in semi- final
2013	Overall	30 (70%)*	40 ± 27* (Large)	23 ± 9* (Medium)	17 ± 32* (Large)	
	Alternative comp.	19 (89%)*	45 ± 31* (Large)	19 ± 9* (Large)	26 ± 36* (Large)	Won Vodacom Cup,
	Currie Cup	11 (36%)	31 ± 12 (Small)	30 ± 4 (Small)	1 ± 15 (Small)	Promoted Super 15 4 th on log, lost in semi- final

Comp. indicates competition played in. Data for points for, against and difference are presented as mean ± SD (ES). * indicates significant difference and ES indicates effect size for difference between competitions in 2012 and 2013.

The differences presented here indicate that any comparison between the two seasons should be interpreted with caution as there were significant, *large* differences in player experience and playing standard between seasons.

3.1.2 Injury incidence and severity

In total, 1425 hours of play (57 matches), 19 161 hours of training (332 training sessions), and 345 injuries (253 match injuries and 92 training injuries) were recorded over two seasons (2012 to 2013). The average injury incidence and severity for both seasons combined was 17 (15 to 19) injuries/1000 h and 20 ± 32 days respectively. The injury incidence in matches was 178 (156 to 199) injuries/1000 h and for training was 5 (4 to 6) injuries/1000 h over the study period. The overall severity of match injuries was 17 ± 31 days, and training injuries was 27 ± 34 days. Match contact injuries had an incidence of 145 (125 to 164) injuries/1000 h and mean severity of 15 ± 28 days per injury, while match non-contact injuries occurred with an incidence of 32 (23 to 42) injuries/1000 h and a mean severity of 25 ± 40 days per injury. Training contact and non-contact injury incidence was 1.8 (1.2 to 2.4) injuries/1000 h and 3.0 (2.2 to 3.7) injuries/1000 h respectively. The mean severity was 30 ± 44 days for contact training injuries and 24 ± 27 days for non-contact training injuries.

Table 3.3 details the differences in exposure, injury incidence, injury severity, injury circumstance and injury mechanism between the two seasons. The total exposure to rugby was greater in 2013 due to 3 extra matches and 5 additional weeks of training. The overall incidence of injury was similar between seasons, but training injury incidence was significantly higher in 2012, while match injury incidence was greater in 2013. There were no differences in mean injury severity across seasons for any matches/training or contact/non-contact conditions. The injury burden was higher in 2013 (2012 season 3056 vs. 2013 season 3647 days). There were significant differences in the total proportion of injuries accounted for by matches and training across seasons. In 2012, 47% of the total injury burden was accounted for by training injuries, but this was reduced to 28% in 2013. Similarly, the proportion of total injury burden accounted for by non-contact injuries was less in 2013 (2012 season 50% vs. 2013 season 28%).

Table 3.3 – Exposure, injury incidence, injury circumstances, severity and mechanism of injury for two rugby union seasons.

	2012	2013
Exposure (hours)		
Overall	8 803	11 783
<i>Match</i>	675 (27 matches)	750 (30 matches)
<i>Training</i>	8 128 (34 weeks)	11 033 (39 weeks)
Injuries/1000 h (95%CI)		
Overall	18 (15 to 20)	16 (14 to 19)
<i>Match</i>	150 (120 to 179)	203 (170 to 235)*
<i>Training</i>	7 (5 to 8)	4 (2 to 5)*
Injury Severity (days)		
Overall	20 ± 34	19 ± 30
<i>Match</i>	16 ± 32	17 ± 29
<i>Training</i>	27 ± 36	26 ± 31
<i>Contact</i>	16 ± 29	18 ± 32
<i>Non-contact</i>	28 ± 41	21 ± 19
Injury Burden		
(total days lost)	3056	3647
Injury circumstances		
(% total injury burden)		
Match	52.7	72.5
Training	47.3	27.5*
Injury Mechanism %		
(% total injury burden)		
Contact	49.9	71.8
Non-Contact	50.1	28.2*

* indicates significant difference between 2012 and 2013, p <0.05.

Table 3.4 indicates that lower limb injuries accounted for the highest proportion of injuries in both seasons. Upper limb injuries had the next largest effect on total injury burden, and head and neck and trunk injuries were responsible for the smallest proportion of total days lost. The injuries that occurred in the greatest number in 2012 were contact head and face (22), contact shoulder/clavicle (17) and non-contact posterior thigh (17) injuries. The pattern was similar in 2013 except that there was an increase in the number of contact shoulder/clavicle injuries (2012 season 17 vs. 2013 season 38).

In 2012, the most costly injuries in terms of total burden were non-contact knee and contact shoulder/clavicle injuries which accounted for 30% and 16% of the total injury burden respectively. In 2013, the injuries that represented the greatest injury burden were contact shoulder/clavicle injuries (30%), contact ankle injuries (13%) and non-contact posterior thigh injuries (11%). There was a reduction in the number (2012 season 14 vs. 2013 season 4) and mean severity (2012 season 65 ± 68 vs. 2013 season 43 ± 40 days) of non-contact knee injuries across seasons. While the absolute number of non-contact posterior thigh injuries remained similar across seasons, there was an increase in mean severity from 2012 to 2013 (2012 season 13 ± 10 vs. 2013 season 22 ± 14 days).

Table 3.4 - Count, mean severity and % total injury burden according to injury site for 2012 and 2013 seasons.

	2012		2013	
	Contact	Non-Contact	Contact	Non-Contact
Head and Neck	23 (8), 6%		21 (8), 4%	
Head/Face	22 (8), 6%		19 (8), 4%	
Neck/Cervical spine	1 (0), 0%		2 (6), 0%	
Trunk	7 (8), 2%	2 (23), 1%	19 (15), 7%	4 (11), 1%
Sternum/Ribs	5 (11), 2%		15 (6), 2%	
Abdomin				
Low back	2 (2), 0%	2 (23), 1%	2 (2), 0%	4 (11), 1%
Sacrum/pelvis			2 (92), 5%	
Upper Limb	32 (22), 23%	3 (17), 1%	55 (24),	1 (14), 0%
Shoulder/clavicle	17 (28), 16%	1 (38), 1%	35% 38 (29), 30%	1 (14), 0%
Upper arm	3 (41), 4%	2 (6), 0%	2 (4), 0%	
Elbow	1 (0), 0%		2 (16), 1%	
Forearm				
Wrist	4 (16), 2%		2 (2), 0%	
Hand/Finger/Thumb	7 (6), 1%		11 (15), 4%	
Lower Limb	36 (16), 19%	50 (29), 48%	48 (19),	43 (23), 27%
Hip/Groin	2 (1), 0%	5 (15), 3%	23% 2 (22), 1%	8 (22), 5%
Anterior Thigh	6 (6), 1%	2 (25), 2%	8 (2), 0%	3 (28), 2%
Posterior Thigh	2 (9), 1%	17 (13), 7%		18 (22), 11%
Knee	12 (12), 5%	14 (65), 30%	14 (14), 5%	4 (43), 5%
Lower leg/Achillies	5 (44), 7%	12 (16), 6%	4 (19), 2%	9 (15), 4%
Ankle	6 (12), 2%		17 (29), 13%	1 (9), 0%
Foot/Toe	3 (30), 3%		3 (24), 2%	

Data reported as number of injuries - N (mean severity), % total injury burden.

Table 3.5 - Count, mean severity and % total injury burden according to injury type for 2012 and 2013 seasons.

	2012		2013	
	Contact	Non-Contact	Contact	Non-Contact
Fractures and bone stress	9, (37), 9%	1 (42), 1%	7, (50), 10%	
<i>fracture</i>	8 (40), 9%	1 (42), 1%	5 (56), 8%	
<i>other</i>	1 (15), 0%		2 (36), 2%	
Joint and ligament injuries	21 (23), 14%	11 (60), 18%	45 (36), 44%	3 (39), 4%
<i>dislocation, subluxation</i>	4 (18), 2%		12 (50), 16%	
<i>sprain</i>	12 (15), 5%	5 (53), 7%	23 (28), 18%	2 (10), 1%
<i>lesion of mensicus, cartilage or disc</i>	5 (48), 7%	6 (66), 11%	10 (37), 10%	1 (98), 3%
Muscle and tendon injuries	45 (12), 15%	37 (21), 21%	70 (7), 14%	45 (21), 25%
<i>muscle rupture, tear, strain, cramp</i>	9 (50), 12%	34 (15), 14%	3 (93), 8%	39 (20), 21%
<i>tendon injury, rupture, tendinopathy, bursitis</i>	2 (15), 1%	2 (124), 7%	1 (2), 0%	6 (24), 4%
<i>heamotoma, contusion, bruise</i>	34 (2), 2%	1 (14), 0%	66 (3), 6%	
Laceration and skin injuries	1 (4), 0%		2 (0), 0%	
<i>abrasion</i>				
<i>laceration</i>	1 (4), 0%		2 (0), 0%	
Central/peripheral nervous system injuries	20 (8), 4%	1 (38), 1%	19, (8), 4%	
<i>brain - concussion</i>	19 (8), 4%		17 (8), 4%	
<i>brain - structural</i>				
<i>spinal cord</i>				
<i>nerve injury</i>	1 (3), 0%	1 (38), 1%	2 (7), 0%	
Other injuries	2 (1), 0%	5 (5), 1%		

Data reported as number of injuries - N (mean severity), % total injury burden.

Table 3.5 shows that in both seasons joint and ligament and muscle and tendon injuries accounted for the majority of the teams injury burden. Heamotomas and non-contact muscle strains were the injuries that occurred most frequently in each year. There was a large increase in the number (2012 season 21 vs. 2013 season 45) and severity (2012 season 23 ± 31 vs. 2013 season 36 ± 39 days) of contact joint and ligament injuries in 2013.

3.4 Discussion

Injury risk evaluation of the 2012 rugby season indicated that the team was experiencing greater incidences of match and training injuries than would be expected for a professional team. This determination was made through comparison with a recent meta-analysis of injuries in senior men's professional rugby union (Williams *et al.*, 2013). The meta-analysis shows that the expected match and training injury incidence is 81 (63 to 105) and 3 (2 to 4) injuries/1000 h injuries per 1000 player hours respectively (Williams *et al.*, 2013). For this team, however, match and training injury incidence was 150 (120 to 179) and 7 (5 to 8) injuries/1000 h injuries per 1000 player hours respectively in the 2012 season. The overall injury rate (18 (15 to 20) injuries/1000 h) was double the average experienced by other South African teams in Super Rugby in 2012 (9 (8 to 11) injuries/1000 h) (Schwellnus *et al.*, 2014).

The mean severity of all injuries sustained was 20 ± 32 days, which is similar to the mean injury severity reported for level 1 clubs (21 days) (Williams *et al.*, 2013). In contrast, the mean severity of training injuries (27 ± 34 days) was higher than previously reported (22 days) (Williams *et al.*, 2013).

The results of this injury risk evaluation indicate that players in this team are exposed to a higher level of risk for injury than similar player cohorts. The reasons for this abnormally high level of injury risk still require investigation.

Previous study in rugby union players has shown that training volume is positively associated with injury incidence (Viljoen *et al.*, 2009) and severity (Brooks *et al.*, 2008). It is therefore possible, that the reason for the higher level of injury risk in the team examined is related to the training volumes that the players are exposed to. Conversely, rugby league research has demonstrated that players with poorly developed physical qualities are more susceptible to injury (Gabbett *et al.*, 2012a), indicating that the injury problem could be due to players not being well conditioned enough.

These results were reported to the players, coaches and medical staff, and it was agreed that the level of risk was unacceptable, and that the team should invest in injury mitigation strategies. The medical and strength and conditioning staff identified three target areas for injury mitigation programmes: 1. Training injuries, 2. Non-contact injuries and 3. Shoulder/clavicle injuries.

3.4.1 Training injuries

Both the incidence and severity of training injuries were noted as being higher than for professional players studied previously (Williams *et al.*, 2013). In 2012, training injuries accounted for 47% of the teams total injury burden. The medical staff felt that training injury severity may be greater than match injury severity because when a player is injured in a match, he receives immediate medical treatment, but at training he would not. In 2012, the medical staff were not present on the side of the field during training sessions. As a result, when injuries occurred, players often attempted to “survive” to the end of the session before reporting their injury. Players not removed from training immediately may have incurred additional damage by persevering with training, thus, lengthening their recovery time. A decision was taken to have either the team doctor or physiotherapist field-side for all training sessions in 2013. This is considered good practice in a number of professional sports teams.

A further concern of the coaching and medical staff regarding training injuries was that perhaps the training load was too high, training sessions were too long, or players were starting training sessions insufficiently recovered from the previous match or training session. These factors may have contributed to player fatigue that may in turn increase injury risk. Additional concerns were that too much contact training and/or too much running training was taking place. As a consequence, investigations were initiated to use GPS tracking to accurately determine the movement requirements of matches for players in different positions, so that training activities and loads could be assessed against this criteria. The strength and conditioning staff committed to trying to increase the specificity of training based on GPS data. Furthermore, they committed to implementing some recovery diagnostic measures to try to better establish the “readiness for training” of players following matches. The details of these projects are further explained in subsequent chapters.

3.4.2 Non-contact injuries

In 2012, non-contact injuries accounted for 50% of the teams total injury burden. While in many cases, contact injuries may be unavoidable; non-contact injuries are a good target for injury prevention because they are related to manageable factors such as training load and recovery (Gabbett, 2010b). In addition to improved management of training loads, which is discussed above, examination of injury site data (table 3.4) showed that non-contact knee injuries accounted for 30% of the total injury burden in 2012. Non-contact hamstring and lower leg/Achilles injuries accounted for a further 7% and 6% of the total injury burden respectively. “Prehabilitation” training programmes have been shown to be effective in reducing knee, hamstring and calf injuries (Herman *et al.*, 2012). These programmes were reviewed by the strength and conditioning staff and based on these a number of “prehabilitative” landing, agility and stability exercises were added to the warm up routine. Eccentric hamstring training,

unilateral strength training and gluteus muscle activation exercises were added to the strength training programme.

3.4.3 Shoulder/clavicle injuries

The profile of contact injuries sustained was examined to determine if any training interventions could be made to reduce contact injuries. Shoulder injuries accounted for 16% (476 days) of total lost playing time in 2012. This is double the mean number of days lost per season reported in professional English rugby clubs (241 days) (Headley, Brooks and Kemp, 2007). Research indicated that poor internal shoulder rotation (McDonough & Funk, 2014), poor 1RM pull up (Gabbett *et al.*, 2012a) and imbalance between pushing and pulling strength (Baker & Newton, 2004) are all predisposing factors for injury. The strength training programme of the team was adjusted to address all of these factors in an attempt to reduce shoulder injuries.

3.4.4 2013 Injury Audit

The original intention of this research project was for the 2013 injury data to inform on the efficacy of various injury risk mitigation interventions undertaken by the team. However, uncontrollable factors such as a change in the competition participated in and changes in coaching and playing staff make direct comparisons difficult. The results are presented here to provide a practical perspective on how these results might be assessed in a dynamic real-world situation.

Overall, there was no significant difference in injury incidence (2012 season 18 (15 to 20) vs. 2013 season 16 (14 to 19) injuries/1000 h) or severity (2012 season 20 ± 34 vs. 2013 season 19 ± 30 days) between seasons. Match injury incidence was significantly higher in 2013 (2012 season 150 (120 to 179) vs. 2013 season 203 (170 to 235) injuries/1000 h, $p < 0.05$) despite the standard of competition being arguably lower in the alternative competition. There was a large increase

in the absolute number of joint and ligament injuries in 2013 (2012 season 82 vs. 2013 season 115).

The increases in match injury incidence and joint and ligament injuries in the 2013 season may be related to the comparative inexperience of the 2013 vs. the 2012 player group (2012 players 63 ± 60 vs. 2013 players 20 ± 42 games experience, $ES = Large$). Players of lesser experience have demonstrated reduced tackle ability (Gabbett *et al.*, 2009), and poor tackle technique has been identified as a risk factor for injury (Burger *et al.*, 2015). This may provide some explanation for the increase in shoulder/clavicle contact injuries observed.

Other factors that may have affected the match injury rate could be the increased length of the season (2012 season 34 vs. 2013 season 39 weeks), and the increased number of matches (2012 season 27 vs. 2013 season 30 matches). It is also possible that because of the greater awareness of the injury problem by both players and management, a greater number of injuries were reported and treated.

In 2013, there was a reduction in training injury incidence (2012 season 7 (5 to 8) vs. 2013 season 4 (2 to 5) injuries/1000 h, $p < 0.05$), as well as a reduction in the percentage total injury burden accounted for by training (2012 season 47 vs. 2013 season 28%, $p < 0.05$) and non-contact injuries (2012 season 50 vs. 2013 season 28%, $p < 0.05$). Although, these are positive indicators that player management was improved during the 2013 season, it is concerning that match injury incidence was increased during the same period. It is possible that due to concerns regarding the number of training and non-contact injuries in 2012, the training load was reduced in 2013 and did not adequately prepare the players for match play. The case has previously been made that when strength and conditioning staff focus only on injury prevention in a high performance

environment, training may not be hard enough and may negatively affect team performance and injury rates (Gabbett, 2015a).

The total number of non-contact knee injuries was reduced from 14 in 2012 to 4 in 2013, making a significant reduction in injury burden (2012 season 910 vs. 2013 season 172 days). The absolute number of non-contact posterior thigh and non-contact lower leg/Achilles injuries remained consistent across seasons, but the mean severity of non-contact posterior thigh injuries increased (2012 season 13 ± 10 vs. 2013 season 22 ± 14 days). This increase in recovery time may reflect a more conservative approach adopted by the team medical staff as a result of increased awareness of the injury problem.

Efforts to reduce contact shoulder injuries were ineffective as the absolute number of contact shoulder/clavicle injuries (2012 season 17 vs. 2013 season 38) and relative burden (2012 season 16% vs. 2013 season 30%) doubled from 2012 to 2013.

3.5 Conclusion

The aim of this injury risk estimation and evaluation project was to illustrate how utilising injury risk management model in an applied setting may inform coaching practice with regard to injury management. Fuller *et al.* (2012) notes that “Risk communication is perhaps the most important element of the risk management process” as this provides stakeholders with the information necessary to initiate risk mitigation strategies. This case study lead to an examination of the practices of the team coaching, strength and conditioning and medical staff with regard to the management of training and non-contact injuries, and ultimately caused changes in practice. Examination of the most prevalent types of injury lead to the incorporation of targeted prehabilitation exercises into the teams warm up and strength programmes. While cause and effect cannot be established, there was a notable decrease in non-contact knee injuries in the second season. Measuring

the burden of training and non-contact injuries lead to an examination of the specificity training practices for players in different positions which is further detailed in subsequent chapters of this thesis.

CHAPTER 4 - PRE-SEASON FUNCTIONAL MOVEMENT SCREEN AS A PREDICTOR OF SEVERE INJURIES IN PROFESSIONAL RUGBY UNION PLAYERS

4.1 Introduction

Despite numerous interventions by World Rugby to make the game safer through law changes (Fuller *et al.*, 2009; Hendricks *et al.*, 2014a), the risk of injury is still relatively high in rugby union (Williams *et al.*, 2013). It follows that there is a need for the further development of strategies to reduce injuries. One strategy for reducing the risk of injury is to use screening tools that identify players at greater risk of injury prior to participation (Krumrei *et al.*, 2014). Once these players have been identified, corrective strategies can be implemented. In terms of the injury risk management model (Fuller *et al.*, 2004a; Fuller *et al.*, 2012), accurately identifying injury risk factors through athlete screening is key to implementing risk mitigation strategies. Studies aimed at identifying intrinsic and extrinsic injury risk factors should focus on identifying athletes that fall within the high-risk or low-risk regions of the population's risk distribution (Fuller, 2007c).

The Functional Movement Screen™ (FMS) is a screening tool that tests balance, core strength and range of motion simultaneously. The results of the FMS provide a holistic, integrative assessment of the players' quality of movement (Cook *et al.*, 2006a,b). It has been proposed that poor performance in this type of comprehensive movement examination may be a risk factor for injury in sport (Krumrei *et al.*, 2014; Plisky *et al.*, 2006). A recent review of FMS research indicated that there was "moderate scientific evidence" to support the use of FMS as a predictor of injury risk (Kraus *et al.*, 2014). For example, Kiesel *et al.* (2007) showed that a FMS score ≤ 14 was predictive of serious injury (>21 days) in professional American Football players (Kiesel *et al.*, 2007), and that

movement asymmetries highlighted by the FMS test increased relative injury risk (Kiesel *et al.*, 2014). Chorba *et al.* (2010) showed a significant association between FMS score ≤ 14 and injury in female collegiate athletes (Chorba *et al.*, 2010). Functional movement screen score has also been associated with injury in military recruits (Lisman *et al.*, 2013) and general populations (Letafatkar *et al.*, 2014). In contrast, some studies have shown no association between FMS score and injury risk (Klusemann *et al.*, 2011; Warren, Smith & Chimera, 2014).

Most injuries ($\approx 80\%$) in rugby union are the result of contact events such as collisions and tackles (Williams *et al.*, 2013). It is generally thought that dysfunctional movement patterns, as identified by FMS, are unrelated to the incidence of contact injury, and has led some researchers to exclude contact injuries from FMS injury analysis (Warren *et al.*, 2014). Non-contact injuries on the other hand, are thought to be related to poor neuromuscular control, core-strength or muscular imbalances, or to repetitive loads imposed on top of a dysfunctional movement pattern (Bahr *et al.*, 2005). The FMS screen was designed to expose these risk factors (Cook *et al.*, 2006a,b). Non-contact injuries represent a considerable portion of overall injuries in rugby union ($\approx 20\%$).

Based on the original study by Kiesel *et al.* (2007), an FMS score ≤ 14 has become the generally accepted indicator of increased injury risk for team sports, however this assumption has not been widely tested outside of American football. Letafatkar *et al.* (2014) indicated that a score of < 17 was the best indicator of injury risk in a student population. However, Kazman *et al.* (2014) performed a factor analysis that indicated that the FMS test is not a unitary construct, and that composite scores (total out of 21) should be interpreted with caution. Despite these concerns, no research has yet associated an individual FMS component with injury. Kiesel *et al.* (2011) determined that the individual FMS component most associated with a low FMS score was the overhead squat.

Therefore, this study aims to determine whether a low FMS score is a risk factor for contact, non-contact injury or both in professional rugby union players. A further aim is to determine what FMS score is the most accurate predictor of injury in this population. A final aim is to determine whether any individual FMS component test is related to injury risk in rugby union players.

4.2 Methods

4.2.1 Experimental Approach to the Problem

A prospective, observational, longitudinal design was used to assess the application of the FMS as a predictor of severe injury in professional rugby union players. Participants completed FMS tests prior to the start of competitive rugby competitions, and injuries to these players were monitored for 6 months following the test. Insufficient data were available from the 2012 and 2013 seasons to draw firm statistical conclusions, so data from the 2011 season was included in the analysis. Using receiver operated characteristic (ROC) curves and 2x2 contingency tables, odds ratios, sensitivity and specificity were calculated to determine the accuracy of the prediction.

4.2.2 Participants

This research was conducted in conjunction with the same professional South African rugby union team examined throughout this thesis. Players representing this team were tested on four occasions (January 2011, July 2011, January 2012 and January 2013), during the pre-season periods prior to the start of professional competitions. As is the nature of professional sport, new players were contracted and other players were released to play elsewhere over the course of the study. Only players who gained regular selection for the starting team during the relevant period of competition (selected >60% of matches for which they were available) were included in the study. In total, 62 players (Stature 1.87 ± 0.08 m, body mass 103.1 ± 13.1 kg) took part in the study across 4 testing periods. No player was tested on all four testing occasions (40 players

were tested once, 16 tested twice and 6 were tested on 3 occasions). A total number of 90 FMS tests were included in the final data set (January 2011 = 27, July 2011 = 29, January 2012 = 16 and January 2013 = 18 subjects). The University of Johannesburg Ethical Review Board approved this research, and informed consent was obtained from all players, including permission for their historical data to be used for scientific investigation. The study conformed to the Declaration of Helsinki (2013) (World Medical Association, 2013).

4.2.3 Procedures

The FMS test consists of seven movement tests; 1. Deep Squat, 2. Hurdle Step, 3. In-line Lunge, 4. Shoulder Mobility, 5. Active Straight Leg Raise, 6. Trunk Stability Push-Up and 7. Rotary Stability Test (Cook *et al.*, 2006a, b). Each component test is scored on an ordinal scale from 0 to 3 (0, 1, 2 or 3) based on the quality of the movement pattern exhibited, giving a composite test score out of 21 for all test components. Included in the FMS are three additional clearing tests for 1. Shoulder, 2. Spinal extension and 3. Spinal flexion. FMS has good inter-rater reliability in trained and untrained testers (ICC = 0.91) (Elias, 2013), and raters of varied experience (ICC = 0.87 - 0.89) (Smith *et al.*, 2013).

All testing was conducted by a registered biokineticist, and qualified FMS tester employed by the team. Tests were recorded on video and analysed using Dartfish video analysis software (Dartfish; Fribourg, Switzerland), to ensure objectivity of measurement. Players were familiarised with the test before the start of the study. All players were tested within 1 week of each other on each of the 4 testing occasions. The composite score, as well as the score for each of the FMS component tests were recorded. Players who scored ≤ 14 overall, or < 2 on any component test, were recommended to follow “prehabilitation” programmes to address their movement dysfunctions. These prehabilitation programmes are a confounding factor in the study design, but were ethically required following the identification of potential injury risk factors. Compliance

with the prehabilitation programme was not enforced, and the effect of this intervention was not assessed in this study.

The team's medical staff recorded injury data according to the methods described in Chapter 3. A severe injury is defined as an injury that caused a player to be excluded from matches and/or practice for a period of 28 days or more, in accordance with the International Rugby Board (IRB) consensus statement on injury definitions (Fuller *et al.*, 2007a). Only severe injuries that occurred within six months (180 days) of an FMS test were included in the analysis. Survival time was calculated as the number of days from an FMS test until a severe injury occurred. Total injuries and total time injured were recorded for each player and used to determine the average injury duration.

4.2.4 Statistical Analysis

Power analysis revealed that data from 2012 and 2013 had insufficient power (>0.80) to elicit a real difference. For this reason, historical FMS and injury data from 2011 was included, and all of the test data were pooled as a single test sample, and analysed using a linear mixed model procedure. This procedure was chosen due to its ability to manage repeated measures with an inconsistent subject group (West, 2009). The data were processed to give each player a single observation on each occasion that they had an FMS test. Each observation had variables representing the test occasion (4 levels), player identity (62 levels), FMS score, and the grouping variable "Sustained Severe injury?" (Yes/No). Test occasion was treated as a repeated effect with a first-order autoregressive covariance type, while player identity was treated as a random effect. The power of this analysis was calculated >0.95 , when 90 observations were included.

The linear mixed model procedure was used to determine if there was a difference in composite FMS score between players who suffered a severe injury and those who had not. The model was also applied to include only contact and

only non-contact injuries. This procedure was repeated for each of the seven FMS component tests. Data are presented as mean $\pm$ SD, and Cohen's effect size statistic is calculated to allow for magnitude based inferences to be made. Effect sizes of 0.2, 0.5, 0.8 and 1.2 were considered *small, medium, large and very large* respectively (Hopkins *et al.*, 2009).

Receiver-operated characteristic (ROC) curves were produced to assess the predictive ability of the FMS composite score and all FMS component tests that were different between injured and non-injured groups. ROC curves determine the cut-off score that maximizes the sensitivity and specificity of the tests as predictors of injury. For a diagnostic tool to be applied as a predictor of injury, the tool should maximize the chances of a correct prediction (True +’s) and minimize incorrect predictions (False +’s). A lower 1-specificity value reduces the number of false-positives the test will produce, while higher sensitivity measures the number of injured cases that will be correctly predicted (True +’s). Therefore, the value with the highest sensitivity and lowest 1-specificity value is selected as the cut-off point. The method for producing a ROC curve is to produce cut-off values that are the average of two consecutive ordered test values; e.g. test values of 12 and 13 produce a cut-off value of 12.5. The final cut-off value is then between 2 half points, indicating precisely which whole number should be chosen. This value corresponds to the upper left line of the ROC curve.

All 90 FMS observations were included in the ROC curve analysis, despite the fact that repeat measures were performed on 22 of the players. These 22 players accounted for 28 tests included in the analysis. The result of the FMS test was different across test occasion in 24 of the 28 repeat tests. The researcher decided that these differences indicated a sufficient amount of independence between tests for all samples to be included.

Two-by-two (2x2) contingency tables were produced dichotomizing those who suffered a severe injury (injured), and those who did not (not injured) against those above and below the cut-off point determined by ROC curve. Odds ratios, sensitivity and specificity were then calculated. Fishers exact test (one tailed) was used to determine whether there was a significant association between the test result and injury. It was assumed that a FMS score below the cut-off value would be associated with injury.

Following the determination of the appropriate cut-off point, players were grouped according to whether they fell above; High-FMS (≥ 14); or below; Low-FMS (≤ 13); the cut-off point. A Kaplan-Meier survival analysis was performed to compare the fractional survival of subjects in the High-FMS and Low-FMS groups, differences were determined by Log-Rank test. Further to this, the total injured days and the average injury duration (both measures included all injuries, not only severe injuries) were compared between groups using the linear mixed model technique described above. The researcher acknowledges that it is inappropriate to assess the cut-off point in the sample that it was determined from, and that this leads to a high likelihood of type 1 error. These results are reported to make an argument for the potential value of this type of screening, but should be further assessed in an independent sample.

All statistical analyses were performed using SPSS version 22 software (IBM Inc.) and statistical significance was set at $p \leq 0.05$ for all analyses. Wherever relevant, subject numbers (n =) are presented.

4.3 Results

4.3.1 Linear mixed model analysis

The mean composite score for all FMS tests conducted over the course of this study was 14.1 ± 1.7 (n = 90). Table 4.1 presents the mean FMS composite score and the mean scores for each FMS component test for injured and non-injured

Table 4.1 – Mean scores of injured and non-injured players in FMS test and component tests for all injuries, contact injuries and non-contact injuries.

			FMS Composite Score	Deep Squat	Hurdle Step	In-Line Lunge	Shoulder Mobility	Active Straight Leg Raise	Trunk Stability Push Up	Rotary Stability
All Injuries	Injured	N=26	13.2 ± 1.7*	1.8 ± 0.7	2.0 ± 0.4	2.0 ± 0.7*	1.5 ± 0.6	1.8 ± 0.5*	2.3 ± 0.5	1.8 ± 0.5
	Not injured	N=64	14.5 ± 1.5	2.1 ± 0.4	2.1 ± 0.4	2.3 ± 0.5	1.7 ± 0.7	2.2 ± 0.6	2.4 ± 0.6	1.8 ± 0.5
	Effect size		<i>large</i>	<i>medium</i>	<i>small</i>	<i>medium</i>	<i>small</i>	<i>medium</i>	<i>trivial</i>	<i>trivial</i>
Contact Injuries	Injured	N=14	13.1 ± 2.0*	1.6 ± 0.8*	2.1 ± 0.3	1.8 ± 0.7*	1.5 ± 0.7	1.8 ± 0.6*	2.2 ± 0.4	1.9 ± 0.5
	Not injured	N=76	14.3 ± 1.5	2.1 ± 0.4	2.1 ± 0.4	2.3 ± 0.5	1.6 ± 0.7	2.1 ± 0.6	2.4 ± 0.6	1.8 ± 0.5
	Effect size		<i>medium</i>	<i>large</i>	<i>trivial</i>	<i>large</i>	<i>trivial</i>	<i>medium</i>	<i>small</i>	<i>small</i>
Non-contact injuries	Injured	N=12	13.3 ± 1.4	2.1 ± 0.5	1.9 ± 0.5	2.1 ± 0.7	1.4 ± 0.5	1.8 ± 0.5*	2.4 ± 0.5	1.6 ± 0.5
	Not injured	N=78	14.3 ± 1.7	2.0 ± 0.5	2.1 ± 0.4	2.2 ± 0.5	1.7 ± 0.7	2.1 ± 0.6	2.4 ± 0.6	1.8 ± 0.5
	Effect size		<i>medium</i>	<i>small</i>	<i>small</i>	<i>trivial</i>	<i>small</i>	<i>medium</i>	<i>trivial</i>	<i>medium</i>

* indicates a significant difference between injured and non injured groups, p <0.05.

Table 4.2 – Predictive power of FMS for total, contact and non-contact severe injuries.

	Sensitivity (95%CI)	Specificity (95%CI)	Odds Ratio (95%CI)	Fishers Exact Test
All Injuries	0.61 (0.41 to 0.80)	0.77 (0.64 to 0.86)	5.2 (2.0-13.9)	p < 0.001
Contact Injuries	0.71 (0.42 to 0.92)	0.72 (0.61 to 0.82)	6.5 (1.8 to 23.0)	p = 0.003
Non-Contact Injuries	0.83 (0.52 to 0.98)	0.46 (0.35 to 0.58)	4.3 (0.9 to 21.0)	p = 0.0497

players, and presents similar analysis considering only contact or non-contact injuries. There was a significant difference in composite FMS score between the injured and non-injured groups (injured 13.2 ± 1.7 vs. non-injured 14.5 ± 1.5 , ES = *large*) for all injuries. The mean distribution of FMS scores for injured and not injured groups is illustrated in figure 4.1.

Figure 4.1 – Composite FMS scores of players not injured and players who suffered severe injury >28 days. Crosses indicate individual composite scores, large error bars depict mean and standard deviation of the composite FMS scores. * indicates significant difference between the 2 groups.

The significant difference in FMS scores persisted when only contact injuries were considered (injured 13.1 ± 2.0 vs. non-injured 14.3 ± 1.5 , ES = *medium*), but not when only non-contact injuries were considered (injured 13.3 ± 1.4 vs. non-injured 14.3 ± 1.7 , ES = *medium*). There were significant differences in the scores for “in-line lunge” and “active straight leg raise” between injured and non-injured groups for all injuries. When only contact injuries were considered, there were significant differences in “deep squat”, “in-line lunge” and “active straight leg raise” scores between injured and non-injured players. Only “active straight

leg raise” was different between injured and non-injured players for non-contact injuries.

4.3.2 Receiver operated characteristic (ROC) curves

Figure 4.2 - ROC curves for the FMS test relating to injured or non-injured status. Analysis performed on all injuries, contact injuries and non-contact injuries. Diagonal segments are produced by ties. Grey circles show points on the graph with the same score, and red lines indicate the segments of each curve that maximize sensitivity and 1-specificity.

ROC curves (Figure 4.2) were produced and determined that a cut-off composite FMS score of 13 maximized sensitivity and specificity of the test for all injuries and for contact injuries. A cut-off score of 14 was the most appropriate for non-contact injuries. 2 x 2 Contingency tables were produced using these cut-off values for all injuries, contact injuries and non-contact injuries to determine sensitivity, specificity and overall odds ratio. For all injuries, the cut-off point of

13 represented an overall odds ratio of 5.2 (95% CI = 2.0-13.9); indicating that the odds of severe injury to a professional rugby player are 5.2 times greater with an FMS score was 13 or less. For contact injuries, a FMS cut-off score of 13 predicted an odds ratio of 6.5 (95%CI = 1.8 to 23.0). For non-contact injuries, a FMS cut-off score of 14 predicted injury with an odds ratio of 4.3 (95%CI = 0.9 to 21.0). Sensitivity, specificity, odds ratios and Fisher's exact test results are shown in table 4.2.

ROC analysis was also applied to each of the FMS component tests that were identified as different between injured and non-injured groups. Only "active straight leg raise" was associated with overall injury in this analysis. All other component tests were no better than chance at predicting injuries. A cut-off score of ≤ 2 for "active straight leg raise" predicted injuries with a sensitivity of 0.96 (95%CI = 0.92 to 0.99) and specificity of 0.29 (95%CI = 0.18 to 0.43). The overall odds ratio for this prediction was 9.4 (95% CI = 1.2 to 76, Fisher's exact test $p = 0.01$).

4.3.3 FMS cut-off assessment

The cut-off score of 13 was then used to divide the subjects into High-FMS (≥ 14) and Low-FMS (≤ 13) groups. Kaplan-Meier survival analysis determined that the survival proportion for overall injuries was significantly greater for High-FMS vs. Low-FMS groups (High-FMS 81% 95CI = 69 to 89% vs. Low-FMS 50% 95CI = 31 to 69%, $p < 0.05$) (figure 4.3). There was also a significant difference in proportional survival between groups for contact injuries (High-FMS 93% 95CI = 82 to 97% vs. Low-FMS 63% 95CI = 42 to 78%, $p < 0.05$), but not for non-contact injuries (High-FMS 95% 95CI = 80 to 99% vs. Low-FMS 80% 95CI = 65 to 89%, $p < 0.05$). The two groups were compared in terms of mean injured days per player and mean recovery time per injury. These data are presented in Table 4.3.

Figure 4.3 – Kaplan-Meier survival function plot of the Low-FMS and High-FMS groups for total injuries.

Table 4.3 - Average days injured per player and average days injured per injury for High-FMS and Low-FMS groups (FMS cut-off score ≤ 13).

	Low-FMS (n=26)	High-FMS (n=64)	Estimated Effect (95%CI)
Injured days per player (days)	47 $\pm$ 47*	25 $\pm$ 39	23 (4 to 41)
Recovery time per injury (days)	29 $\pm$ 38*	10 $\pm$ 16	20 (8 to 31)

* indicates significant difference between groups, $p < 0.05$

4.4 Discussion

4.4.1 FMS as a risk factor for injury

The main aim of this study was to determine whether a low FMS test score is a risk factor for severe injury in professional rugby union players. FMS test results were compared with records of injuries that occurred in the six months following testing. It was determined that the mean composite FMS scores of players that

suffered severe injury were significantly lower than the scores of those players that did not (injured 13.2 ± 1.7 vs. non-injured 14.5 ± 1.5 , ES = *large*). This is the first study to demonstrate reduced FMS scores in rugby union players that subsequently suffered severe injury, but is similar to the result obtained by Kiesel *et al.* (2007) in American Football players (injured 14.3 ± 2.3 vs. non-injured 17.4 ± 3.1 , ES = *large*). Research has also demonstrated lower FMS scores in groups of female collegiate athletes (Chorba *et al.*, 2010) and active students (Letafatkar *et al.*, 2014) that became injured. This result, therefore, adds to the growing body of evidence that a low FMS score is a risk factor for injury.

A ROC curve analysis determined that in professional rugby union players, a FMS score of 13 was the best predictor of severe injury. This score maximised specificity (0.77) and sensitivity (0.61) of the test, meaning that in a group of professional rugby union players, a coach could expect 61% of players with FMS ≤ 13 to sustain severe injuries, and 77% of the players with FMS > 13 to remain free of severe injury. Simply put, players with an FMS score ≤ 13 have a 5.2 times greater likelihood of severe injury. Previous research has shown similar sensitivity, specificity and odds ratios of the FMS in other sporting populations. Specifically, the odds ratio for injury among low-FMS groups is 11.7 in American Football players (Kiesel *et al.*, 2007), 3.9 in female collegiate athletes (Chorba *et al.*, 2010) and 4.7 in an active student population (Letafatkar *et al.*, 2014). These results demonstrate that the FMS displays some level of consistency in determining the odds of injury across heterogeneous sporting populations.

The identification of low FMS score as a risk factor for severe injury in professional rugby union players is a valuable step within the injury risk management model as the risk associated with a low FMS score has now been quantified. The next step in the injury risk management strategy is to implement a risk mitigation strategy in the hope of reducing this risk. Research has shown that low FMS scores can be improved through corrective training programmes

(Chorba *et al.*, 2010; Kiesel *et al.*, 2011). It is not, however, known whether these improvements in FMS score are associated with a concomitant reduction in injury risk. Future research to quantify the effect of a training intervention aimed at improving low FMS scores on injury risk will determine whether this risk mitigation strategy is successful

4.4.2 FMS and contact injury risk

This research study is the first to examine the ability of FMS to predict contact injuries. Mixed model analysis showed that there was a significant difference in composite FMS scores of players who suffered severe contact injury versus those who did not. The ROC analysis indicated that players with a composite FMS score of ≤ 13 are statistically more likely to sustain a contact injury (Odds ratio = 6.5, 95%CI = 1.8 to 23.0). The ability of the FMS test to predict contact injuries is a surprising result. Due to the fact that the majority of collision sport injuries occur during physical collisions and tackles, these injuries are generally thought unavoidable (Gabbett, 2010b). However, these results suggest that there may be a movement quality component that is related to the occurrence of certain severe contact injuries.

The researcher would like to propose two potential mechanisms as to how dysfunctional movement patterns, as demonstrated by the FMS test, may affect contact injury incidence in rugby union. Firstly, tackling is a highly technical skill that requires high coordination to be executed safely (Hendricks *et al.*, 2014b). Tackling is one of the major mechanisms of injury in rugby union (Williams *et al.*, 2013), but injury incidence is not related to the number of tackles a player performs (Gabbett, Jenkins & Abernethy, 2011b). This suggests that injury risk may be related to how well a player executes tackles rather than how often he tackles. A dysfunctional movement pattern may reduce the likelihood of a tackle being performed optimally, leading to increased injury risk. For example, a player with poor deep squat, in-line lunge and/or active straight leg raise scores, may

find it difficult to dip his hips far enough to execute a tackle at an appropriate height and with correct spinal alignment, thus predisposing him to contact injury. Recent research has linked poor tackle technique with increased contact injury incidence in rugby union (Burger *et al.*, 2015).

A second potential mechanism relates to the accumulation of fatigue. It is likely that players with lower FMS scores move less efficiently than players with higher FMS scores, and that these inefficiencies cause fatigue to accumulate more rapidly in low FMS groups. Fatigue has previously been established as a risk factor for injury in contact sports (Gabbett, King & Jenkins, 2008a). A potential mechanism for this is that fatigue reduces neuromuscular coordination (Schmitz *et al.*, 2014), which would in turn reduce tackling ability. Players with lower FMS scores therefore may fatigue more quickly placing them at increased risk for contact injury earlier in the game than players with more efficient movement patterns.

Based on these theories, it is still likely that certain contact injuries would remain unavoidable, however, others may be related to fatigue and/or technique factors. Further research in this area should look to include data relating to the nature of contact, how late in the game they occurred, the fatigue status of the player and whether any manageable technical and/or co-ordination factors were at fault.

4.4.3 FMS and non-contact injury risk

In this study, FMS composite scores were less accurate at predicting non-contact injuries than contact injuries. The FMS score of players who suffered severe non-contact injuries was not different from those who did not, although there was a non-significant trend towards the scores being lower ($p = 0.063$). In addition, the effect size ($ES=medium$) was the same as for contact injuries that were statistically different between injured and uninjured groups. However, ROC

analysis showed that players with a composite FMS score of ≤ 14 are statistically more likely to sustain a severe non-contact injury (Odds ratio = 4.3, 95%CI = 0.9 to 21.0). Previous research is equivocal regarding whether the FMS is able to predict non-contact injuries specifically. Certain studies found that FMS score was not related to the occurrence of non-contact (Warren *et al.*, 2014), or overuse injuries (Lisman *et al.*, 2013; O'Connor *et al.*, 2011). Other studies have shown FMS scores to be significantly lower in participants that suffered non-contact injury (Letafatkar *et al.*, 2014) and that FMS scores increased the predictive value of an overuse injury model (Lisman *et al.*, 2013). Theoretically, the FMS screen should predict non-contact and/or overuse injuries better than it does contact injuries, because these are directly affected by movement patterns that the FMS test purports to measure (O'Connor *et al.*, 2011). However, this is yet to be empirically substantiated. Since non-contact injuries occur infrequently compared to contact injuries in rugby union, it will take more time and larger samples of players to clearly establish this relationship in this population.

4.4.4 FMS component tests as injury risk factors

The use of the composite FMS score as a predictor of injury has been criticized recently due to the fact that it is not a unitary construct (Kazman *et al.*, 2014), but a recent review has called for further verification of this finding (Kraus *et al.*, 2014). With this in mind, we examined whether any of the FMS component tests had any value as injury predictors. “Active straight leg raise” was different between injured and non-injured groups for contact injuries, non-contact injuries and all injuries. “In-line lunge” was different between groups for contact and overall injuries, while “deep squat” was only different in the contact injuries analysis. Each of these components was subjected to ROC analysis, and only “active straight leg raise” was shown to be better than chance at predicting injuries. An “active straight leg raise” score of ≤ 2 predicted severe injuries with a sensitivity of 96%, but the specificity was low (29%). A low leg raise score increased the odds of injury by 9.4 times. Other research has associated “in-line

lunge” score of ≤ 2 with increased risk of injury (Warren *et al.*, 2014). The evidence presented here suggests that “active straight leg raise” could be utilized independently from the rest of the FMS test as a predictor of injury in professional rugby union players.

4.4.5 Practical impact

The practical value of the FMS test in a professional team environment was assessed through survival analysis and comparison of total time injured and mean recovery time. These analyses should ideally be performed on an independent sample, but are included here to make a point about the applications of this test. Kaplan-Meier survival analysis revealed that 81% of the High-FMS group survived six months without severe injury, while only 50% of the Low-FMS group survived. Furthermore, the Low-FMS group spent 23 more days per player unavailable for training, and took 20 days longer to recover per injury than the High-FMS group. This is the first study to report an association between FMS and injury duration. It is possible that following injury, players with a better initial FMS score, begin rehabilitation capable of better movement quality and that this factor somehow assists rehabilitation. Further investigation into whether injury rehabilitation times are better for players with higher FMS scores is required.

4.4.6 FMS differences according to sample and methodology

A notable difference between this study and other studies that have compared injury to FMS score is the injury definition used. The World Rugby (formerly IRB) definition of severe injury (> 28 days) (Fuller *et al.*, 2007a) is longer than the “serious” injury (>21 days) utilized by Keisel *et al.* (2007). Other studies have defined injuries as events that require medical attention (Chorba *et al.*, 2010), and any injury that caused a missed participation (Letafatkar *et al.*, 2014). It seems that the link between low FMS scores and injury does not become apparent in contact sports like American Football and rugby union until the

severity of the injury is included in the analysis. This is possibly because exposure to contact sport inevitably results in a number of injuries like contusions and lacerations, which have relatively short recovery times, and are unrelated to movement quality variables.

The mean composite score for the rugby union players in this study (14.1 ± 1.7) was lower than the scores that have been previously reported in team sports such as American football (16.9) (Kiesel *et al.*, 2007), Gaelic field sports (15.5 ± 1.45) (Fox, O'Malley & Blake, 2014), and an active general population (15.7 ± 1.9) (Schneiders *et al.*, 2011). Our result is however similar to that reported for female collegiate athletes (14.3 ± 1.8) (Chorba *et al.*, 2010). It may be that these differences relate to the different training regimens followed by athletes in different sports, or may be related to the cohort studied. Interestingly, Keisel *et al.* (2011) reported differences between the mean scores of football linemen (11.8) and non-linemen (13.3) in the same sample (Kiesel *et al.*, 2011). There may be a relationship between increased size, muscle mass, or specific strength and power training regimes and low FMS scores, further investigation is warranted.

The establishment of a cut-off point of 13 in this study differs from that of Kiesel *et al.* (2007) and Letafatkar *et al.* (2014) who reported cut off points of 14 and 17 for American Football players and physically active students respectively. This finding underlines the differences in the physical attributes and training regimes of athletes in different sports, and confirms that it is incorrect to merely apply the FMS cut-off value of 14 determined in American Football players (Kiesel *et al.*, 2007) across all other sports. Rather, a FMS cut-off should be considered to be sports specific, taking into account the demands of the sport and participants. This study suggests that a cut-off score of 13 is the most sensitive for predicting severe injury in professional rugby union players.

This research adds to the growing body of evidence for the predictive value of the FMS screen for injuries (Chorba *et al.*, 2010; Kiesel *et al.*, 2007; Kiesel *et al.*, 2014; Letafatkar *et al.*, 2014). Although some studies have failed to establish this link (Klusemann *et al.*, 2011; Warren *et al.*, 2014), there is sufficient positive evidence for the application of this test to warrant its use in professional team settings.

4.5 Conclusion

Identifying risk factors that increase overall player injury risk is an important step within the injury risk management framework. This research has established a low FMS score (≤ 13) as an identifiable risk factor for severe contact and non-contact injuries in professional rugby union players. These findings have implications for the responsible management of players. Players should be screened at the start of the season, and “at risk” players should be placed on corrective exercise programmes. Research has shown that FMS scores improve with corrective exercise programmes (Chorba *et al.*, 2010; Kiesel *et al.*, 2011). Although it has not yet been established that improving FMS score reduces individual injury risk, this seems like a good target for injury risk mitigation programmes.

CHAPTER 5 – MONITORING TRAINING AND FATIGUE TO MINIMISE INJURY RISK IN PROFESSIONAL RUGBY UNION PLAYERS

5.1 Introduction

Well-developed physical qualities and skills are essential for performance in professional rugby union (Gabbett *et al.*, 2011a; Gabbett *et al.*, 2013a; Gabbett *et al.*, 2013b; Gabbett, Jenkins & Abernethy, 2011d; Waldron *et al.*, 2014). As a result, coaches are under continual pressure to produce high-quality conditioning and skills training programmes. The relationship between training and physical performance is clearly established, with increases in training load leading to improved performance (Foster *et al.*, 1996). However, negative consequences of training (illness, injury) also occur at higher rates when training loads are high (Foster, 1998; Gabbett, 2004a). Therefore, it is essential that coaches regulate the training load in their programmes to get a balance between sufficient training to induce positive changes in performance while not being so intense as to increase the risk of injury (Gamble, 2004a).

An injury risk evaluation process (Chapter 3), determined that injury risk for players representing the rugby union team studied was too high. A concern identified by the coaches and medical staff was that possibly the team training load was too high. While performance in athletic tasks tends to improve with additional training (Foster *et al.*, 1996), it is also known that the highest incidence of illness and injury occur when training loads are highest (Foster, 1998). This training load injury response is believed to be the result of fatigue caused by high levels of activity and insufficient recovery (Foster, 1998). Foster (1998) suggested that simple methods of monitoring training, fatigue and recovery may keep athletes from exceeding the individual training thresholds that put them at risk for overtraining and injury. With this in mind, and as part of the teams' injury risk mitigation programme, the current investigation was

undertaken to determine how the relationship between training load and fatigue in professional rugby union players could be best monitored.

Only a few studies have investigated the effect of training load on injury in rugby union players (Brooks *et al.*, 2005b; Brooks *et al.*, 2005c; Brooks *et al.*, 2008a; Viljoen *et al.*, 2009). Brooks *et al.* (2008a) assessed a group of professional players in England and found no relationship between training volume and injury incidence, but higher training volumes did increase injury severity. Data from the same group of players indicated that 34% of all injuries were sustained during the pre-season period where there was a larger focus on physical conditioning, and that the training activity most likely to result in injury was running (Brooks *et al.*, 2005b). A study of the 2003 England Rugby World Cup squad demonstrated that training injury incidence was highest during the squad's training camp, where there was a larger conditioning focus than other training periods (Brooks *et al.*, 2005c). Research from a South African professional rugby union team showed that decreases in total training volume per season were associated with small decreases in injury rates, but team performance declined during the same period (Viljoen *et al.*, 2009).

Studies in rugby league players produce a clearer picture of the training injury relationship in collision sports. Significant correlations between training load and injury have been shown in elite players, demonstrating that the harder players train, the more likely they are to be injured (Gabbett *et al.*, 2011c). Furthermore, reductions in pre-season training loads lead to a decrease in injuries in sub-elite players, without causing a reduction in training-induced physical qualities (Gabbett, 2004b). These studies make it clear that there is a dose-response relationship between training and fatigue in collision sports, and that this fatigue is a risk factor for injury. Therefore, training loads and the fatigue response to these loads should be monitored carefully (Twist & Highton, 2015).

When assessing the training load injury relationship in collision sports, it is important to differentiate between contact injuries, resulting from physical collisions and tackles, and non-contact soft tissue injuries that result from large training loads and inadequate recovery with residual fatigue (Gabbett, 2010b). Gabbett *et al.* (2010) demonstrated that professional rugby league players were significantly more likely to sustain a non-contact soft tissue injury if they exceeded various training load thresholds. While certain contact injuries will be unavoidable, evidence is growing that fatigue may play a role in predisposing players to contact injury in certain instances (Brooks *et al.*, 2005a; Hendricks *et al.*, 2014c; Usman *et al.*, 2011), and therefore, should be considered as a risk factor. With these factors in mind, the primary aim of this research study is to investigate the relationship between training volume, intensity and load with contact and non-contact injury incidence in matches and practice in South African professional rugby union players.

An understanding of the average volumes and loads of training that players can tolerate is valuable, but should be considered in the context of individual responses to training (Mann *et al.*, 2014). In a group of players, a given training load will be perceived differently based on individual factors such as body mass, strength, aerobic capacity, recovery status and personal stress. Therefore, a “safe” training load may still be large enough to induce negative consequences in some players, while at the same time, may not be large enough to induce adaptation in other players. Consequently, individual monitoring of players response to training should form part of the training programme (Halson, 2014).

One method of individual athlete monitoring available to coaches is the use of self-report measures of perceptual fatigue (Taylor *et al.*, 2012). These questionnaires exhibit a dose-response relationship with training load and can thus be used to monitor physical training (Raglin, 2001). A number of well-established psychometric questionnaires are available, but due to time

limitations in professional team settings, many organizations have opted for shortened, customised questionnaires (Taylor *et al.*, 2012). A secondary aim of this study is to report on the efficacy of using perceptual fatigue question responses as an indicator of fatigue status and predictors of injury.

A further consideration about monitoring fatigue in professional rugby players is whether players are fully recovered following match participation. Training in the context of incomplete recovery leads to reduced performance and increases susceptibility to injury (figure 2.3) (Twist & Highton, 2015). Recovery from match exertions can be assessed as a measure of neuromuscular function through jump tests (McLellan *et al.*, 2012; Twist *et al.*, 2012; West *et al.*, 2013). In addition to assessing neuromuscular function, some professional teams have begun assessing range of motion (ROM) in various joints as a proxy for muscle recovery in their assessment of readiness to train (Rugby Strength Coach Podcast, 2015). A final aim of this research study will be to assess the use of “readiness to train assessments”, which include both jump and ROM tests, to determine whether players have sufficiently recovered from match play to begin a new week of training.

5.2 Methods

5.2.1 Experimental approach to the problem

A prospective observational design was used to determine the relationships between training volume, intensity and load and injuries (incidence and severity) in a cohort of rugby union players representing a professional South African team. A case study was performed to determine the value of perceptual fatigue questions in tracking player response to training and as a predictor of injury. Further case studies were initiated to determine the effectiveness of “readiness to play” protocols in identifying fatigued players and players at risk of injury.

5.2.2 Procedures

Participants and injury data

Data were collected from the same 66 players who represented the team during the 2012 and 2013 seasons and were previously described in Chapter 3. The same injury data set as described in Chapter 3 was used in this study.

Training volume, intensity and load

Training volume (length of time spent on training activities) was reported by the team strength and conditioning coach for each training session. Total weekly training volumes were determined by summing these session durations. Training volume data were recorded for 99 weeks across the 2012 and 2013 seasons. An attempt was made to record training load data according to the methods of Foster *et al.* (2001). The intensity of individual training sessions was determined using a modified rating of perceived exertion (RPE) scale, and training load was calculated by multiplying the training session intensity by the duration of the training session (RPE.mins) (Foster *et al.*, 2001). Intensity estimates were obtained approximately 30 min after the completion of the training session on each day, using a self-report form (figure 5.1) that also included questions related to perceptual fatigue (detailed in next section). Players were asked to complete and return the questionnaire before leaving the training ground each day. This method of data reporting was selected as the most pragmatic because no member of the medical or strength and conditioning staff could consistently be made available to collect the RPE and perceptual fatigue data. Player compliance to this protocol was disappointing. A decision was made that data would be excluded from analysis if a minimum of 20 players had not completed all questionnaires for a given week. As a result, data from 15 weeks of training were excluded from analysis and the project was abandoned after 39 weeks due to poor compliance. The remaining 24 weeks had complete responses from more than 20 players and are analysed here.

Perceptual fatigue responses

A daily perceptual fatigue response form was developed and implemented by the team medical staff to assess psychophysiological stress (Figure 5.1). The questionnaire consisted of 5 questions relating to 1. Session RPE (training intensity), 2. How well did you sleep last night? (sleep), 3. How do you feel generally today? (wellness), 4. selecting the number of recovery actions completed from a predefined recommended list (recovery actions), and 5. indicating the site and severity of any pain experienced (pain). The team medical staff checked the results of the response form daily to determine any notable changes among players. Players who displayed deterioration in their average sleep or wellness scores were interviewed by the team doctor, and where appropriate recommendations for rest or modified training were made to the coaching staff.

Daily Perceptual Fatigue Response Form

Name: _____ **Date:** _____

1. Session RPE: _____

2. How well did you sleep last night (circle a number)?

☹️ 10 9 8 7 6 5 4 3 2 1 😊

3. How do you feel generally today (circle a number)?

☹️ 10 9 8 7 6 5 4 3 2 1 😊

4. Which recovery strategies did you use fully yesterday?

☐ nutrition ☐ stretching ☐ pool ☐ skins

☐ hydration ☐ massage ☐ ice bath ☐ limit alcohol

5. Muscle/Joint soreness

Indicate on the body chart area(s) of soreness out of 10
(0 = no pain, 10 = severe pain)

The body chart consists of two line drawings of a human figure. The left drawing is a front view, and the right drawing is a back view. Each drawing has labels for the 'Right' and 'Left' sides of the body.

Figure 5.1 – Daily training intensity and perceptual fatigue response form.

Mean weekly sleep and wellness scores for the entire player group were compared with training load and injury data. The aim of this analysis was to determine the usefulness of these perceptual fatigue questions for monitoring training response and predicting injury. As discussed previously, compliance with the questionnaire data collection protocol was disappointing, but sleep, wellness and recovery action measures were better reported than daily RPE, making it possible to include data from 36 weeks in the analysis. Pain measures were inconsistently reported and could not be assessed.

Readiness to train protocols

Counter-movement jump (CMJ) test

A CMJ test protocol was implemented to determine the recovery status of players at the beginning of a week. The procedures followed were similar to those previously described by Twist *et al.* (2012). The protocol was followed for a period of 17 weeks, but because the players were unavailable due to tours and bye weeks, only 12 weeks of data were collected.

All players were familiar with counter-movement jumps (CMJ) as they regularly performed these as part of their training routines. The CMJ was assessed as total flight time, calculated as the difference between landing and take-off time, recorded using an electronic timing mat system (Just Jump System, Probotics, Inc., Huntsville, AL). The CMJ assessment measure selected was flight time, as it provided the most reliable performance measure (Cormack *et al.*, 2008). The jump test protocol allowed players a two-minute warm-up consisting of dynamic stretches and plyometrics, and a practice jump before performing three CMJs for maximal flight time. Players stood upright on the jump mat before dipping to a self-selected depth and exploding upwards to achieve maximal jump height and landing back on the timing mat. The longest flight time of the three jumps was recorded for analysis. Reliability data for this measurement within this group of

players showed an intraclass correlation (ICC) of 0.86 (95% CI = 0.76 to 0.92), and a coefficient of variation (CV) of 2.3%.

Two baseline counter-movement jump testing sessions took place spaced 1 week apart. Both baseline sessions took place during a mid-season on a Monday morning following weekends where no match had taken place, so that players were in a rested state. At each baseline testing session, all three jump flight times were recorded and then pooled providing six baseline measures for each player. Mean flight time and CV were determined for each individual player and set as the baseline score. Thereafter, every Monday morning (first day players reported for training following a match), all players (both match participants and non-participants) performed a CMJ test before starting training. Each week, these tests were compared with the baseline test and the magnitude of difference assessed as Δ small (CV x 0.3), Δ medium (CV x 0.9) or Δ large (CV x 1.6) according to the methods of Hopkins *et al.* (2009). Players identified with large differences from baseline testing were reported to the head of strength and conditioning, who would typically discuss with the player why he was under recovered, and modify training, if necessary.

ROM – ankle dorsiflexion and sit and reach tests

As an alternative to the jump test protocol, a battery of ROM tests was assessed for its ability to assess player recovery following match participation. This protocol was assessed over 14 weeks. Upon arrival at training on a Monday morning, and prior to any warm-up, all players (match participants and non-participants) performed bilateral ankle dorsiflexion (Konor *et al.*, 2012) and sit-and-reach (American College of Sports Medicine, 2000) tests, which were assessed by the team physiotherapist.

Maximal ankle dorsiflexion ROM was measured in a weight-bearing lunge position, facing a wall and using a metric tape measure. The test was performed

barefoot, standing, with the heel in contact with the ground, the knee in line with the second toe, and the big toe 10 cm away from the wall. Players were asked to lunge forward, directing their knees toward the wall (in line with the second toe) until their knees touched the wall. The foot was progressed away from the wall until they were unable to touch the wall with their knee without lifting the heel from the ground. The largest distance of the large toe from the wall where the knee could touch the wall without the heel lifting was recorded to the nearest centimetre. The reliability of this test has been previously established (Konor *et al.*, 2012) with an ICC of 0.98 (95% CI = 0.96 to 1.00) and a standard error of measurement (SEM) of 0.4-0.6 cm.

The sit-and-reach test was performed with players barefoot and seated with knees straightened. A measuring tape was fixed to the floor and players positioned themselves with their heels at the 38 cm mark and the 0 cm side of the tape measure towards them. Players were instructed to slide their hands along the tape, reaching as far forward as possible. The mark reached by the fingertips on the tape measure was recorded to the nearest centimetre (American College of Sports Medicine, 2000).

The team medical staff proposed “red flag” indicators from these two tests that would indicate if a player was not fully recovered from the previous match. The criteria for these “red flag” tests were ankle dorsiflexion of <10 cm on either side, a dorsiflexion difference of ≥ 3 cm between legs and a sit and reach score of <15 cm. Players displaying any one of these “red flags” were interviewed by the head of strength and conditioning and training was modified if required.

5.2.3 Statistical Analysis

Differences in weekly training volume between pre-season and in-season for each year and between study years (2012 and 2013) were determined using a series of independent samples t-tests. A Bonferonni correction was applied

because of the multiple comparisons made. Time spent on different training activities in pre-season and in-season was similarly assessed.

Pearson product-moment correlations were performed to determine the relationship between training volume, intensity and load, and injury incidence and severity. Further correlations were performed for the relationships between the mean weekly sleep, wellness and recovery action scores, and injury measures. Correlations are reported as r , $\pm 95\%$ confidence limits. Due to the practical nature of this study, clinical or mechanical magnitude based inferences were made as appropriate regarding the likelihood of meaningful effects. These inferences were made using the “Confidence limits & clinical chances” spread sheet developed by Hopkins (2007) and downloaded from www.sportsci.org (Hopkins, 2007).

To determine the effect of training volume on match and contact injury incidence and severity, weeks were divided into quintiles according to the total volume of training completed each week (< 6.3 h, 6.3–8.3 h, 8.3–9.0 h, 9.0–10.0 h, >10 h). The incidences and severities of match and practice injuries were recalculated for each of these training volume categories, and chi-squared tests were used to identify differences between categories.

Both readiness to train protocols (CMJ and ROM) were assessed using a linear mixed model procedure. This procedure was chosen due to its ability to manage repeated measures on multiple subjects with an inconsistent subject group (West, 2009). The data were processed to give each player a single observation on each occasion (week) that they had a readiness to train test. Each observation had variables representing the test occasion, player identity, test score, whether the player sustained an injury in the week (injured/not injured) and whether a player had participated in a match prior to performing the test (participant/non-participant). Each test occasion was treated as a repeated effect with a first

order autoregressive covariance type, while player identity was treated as a random effect. To determine the effectiveness of each protocol in identifying fatigued players, the model was run using the grouping variable participant/non-participant. To determine the relationship “red flag” screens to injury occurrence, grouping variables for CMJ Δ large (yes/no), dorsiflexion distance <10 cm (yes/no), between leg dorsiflexion difference ≥ 3 cm (yes/no), and sit and reach distance <15 cm were produced and tested within the model. Estimated effect (95%CI) of the grouping variable is reported for all mixed model analyses. In addition, the proportion of match participants and non-participants that “failed” the readiness to train tests is reported and these rates were compared using a z-test (Medcalc.org). Unless otherwise stated, statistical analyses were performed using SPSS statistics software package (version 22, IBM Inc.) and statistical significance was set at $p \leq 0.05$ for all analyses.

5.3 Results

5.3.1 Training volumes

The average weekly training volumes of the team during pre-season and in-season training phases for the 2012 and 2013 seasons are presented in table 5.1. Pre-season training volumes were higher than in-season training volumes in both seasons. There was no significant difference in training volume in either pre-season or in-season across the 2 seasons.

Table 5.1 – Mean weekly training volumes (hours) during the pre-season and in-season periods.

Year	Pre-season	In-season	Overall
2012	10.0 $\pm$ 1.4 (9)*	8.2 $\pm$ 1.5 (34)	8.5 $\pm$ 1.6 (43)
2013	11.2 $\pm$ 3.3 (6)*	8.1 $\pm$ 2.2 (39)	8.6 $\pm$ 2.6 (45)
Combined	10.7 $\pm$ 2.6 (15)*	8.2 $\pm$ 2.0 (73)	8.6 $\pm$ 2.2 (98)

Data are presented as mean $\pm$ SD (N). N = the number of weeks * indicates significant difference ($p < 0.05$) pre-season to in-season.

Figure 5.2 - Typical composition of training sessions during pre-season and in-season for the 2012 and 2013 seasons. * indicates significant difference pre-season to in-season ($p < 0.05$).

Figure 5.2 shows the typical composition of training per week for pre-season and in-season. Pre-season training volumes were higher due to increased periods of time spent on gym training and alternative training. Players spent a similar amount of time in on-field training during pre-season and in-season, although the range was greater during pre-season due to some longer on field training sessions. In addition, the on-field training sessions during pre-season were characterized by increased periods of time spent on endurance and high-intensity conditioning (running without the ball), while in-season periods were characterized by match-related skill-based training.

5.3.2 Relationship between training volume, intensity and load with injuries

The correlation coefficients of the relationships between training volume, intensity and load with injury incidence and severity are displayed in table 5.2.

Training volume

Training volume and total injury incidence was significantly correlated (-0.38 , ± 0.19 , *very likely beneficial, most unlikely harmful*, $p = 0.001$) indicating that increasing training volume would reduce total injury incidence. There was no

correlation between match injury incidence and weekly training volume (0.02, ± 0.26 , *unlikely harmful, very unlikely beneficial*, $p = 0.894$). This relationship was no stronger when considered as match contact (-0.03, ± 0.26 , *very unlikely harmful, unlikely beneficial*, $p = 0.848$) or non-contact injuries (0.04, ± 0.26 , *unlikely harmful, very unlikely beneficial*, $p = 0.896$). Similarly, there was no relationship between training volume and practice contact (0.06, ± 0.23 , *unlikely harmful, very unlikely beneficial*, $p = 0.615$) and non-contact (-0.01, ± 0.23 , *very unlikely harmful, unlikely beneficial*, $p = 0.934$) injury incidence.

Table 5.2 – Pearson correlation coefficients and clinical inferences for the relationship of training volume, intensity and load with injury incidence and severity.

	Volume (h/week)	Intensity (RPE)	Training load (RPE.min)
Injury incidence (injuries/1000 h)			
Total	-0.38, $\pm 0.19^*$ <i>very likely beneficial, most unlikely harmful</i>	0.33, ± 0.37 <i>possibly harmful, very unlikely beneficial</i>	-0.29, ± 0.37 <i>possibly beneficial, very unlikely harmful</i>
Contact	-0.34, $\pm 0.19^*$ <i>likely beneficial, most unlikely harmful</i>	0.02, ± 0.4 <i>unlikely harmful, unlikely beneficial</i>	-0.04, ± 0.4 <i>unlikely beneficial, unlikely harmful</i>
Non-contact	-0.12, ± 0.22 <i>unlikely beneficial, most unlikely harmful</i>	0.43, $\pm 0.34^*$ <i>likely harmful, most unlikely beneficial</i>	-0.34, ± 0.36 <i>likely beneficial, very unlikely harmful</i>
Mean injury severity (days)			
Total	-0.04, ± 0.22 <i>very unlikely harmful, unlikely beneficial</i>	0.47, $\pm 0.33^*$ <i>likely harmful, most unlikely beneficial</i>	0.3, ± 0.37 <i>possibly harmful, very unlikely beneficial</i>
Contact	-0.07, ± 0.22 <i>very unlikely harmful, unlikely beneficial</i>	0.07, ± 0.4 <i>possibly harmful, unlikely beneficial</i>	0.22, ± 0.39 <i>possibly harmful, very unlikely beneficial</i>
Non-contact	-0.02, ± 0.22 <i>very unlikely harmful, unlikely beneficial</i>	0.55, $\pm 0.3^*$ <i>very likely harmful, most unlikely beneficial</i>	0.24, ± 0.38 <i>unclear</i>

Data presented as r , $\pm 95\%$ confidence limit. Clinical inferences presented in *italics* * indicates significant correlation ($p < 0.05$).

There was a significant difference in match injury incidence in different training volume quintiles ($\chi^2(4) = 16.23$, $p = 0.003$) (figure 5.3). Injury incidence was highest when training volumes were very high (182 (126 to 238) injuries/1000 h at >10 h per week) or very low (174 (131 to 218) injuries/1000 h at <6.3 h per

week). The training volume that elicited the lowest injury incidence (115 (68 to 162) injuries/1000 h) was 8.3-9.0 h per week. When injury data were differentiated by contact and non-contact injuries, there were still no correlations, but significant differences across quintile for both contact ($\chi^2(4) = 10.99$, $p = 0.027$) and non-contact ($\chi^2(4) = 12.72$, $p = 0.013$) injuries. These followed a similar pattern to overall injuries with the highest injury incidence in quintile 5. There was no difference in injury severity across training volume quintiles for overall, contact or non-contact injuries.

Figure 5.3 – Overall, contact and non-contact match injury incidences within 5 training volume quintiles. Overall ($\chi^2(4) = 16.23$), contact ($\chi^2(4) = 10.99$) and non-contact ($\chi^2(4) = 12.72$) conditions displayed significant differences from the expected distribution.

There were significant differences in overall ($\chi^2(4) = 25.35$, $p < 0.001$), contact ($\chi^2(4) = 9.68$, $p = 0.046$) and non-contact ($\chi^2(4) = 34.48$, $p < 0.001$) practice injury incidence when assessed according to weekly training volume quintile (figure 5.4). For contact practice injuries the injury incidence was lowest in weeks where the training volume was <6.3 h (0.6 (-0.2 to 1.5) injuries/1000h), and constant through the higher training volume quartiles. Non-contact and overall injury

incidence was significantly higher in quintiles 3 and 4 (8.3 to 10.0 h training per week). There was no difference in practice injury severity across quintiles for any injury mechanism.

Figure 5.4 – Overall, contact and non-contact practice injury incidences within 5 training volume quintiles. Overall ($\chi^2(4) = 25.35$), contact ($\chi^2(4) = 9.68$) and non-contact ($\chi^2(4) = 34.48$) conditions displayed significant differences from the expected distribution.

Training intensity

There was a significant negative correlation between training intensity (mean RPE) and training volume ($-0.59, \pm 0.28$, *very likely negative*, $p = 0.003$), indicating that training intensity was highest in the weeks with the lowest training volume. A significant correlation was present for training intensity (mean RPE) and overall non-contact injury incidence ($r = 0.43, \pm 0.34$, *likely harmful, most unlikely beneficial*, $p = 0.038$). This relationship was not present for overall injury incidence ($0.33, \pm 0.37$, *possibly harmful, very unlikely beneficial*, $p = 0.117$) or contact injury incidence ($0.02, \pm 0.4$, *unlikely harmful, unlikely beneficial*, $p = 0.931$).

Training intensity was significantly correlated with mean overall injury severity (0.47, ± 0.33 , *likely harmful, most unlikely beneficial*, $p = 0.019$) and non-contact injury severity (0.55, ± 0.3 , *very likely harmful, most unlikely beneficial*, $p = 0.005$) but did not correlate with contact injury severity (0.07, ± 0.4 , *possibly harmful, unlikely beneficial*, $p = 0.731$). Similar relationships were apparent for match injuries, with overall match injury severity (0.54, ± 0.34 , *likely harmful, most unlikely beneficial*, $p = 0.018$) and match non-contact injury severity (0.66, ± 0.28 , *very likely harmful, most unlikely beneficial*, $p = 0.003$) significantly correlated with training intensity in the week prior to the match, but not match contact injury severity (0.13, ± 0.45 , *possibly harmful, unlikely beneficial*, $p = 0.590$).

Training load

The calculated training load (RPE.min) did not correlate significantly with any measure of injury incidence or severity, but increasing training load had a likely beneficial effect on non-contact injury incidence (0.34, ± 0.36 , *likely beneficial, very unlikely harmful*, $p = 0.105$).

5.3.3 Perceptual fatigue questions

Daily sleep and wellness

Mean weekly measures of sleep quality and wellness were correlated with each other (0.39, ± 0.27 , *likely positive*, $p = 0.013$). Training volume increases were *likely harmful* (0.32, ± 0.32 , *likely harmful, most unlikely beneficial*, $p = 0.08$) and training intensity increases were *possibly beneficial* (-0.27, ± 0.33 , *possibly beneficial, very unlikely harmful*, $p = 0.21$) to sleep quality, but neither relationship was statistically significant. Wellness showed no association with either training volume (0.07, ± 0.35 , *unlikely harmful, unlikely beneficial*, $p = 0.691$) or training intensity (0.18, ± 0.34 , *possibly harmful, very unlikely beneficial*, $p = 0.417$). Neither sleep (0.14, ± 0.4 , *possibly harmful, unlikely beneficial*, $p =$

0.535) nor wellness (0.12, ± 0.4 , *possibly harmful, unlikely beneficial*, $p = 0.591$) was correlated with training load (RPE.min).

Correlations between sleep, wellness and recovery actions and measures of injury incidence and severity are presented in table 5.3. Neither sleep nor wellness measures showed any clear association with measures of injury incidence. Sleep showed a non-significant, *likely harmful* correlation with contact injury severity ($r = 0.32$, ± 0.32 , *likely harmful, most unlikely beneficial*, $p = 0.054$), but no relationship with overall or non-contact injury severity. Wellness was significantly correlated with mean injury severity (0.48, ± 0.28 , *very likely harmful, most unlikely beneficial*, $p = 0.003$), and with contact (0.37, ± 0.31 , *likely harmful, most unlikely beneficial*, $p = 0.025$) and non-contact (0.42, ± 0.29 , *likely harmful, most unlikely beneficial*, $p = 0.025$) injury severity.

Table 5.3 – Pearson correlation coefficients and clinical inferences for the relationship of sleep, wellness and recovery actions with injury incidence and severity.

	Sleep	Wellness	Recovery actions
Injury incidence (injuries/1000 h)			
Total	-0.17, ± 0.34 <i>unclear</i>	0.17, ± 0.34 <i>possibly harmful, very unlikely beneficial</i>	0.27, ± 0.45 <i>possibly harmful, very unlikely beneficial</i>
Contact	-0.13, ± 0.34 <i>unclear</i>	0.07, ± 0.35 <i>unlikely harmful, unlikely beneficial</i>	-0.19, ± 0.47 <i>unclear</i>
Non-contact	-0.09, ± 0.35 <i>unclear</i>	0.17, ± 0.34 <i>possibly harmful, very unlikely beneficial</i>	0.61, $\pm 0.33^*$ <i>very likely harmful, most unlikely beneficial</i>
Mean injury severity (days)			
Total	0.22, ± 0.33 <i>possibly harmful, very unlikely beneficial</i>	0.48, $\pm 0.28^*$ <i>very likely harmful, most unlikely beneficial</i>	-0.11, ± 0.48 <i>unclear</i>
Contact	0.32, ± 0.32 <i>likely harmful, most unlikely beneficial</i>	0.37, $\pm 0.31^*$ <i>likely harmful, most unlikely beneficial</i>	-0.20, ± 0.47 <i>unclear</i>
Non-contact	0.01, ± 0.35 <i>unlikely harmful, unlikely beneficial</i>	0.42, $\pm 0.29^*$ <i>likely harmful, most unlikely beneficial</i>	0.01, ± 0.48 <i>unclear</i>

Data presented as r , $\pm 95\%$ confidence limit. Clinical inferences presented in *italics* * indicates significant correlation ($p < 0.05$).

There was a *very likely harmful* relationship between recovery actions and non-contact injury incidence (0.61, ± 0.33 , *very likely harmful, most unlikely beneficial*, $p = 0.012$), indicating that the more recovery actions players engage in, the more likely they are to sustain a non-contact, soft tissue injury. Recovery actions were unrelated to injury severity.

5.3.4 Readiness to train protocols

Counter movement jump test

There was no difference in the mean flight time of players during their rested baseline test (0.70 ± 0.03 s), following match participation (0.70 ± 0.04 s) or non-participation (0.71 ± 0.03 s). Despite this, each week some of the players did not attain baseline flight time levels. This occurred more frequently in the match participants (participants 36% vs. non-participants 18%, $p < 0.0001$) (figure 5.4), but there was no significant difference in change in flight time between match participants and non-participants (participants estimated effect = -0.01 (-0.01 to 0.0) s, $p = 0.067$). On average, 2 ± 1 players per week were identified as having Δ large differences from baseline flight time. There was no difference in injury rate for players in the Δ large CMJ group (Δ large estimated effect = -5.3 (-18.5 to 7.8) % injured, $p = 0.424$).

Figure 5.5 – Change in flight time from baseline testing following match participation or non-participation during 12 weeks of professional competition. Crosses indicate individual weekly differences from baseline score. Large error bars depict mean and standard deviation of Δ baseline for match non participants and participants.

Range of motion tests

No difference was present for dorsiflexion distance (participant estimated effect = -0.1 (-0.6 to 0.3) cm, $p = 0.618$), bilateral dorsiflexion difference (participant estimated effect = 0.05, (-0.3 to 0.4) cm, $p = 0.751$) or sit and reach distance (participant estimated effect = -0.6 (-1.2 to 0.1) cm, $p = 0.086$) between match participants and non-participants. There was also no difference in the frequency of “red flags” for dorsiflexion distance (participants 24% vs. non participants 34%, $p = 0.119$), bilateral dorsiflexion difference (participants 13% vs. non-participants 10%, $p = 0.501$) or sit and reach distance (participants 27% vs. non-participants 23%, $p = 0.516$) between match participants and non-participants. Injury rate was not significantly different for players in the dorsiflexion <10cm group (estimated effect = +7.1 (-1.1 to 15.4) % injured, $p = 0.089$), or the dorsiflexion difference ≥ 3 cm group (estimated effect = +1.2 (-14.4 to 16.8) % injured, $p = 0.877$). Being in the sit and reach <15 cm group increased the injury rate (estimated effect = +8.8 (0.4 to 17.3) % injured, $p = 0.0041$).

5.4 Discussion

The application of the injury risk management framework hinges on the identification of injury risk factors, and an understanding of how these factors may modify risk (Fuller *et al.*, 2004a; Fuller *et al.*, 2012). Foremost among these risk factors is the effect of the training programme that the team follows. Players must be pushed to develop the physical qualities associated with success in rugby union, but this mandate must be tempered by the need to keep players injury free and available for selection. Once the interaction between risk factors and injury is understood, risk mitigation programmes can be introduced.

5.4.1 Effect of training volume on injury incidence and severity

The hypothesis that higher training volumes will lead to a higher incidence of injuries was not wholly supported by the results of this study. Overall, it was shown that an increase in training volume lead to a reduction in overall injury incidence ($-0.38, \pm 0.19$, *very likely beneficial, most unlikely harmful*, $p = 0.001$). This is explained by the fact that rugby union training has much lower injury incidence than match-play (Williams *et al.*, 2013), so increasing the volume of training in a week decreases the relative contribution of time spent in match play to the total exposure time. There was no relationship between overall, contact and non-contact injury incidence for either matches or practice in this study.

Following the example of Brooks *et al.* (2008a) training weeks were divided into volume quintiles to better understand the relationship between match injury incidence and training volume. This analysis produced a V-shaped distribution with the highest injury incidence occurring in the weeks with the highest (>10 h) and lowest (<6.3 h) training volumes. The lowest injury incidence occurred in the middle quintile (8.3-9.0 h). Previous research in amateur rugby union players has shown an increase in injury incidence with increased training duration (Lee, Garraway & Arneil, 2001; Quarrie *et al.*, 2001). In professional players, Brooks *et al.* (2008a) found no difference in injury incidence between training volume

quintiles, but did show an increase in injury severity in the largest training volume quintile. Injury severity was not affected by training volume in this study. The discrepancy in the results between this study and the study of Brooks *et al.* (2008a) may be accounted for by the fact the Brooks studied 502 players from 11 different teams, while the present study focused only on a single team. The particular competition, training and recovery practices of the team may have produced this unique result.

The increased injury incidence in the shortest training weeks may be explained by insufficient recovery between matches. The training weeks with the lowest volume occurred in the context of short turnaround times between matches (typically playing on a Saturday and then on the following Friday). It is possible that the team did not alter their regular programme sufficiently to adjust to the six-day turnaround and players began the subsequent match in a fatigued state. This view is supported by the fact that training intensity was inversely proportional to training volume ($-0.59, \pm 0.28$, *very likely negative*, $p = 0.003$), and increased training intensity was correlated with increased non-contact injury incidence ($r = 0.43, \pm 0.34$, *likely harmful, most unlikely beneficial*, $p = 0.038$). The finding that the weeks with the largest training volume had a high injury incidence fits the model of increased training volume leading to increased training risk.

Analysis of training injury incidence showed that contact injury incidence was lowest in the shortest training weeks, and consistent through all other quintiles. Non-contact training injury incidence was highest in quintile 4 (9-10h). Brooks *et al.* (2008a) showed no difference in training injury incidence or severity with higher training volumes.

The results presented here suggest that low and high training volumes and high training intensity are risk factors for injury in professional rugby union players.

This is the first study to demonstrate an association between low training volumes and injury incidence. Previous studies have shown a linear relationship between training volume and injury (Lee *et al.*, 2001)(Quarrie *et al.*, 2001), but these were in non-professional players with relatively low training volumes compared to this study. The optimal training volume per week for rugby union players in this study is 8.3-9.0 h per week. In this training volume range, match injury incidence is minimized. There is a small increase in non-contact training injury incidence at this training volume, but this is far smaller than the reduction in match injury incidence.

5.4.2 Effect of training intensity and load on injury incidence and severity

The reporting method used for the collection of session intensity (RPE) data in this study was largely inadequate. Players were requested to write their session RPE on a perceptual fatigue report form and hand in daily following training. This system was implemented as the most pragmatic available, because the coaching and medical staff felt that they could not afford to allocate a staff member to collect these data for an hour each day. Player compliance to this process was poor and intensity for a large number of training sessions was unreported. Possible reasons for the poor player compliance to this measure were that (Bilsborough, 2015) –

- Player feedback was often not provided timeously.
- The RPE scale to be consulted was placed on the walls in the team room, but players were unsupervised and may not have consulted these when providing their scores.
- Players were not well informed about why the data were being collected and the possible benefits for them.
- Coaches did not fully support the system, they were willing to “see if it works”, but did not throw their weight behind the data collection.

Ultimately, the system was not well implemented and did not receive a great deal of support from the coaching staff.

Using the data available, a global team training intensity score was obtained for 24, non-consecutive weeks by determining the average of reported training intensities for each week. Training intensity was significantly associated with non-contact injury incidence ($r = 0.43$, ± 0.34 , *likely harmful, most unlikely beneficial*, $p = 0.038$), and with overall (0.47 , ± 0.33 , *likely harmful, most unlikely beneficial*, $p = 0.019$) and non-contact injury severity (0.55 , ± 0.3 , *very likely harmful, most unlikely beneficial*, $p = 0.005$). Previous research has also shown increases in training intensity are associated with increased injury incidence (Gabbett, 2004a). Non-contact injuries are thought to be linked to large training loads and insufficient recovery (Gabbett, 2010b). The association of both non-contact injury incidence and severity with training intensity suggests that even as a rough measure training intensity has a meaningful effect on injury risk, and should be monitored carefully.

Training load is a construct that considers both the volume and intensity of training to estimate the total load which a player experiences. Training load has previously been associated with injury risk in both semi-professional (Gabbett & Domrow, 2007; Gabbett, 2004a; Gabbett, 2004b) and professional (Gabbett *et al.*, 2011c; Gabbett, 2010b) rugby league players, and in Australian Rules football (Rogalski *et al.*, 2013). Ideally, training loads would be calculated daily for each individual player, and the team training load would be determined from the mean of these values (Gabbett *et al.*, 2011c; Gabbett, 2010b). Due to the numerous missed data reports in this study, it was not possible to calculate individual training loads consistently. A global training load was calculated by multiplying the global weekly training intensity score with the training duration for a given week. A non-significant correlation between this global training load score and non-contact injury incidence (0.34 , ± 0.36 , *likely beneficial, very unlikely harmful*, $p = 0.105$) was present, indicating that increased training load had a *likely beneficial* effect.

This result is inconsistent with the wealth of evidence showing that injury incidence increases with training load (Gabbett *et al.*, 2007; Gabbett *et al.*, 2011c; Gabbett, 2004a; Gabbett, 2004b; Gabbett, 2010b). It is likely that the method of calculating a “global” training load score, rather than mean of the teams individually calculated weekly training loads, does not account for the daily individual variation in response to training. Due to the session intensity scores being averaged over the week, the effect of single sessions that individuals found very difficult is likely lost. A second factor affecting this analysis is the small number of data points available (24). For this type of correlational analysis, the presence of a relationship will depend on the range of the training volumes – the greater the range and more heterogeneous the sample, the better chance there is to show a relationship. The small sample size and relatively small amount of variation in training load (range 1746 to 3699 RPE.min) may account for why it was not possible to reproduce the results of previous studies.

5.4.3 Perceptual fatigue questions for monitoring fatigue

The results of this study suggest that the perceptual fatigue response form designed by the rugby team medical staff was not effective as a measure of fatigue or response to training. Mean weekly wellness scores were not associated with training volume, intensity or load. It is possible that the players did not ever become sufficiently fatigued to elicit a perceptual fatigue response, but in light of the high injury burden present in the team, the researcher felt this was unlikely. Previous research has shown that wellness questionnaires are sensitive to changes in training load in a team sport environment (Gastin *et al.*, 2013). These results were achieved with an interactive computer reporting system, and with a player compliance of 70%, indicating that the quality of data collection in this sample may have been an issue.

Mean weekly sleep scores worsened with increased training volume (0.32, ± 0.32 , *likely harmful, most unlikely beneficial*, $p = 0.08$). This response could be the result of earlier start times during high volume weeks requiring players to get up earlier (Sargent *et al.*, 2014). A non-significant relationship between sleep and training intensity could indicate that high training intensity has a possibly beneficial effect on sleep quality (-0.27, ± 0.33 , *possibly beneficial, very unlikely harmful*, $p = 0.21$), but could also be the result of lower training volumes in the weeks with the highest training intensity. Overall, there was no evidence of a dose-response relationship with training load for either sleep or wellness scores, indicating that in the current format this tool cannot be used with confidence to monitor training response.

Possible reasons for the perceptual fatigue report form being ineffective could be that shorter and simpler questionnaires have reduced sensitivity (Robson-Ansley, Gleeson & Ansley, 2009), that players could be attempting to manipulate the outcome of the tests (Nédélec *et al.*, 2012), or that the data collection procedure simply was not effective. While modified self-report forms of this nature are commonplace in professional sport, very few have been subjected to rigorous testing to determine effectiveness of implementation, analysis and interpretation (Gastin *et al.*, 2013). The use of any perceptual fatigue questionnaire in a team sport environment needs to be rigorously assessed to ensure that the information provided is accurate and applicable to its intended purpose.

5.4.4 Perceptual fatigue questions and injury

Sleep duration has previously been associated with injury in adolescent athletes (Milewski *et al.*, 2014), but not in adult, team sport athletes (Dennis *et al.*, 2015). Perceptual measures of fatigue have been associated with increased injury incidence in sporting populations (Lavallée & Flint, 1996; Shrier & Hallé, 2011). The results of this study showed no association between sleep, wellness or any

measure of injury incidence, again illustrating the poor relationship between these measures and training status.

There were significant correlations between wellness and all measures of injury severity (table 5.3), indicating that as wellness worsened, the injury severity increased. A likely harmful relationship between sleep and contact injury severity ($r = 0.32$, ± 0.32 , *likely harmful, most unlikely beneficial*, $p = 0.054$) was present. Research has shown that the duration of recovery from injury can be negatively affected by negative mood state and stress (Covassin *et al.*, 2015). The wellness measure may be a reflection of the psychosocial stress that a player is experiencing. While this stress may not affect the occurrence of injury, it may negatively affect the recovery process resulting in an increase in injury severity.

Recovery actions were *very likely harmful* to non-contact injury incidence (0.61 , ± 0.33 , *very likely harmful, most unlikely beneficial*, $p = 0.012$), indicating that players were injured more frequently in weeks where they performed more recovery actions. This is counter-intuitive, as it would be expected that recovery actions have a positive effect on non-contact injury incidence. A confounding factor in this relationship may be the training load experienced during these weeks. Players experiencing a high amount of training stress may participate in more recovery actions in an attempt to prevent injury, but despite their good intentions the heavy training load could still result in injury. The recovery actions detailed in the questionnaire may not be as effective as expected in protecting against non-contact injury in the presence of very high training volumes.

5.4.5 Readiness to train measures

Counter movement jump test

Player response to CMJ testing following match participation is well established (Twist *et al.*, 2012; West *et al.*, 2013), with jump ability being reduced for 48 to 60 h. This transient decrease in jump ability establishes the CMJ test as a marker

of short-term, neuromuscular fatigue. In the present study, CMJ testing took place on a Monday morning following the weekends match participation. Matches typically took place on either a Friday or Saturday, meaning that the duration of recovery time to the Monday morning test was approximately 60 (Friday game) or 36 (Saturday game) hours. The aim of the readiness to train protocol was not to determine the magnitude or duration of the time-course of recovery, which has been previously established (Twist *et al.*, 2012; West *et al.*, 2013). The aim was to identify which players had not yet achieved full recovery from their match involvement, and inform the coaches so that training could be tapered accordingly.

Mean flight time was not significantly different between match participants and non-participants (participants estimated effect = -0.01 (-0.01 to 0.0) s, $p = 0.067$). This non-significant difference could be expected as jump ability returns to baseline levels between 36 and 60 hours following match participation (Twist *et al.*, 2012; West *et al.*, 2013). Despite this, 36% of players could not achieve baseline jump test scores on Monday morning following match participation. This indicates that roughly one third of players are not fully recovered at the start of a training week and that monitoring to establish readiness to train status is highly warranted. There was no difference in injury rate of players with Δ large from baseline CMJ (Δ large estimated effect = -5.3 (-18.5 to 7.8) % injured, $p = 0.424$). This result may indicate that a short-term reduction in CMJ ability is not a risk factor for injury, or that the reporting system and management of these players was effective in minimizing related injury risk.

Range of motion tests

There was no difference in the ankle dorsiflexion or sit-and-reach tests between match participants and non-participants, nor was there a significantly different percentage of participants who displayed ROM “red flags”. These findings indicate that ROM tests are not sensitive to short term fatigue following match

play, and therefore, should not be used as a readiness to train measure. However, a sit and reach distance <15 cm was significantly associated with injury rate (estimated effect = +8.8 (0.4 to 17.3) % injured, $p = 0.0041$). This is in agreement with previous research that has shown that players with poor ROM have a higher risk of muscle strain type injury (Bradley *et al.*, 2007). Based on this, regular ROM testing is warranted in a team sport environment, particularly following lengthy periods of travel.

5.5 Conclusion

The results presented in this study demonstrate that training volume and intensity are risk factors for injury in professional rugby union players. As such, responsible injury risk management practice dictates that individual responses to training should be closely monitored in an attempt to mitigate the risks associated with training. However, implementing an athlete-monitoring programme in a team sport environment is a challenging task that requires a robust system and a great deal of attention to detail. In its most effective form, a training monitoring system will provide valuable information to coaching staff regarding player response to training and allow for the mitigation of injury risk resulting from player fatigue. Player compliance and the quality of data collected have a large influence on the conclusions that can be drawn from the monitoring programme. An inadequate monitoring system will waste valuable staff time and resources and may lead to incorrect assessment of the efficacy of the training programme and associated training risks. As such, player-monitoring systems should be continually assessed to ensure that they remain sensitive to variation in training and provide an accurate indication of player training responses.

CHAPTER 6 - PHYSICAL DEMANDS OF PROFESSIONAL RUGBY UNION

MATCH PLAY IN SOUTH AFRICA

6.1 Introduction

There is great diversity in the on-field roles and physical attributes of rugby union players (Duthie *et al.*, 2003). Although all players are required to perform core skills such as catching, passing, ball carrying, tackling and rucking during a match, the physical and skill demands of each playing position are different (Duthie *et al.*, 2003). Playing positions are individually named and reflect distinct roles within the game, but are commonly grouped with other positions with similar attributes to create designations such as “forwards “ and “backs”, and “tight-five”, “loose-forwards”, “inside backs” and “outside backs” (Deutsch *et al.*, 2007; Duthie *et al.*, 2003). Forwards are generally involved in actions to contest for and retain possession of the ball, and are generally exposed to high volumes of physical contact as a result (Deutsch *et al.*, 2007; Duthie *et al.*, 2003). Backline players are regularly involved in the execution of tactical movements to gain field position or score, and are able to run more freely with less contact involvements (Deutsch *et al.*, 2007; Duthie *et al.*, 2003). To ensure the conditioning and recovery programmes of the players are appropriate, it is essential to have a good understanding of the physical demands placed on players in these different positions (Cunniffe *et al.*, 2009).

Video time motion analyses (TMA) suggest that the majority of time in rugby union is spent engaged in low intensity activities for all positions, but that the nature of physical exertions differs across position groups (Austin *et al.*, 2011a; Deutsch *et al.*, 2007; Duthie *et al.*, 2005; Quarrie *et al.*, 2012; Roberts *et al.*, 2008). Backs spend more time in low intensity activity than forwards (Roberts *et al.*, 2008), but also spend more time sprinting than forwards (Duthie *et al.*, 2005). When divided into four positional groups (front row forwards, back row forwards, inside backs and outside backs), back row forwards were shown to

spend the greatest amount of time engaged in high-intensity activity, while inside backs covered the most total distance (Roberts *et al.*, 2008).

Despite the valuable information provided by video TMA, its practical application is limited by the time required for coding movement events and subjectivity in the categorization of locomotive events (Coutts *et al.*, 2010). Global Positioning Systems (GPS) provide accurate, non-invasive movement analysis for team sports that has greatly reduced the time required for video TMA (Coutts *et al.*, 2010).

To the researcher's knowledge, five studies have described the movement characteristics of professional rugby union players using GPS (Cahill *et al.*, 2013; Coughlan *et al.*, 2011; Cunniffe *et al.*, 2009; Jones *et al.*, 2015; Reid *et al.*, 2013) . The first two of these studies, Cunniffe *et al.* (2009) and Coughlan *et al.* (2011), used similar methodology; tracking a single forward and a single back during an international rugby union match. The results were similar; players covered >6500 m in both studies and the backs performed a greater number of high-intensity runs and reached greater maximal speeds than the forwards. A major limitation of both of these preliminary studies is that they observed only two players on single occasions, and as such it is difficult to generalize this information. Reid *et al.* (2013) examined 8 players from different positions in a single match, and reported a range of relative running distances of 67.0 to 78.2 m.min⁻¹. Furthermore, they reported that backs covered the most distance walking, while forwards covered the most distance jogging (Reid *et al.*, 2013). Cahill *et al.* (2013) provided a comprehensive study observing players from English Premiership clubs. This study derived subject specific speed zones based on each players maximum observed velocity. Although all players covered relatively small distances while sprinting, the loose forwards sprinted the most. Backs covered more relative distance than forwards. Scrumhalves covered the most total distance and tight forwards the least (Cahill *et al.*, 2013). In a similar study, but based on absolute speed zones, Jones *et al.* (2015) showed the inside and

outside backs have the greatest high speed running demands, while loose forwards have the greatest contact demands and perform the most repeated high-intensity exertions (Jones *et al.*, 2015).

The presence of physical contact contributes significantly to the physical exertions experienced by rugby union players (Johnston *et al.*, 2014e), but is not directly assessed by GPS measurements of distance and speed. Deutsch *et al.* (2007) reported that forwards spend approximately 10 minutes per match engaged in high contact activities like tackling, scrumming, rucking and mauling. In an attempt to quantify these additional loads, manufacturers of GPS devices have included a tri-axial accelerometer to measure impact forces. Accelerometer data has not previously been reported in elite rugby union competition, and may be of some value in terms of quantifying physical impacts sustained and planning recovery strategies.

None of the TMA studies describing the movement characteristics of rugby union players examined elite level players in South Africa. There may be differences in the demands and pace of rugby union play in different geographical regions. For example, analysis indicates that ball in play time is greater for northern hemisphere than for southern hemisphere test matches (46 vs. 42%) (WorldRugby.org, 2015b). In addition, rugby union evolves rapidly due to intermittent law changes so it is important to continually re-evaluate game demands (Quarrie & Hopkins, 2007). Therefore, there is a need to determine the particular movement patterns in South African top-level competition. Accurate determination of game demands will allow for the preparation of strength and conditioning programmes that prepare players to cope with the specific demands of their position.

Following the injury risk evaluation process (Chapter 3), the team's strength and conditioning and medical staff were concerned that perhaps the training loads of

the team were inappropriate. Consistently high training loads would lead to residual fatigue, increasing injury risk, while low training loads would leave players inadequately prepared for competition. This investigation to match demands was therefore initiated to allow for improved training prescription, as part of the injury risk mitigation process.

6.2 Methods

6.2.1 Experimental approach to the problem

A prospective observational study making use of portable GPS devices worn by players during match play described the mean match play requirements of players from different position groups.

6.2.2 Participants

Players from the same South African professional rugby union team studied throughout this thesis were invited to participate in the study for the duration of the 2013 rugby season. Participation was voluntary but endorsed by the management and medical staff of the team. In total 19 players (age 26 ± 2 years; body mass 101.5 ± 12.2 kg, stature 1.86 ± 0.07 m) volunteered. Players who volunteered to participate in the study signed informed consent. All research methods conformed to the directive of the declaration of Helsinki (World Medical Association, 2013), and were approved by the University of Johannesburg ethical review board.

6.2.3 Player grouping

Players were grouped according to 2 different classification systems, neither of which is mutually exclusive, to allow for analysis of different positional attributes. Firstly, players were grouped as either forwards (props, locks, hooker, flanks and eighth man) or backs (scrumhalf, fly half, centres, wings and fullback), and secondly were assigned to one of five positional groups: tight forwards (props and locks), loose forwards (hooker, flanks and eighth man), scrumhalf,

inside backs (fly half and centres) and outside backs (wings and fullback), as previously described (Duthie *et al.*, 2005; Roberts *et al.*, 2008). Data were examined to check the validity of these groupings, and sufficient similarities were found in the movement patterns (distance covered in various speed zones) of players within each group to suggest that these groupings remain valid in this player population.

6.2.4 GPS procedures

All matches took place between March and October 2013 during the local rugby season and were part of senior professional domestic competitions. Players wore individual GPS units (SPI Pro, GPSports, Canberra, Australia) (mass = 76 g; size = 87 x 48 x 20 mm), positioned between the shoulder blades, and supported by an elasticized harness worn underneath the playing jersey. The GPS unit samples positioning data at a frequency of 5 Hz and contained a tri-axial accelerometer that samples at 100 Hz.

The validity and reliability of the SPI-Pro GPS unit (GPSports, Canberra) has been previously established (Coutts *et al.*, 2010; Petersen *et al.*, 2009). In particular, the validity for speed zones walking (SEE $1.0 \pm 0.4\%$), jogging (SEE $3.7 \pm 1.4\%$) and striding (SEE $3.0 \pm 1.1\%$) is strong (Petersen *et al.*, 2009). The validity of distance measures in sprint zones ($>5 \text{ m}\cdot\text{s}^{-1}$) is less accurate (SEE $10.5 \pm 3.9\%$), and typically underestimates sprint distance and should be interpreted carefully (Petersen *et al.*, 2009). These GPS units have been shown to reliably measure peak velocity (CV 2.3 90%CI 2.1-6.6) (Coutts *et al.*, 2010). Despite concerns over the validity of distance measures in sprint zones, these units have previously been used in other rugby related research studies (Cahill *et al.*, 2013; Granatelli *et al.*, 2013; Kempton, Sirotic & Coutts, 2013; McLellan *et al.*, 2012; Wisbey *et al.* 2010).

The validity of measures from the accelerometer in the SPI-Pro unit has not been established. Waldron *et al.* (2011) showed the reliability of accelerometer measures to be disappointing (CV=4.7-5.2%). Interpretation of accelerometer data is complicated because acceleration peaks result from a variety of actions including; foot strikes, running, jumping, falling, tackling and rucking. Researchers have not shown any correlation between high-intensity impacts and collision events like tackles during rugby league matches (McLellan *et al.*, 2012). Despite this, research has shown correlations between high-intensity impacts (>8G) and markers of muscle damage (McLellan, Lovell & Gass, 2011c), as well as neuromuscular markers of post-match fatigue (McLellan *et al.*, 2012) in rugby league. These results indicate that while not directly related to contact events, accelerometer data may give an impression of the overall mechanical load that players are exposed to. Accelerometer data have not previously been reported in elite rugby union competition, and may be of some value in terms of quantifying the degree of physical contact players sustain and planning recovery strategies accordingly.

Players were familiarised with the use of the GPS units at practice sessions before using them in matches. The strength and conditioning coach of the team assigned and fitted the GPS units on match days. There were insufficient units and harnesses for all players to wear at once, so units were rotated among players in each of the five position groups, and according to the monitoring needs of the coaching staff. Units were switched on before the warm up, which started approximately 45 minutes before kick off, to ensure that the satellite signal was received.

After each match, the GPS data files were downloaded to a personal computer and the data analysed using Team AMS software (Version 10, GPSports, Canberra, Australia). The raw data files were segmented into 1st and 2nd halves, to exclude the time recorded during half time, and then exported to Microsoft

Excel (Microsoft Corp, USA). First and second half data were then combined to determine whole game exertions. Three files were excluded because players had not spent sufficient time on the field (<30 minutes, which was outside 2 standard deviations from the mean). 102 Match participation files from 24 separate matches were analysed according to the positional distribution presented in table 6.1.

6.2.5 Movement and Impact Analysis

The dependent variables for this study were total distance (m) covered, maximum speed (m.s^{-1}) attained, the distance covered in differentiated speed zones (walking – $0\text{--}2 \text{ m.s}^{-1}$, jogging – $2\text{--}4 \text{ m.s}^{-1}$, striding – $4\text{--}6 \text{ m.s}^{-1}$, and sprinting – $>6 \text{ m.s}^{-1}$). These speed zones were chosen because they are typical of the locomotive activity profiles of intermittent team sport athletes (Dwyer & Gabbett, 2012) and were previously utilized by Quarrie *et al* (2012). Data were normalized to the amount of time spent on the field to account for different playing times as a result of player substitutions. In addition, two broader speed zones (low intensity running – $0\text{--}4 \text{ m.s}^{-1}$ and high-intensity running - $>4 \text{ m.s}^{-1}$) were calculated to allow for the calculation of a high: low intensity running ratio. Percentage time spent in each speed zone was calculated. Sprint and maximal acceleration counts were included to support analysis of high speed running distance, these are reported as frequencies (1 every n minutes). A sprint was defined as each time a player reached a speed $>6 \text{ m.s}^{-1}$, and a maximal acceleration was defined as any acceleration $>2.75 \text{ m.s}^{-2}$. This acceleration corresponds to a change in speed of 10 km.h^{-1} in a 1 second interval. Accelerometer data were recorded as the total number of impacts $>5 \text{ G}$ and total high-intensity impacts $>8 \text{ G}$, and normalized to playing time. Time on field statistics are reported to allow for calculation of total work volumes. As reports of the mean physical demands of match play are likely to underestimate the most intense matches or periods of competition (Gabbett *et al.*, 2012b), the maximum values for all variables are reported.

6.2.6 Statistical Analysis

Data were analysed using SPSS (IBM.com, version 21) analysis software. Shapiro-Wilk tests were performed on all dependent variables to test the assumption of normality; the majority of variables (60%) did not satisfy this assumption. Data were visually assessed using Normal Q-Q plots and were found to be similarly, and only moderately skewed. A decision was taken to proceed with parametric tests due to the robustness of the particular tests used in dealing with deviations from normality, particularly in the presence of large sample sizes (>50) and similar sized sample groups. Forwards and backs were compared using an independent samples t-test. A Levene's test was applied to the 5 positional groups to assess homogeneity of variance. The majority of variables were normally distributed and in these cases were assessed by one-way ANOVA and *Tukey's post hoc* test. In cases where data was not normally distributed, a Welch robust test for equality of means and Games-Howell *post hoc* test were applied to discern differences between groups. Descriptive statistics (mean $\pm$ SD) were calculated for all variables, and the level of significance was set at $p < 0.05$ for all tests. In addition, due to the practical nature of this study, Cohen's effect size statistic was calculated to determine the practical significance of observed differences. Effect sizes of 0.2, 0.5, 0.8 and 1.2 were considered *small*, *medium*, *large* and *very large* respectively (Hopkins *et al.*, 2009).

6.3 Results

6.3.1 Player characteristics and observations

Table 6.1 provides the physical characteristics of players within each positional group and the number of match and training observations recorded.

Table 6.1 – Descriptive characteristics of the 5 positional groups of professional rugby union players

	N	Age (years)	Stature (m)	Body mass (kg)	Observations (N)	
					Training	Match
Tight forwards	15	25 ± 4	1.91 ± 0.07	114.6 ± 7.5	157	23
Loose forwards	16	24 ± 3	1.86 ± 0.05	101.4 ± 6.4	200	30
Scrumhalves	5	23 ± 2	1.77 ± 0.01	84.9 ± 1.3	53	8
Inside backs	11	23 ± 3	1.83 ± 0.05	93.4 ± 6.2	106	12
Outside backs	11	24 ± 4	1.84 ± 0.05	91.7 ± 4.6	114	29

6.3.2 Movement Analysis

Analysis of basic movement parameters for forwards and backs, and for the five positional groups is presented in Table 6.2. There was no significant difference in the relative distance covered during competitive match play between forwards and backs (Forwards 69 ± 8 vs. Backs 69 ± 9 m.min⁻¹, ES = *trivial*). Positional group analysis revealed that scrumhalves cover a significantly greater distance during match play than all other positional groups (81 ± 12 m.min⁻¹, ES = *medium* to *very large*). Backs had greater maximum speed compared to forwards (Backs 8.8 ± 1.1 vs. Forwards 7.6 ± 1.3 m.s⁻¹, ES = *large*). This can be accounted for by the presence of outside backs in this group who were significantly faster (9.4 ± 0.9 m.s⁻¹, ES = *small* to *very large*) than all other positional groups. The relative distances covered by backs and forwards in each of the four speed zones are presented in figure 6.1, and a similar analysis by positional group is presented in figure 6.2.

The forwards distinguished themselves by covering significantly more distance while jogging than backline players (forwards 36 ± 3 vs. backs 32 ± 5 m.min⁻¹, ES = *large*). Backs however, covered twice as much distance sprinting compared to forwards (backs 3.4 ± 2.0 vs. forwards 1.4 ± 1.3 m.min⁻¹, ES = *very large*). Tight forwards jogged the most distance (29 ± 5 m.min⁻¹, ES = *medium* to *very large*), significantly more than loose forwards, inside and outside backs. Outside backs

jogged the least distance ($18 \pm 4 \text{ m}\cdot\text{min}^{-1}$, ES = *large* to *very large*). There was no difference in distance covered striding between forwards and backs.

Scrumhalves covered the most distance ($16 \pm 5 \text{ m}\cdot\text{min}^{-1}$, ES = *very large*) striding, significantly more than every other group. The loose forwards out performed the tight forwards and outside backs in this speed zone ($11 \pm 4 \text{ m}\cdot\text{min}^{-1}$, ES = *medium* to *very large*). Outside backs performed the most sprinting ($4 \pm 2 \text{ m}\cdot\text{min}^{-1}$, ES = *medium* to *very large*), covering significantly more distance than tight forwards, loose forwards and inside backs in this category. Tight forwards performed the least sprinting, covering just $1 \pm 1 \text{ m}\cdot\text{min}^{-1}$ (ES = *very large*).

Table 6.2 - Comparison of basic movement variables for forwards and backs, and for five positional groups, during professional rugby union match play.

	Forwards			Backs		
	Total	Tight Forward	Loose Forward	Total	Scrumhalf	Inside Back Outside Back
<i>Movement Variables</i>						
Time on Field (min)	69 ± 24	72 ± 24	67 ± 25	78 ± 22	58 ± 16	82 ± 22 82 ± 22 ^c
Distance (m.min⁻¹)	69 ± 8	70 ± 7	68 ± 8	69 ± 9	81 ± 12 ^{a,b,d,e}	67 ± 9 67 ± 5
Maximum Speed (m.s⁻¹)	7.6 ± 1.3*	7.1 ± 1.2	8.0 ± 1.2 ^a	8.8 ± 1.1	8.0 ± 0.7	8.0 ± 0.9 9.4 ± 0.9 ^{a,b,c,d}

*Indicates forwards significantly different ($p < 0.05$) from backs. ^{a,b,c,d,e} indicates significantly different from tight forwards, loose forwards, scrumhalf, inside backs and outside backs respectively.

Table 6.3 - Comparison of low and high-intensity running distances for forwards and backs, and for five positional groups, during professional rugby union match play.

	Forwards			Backs		
	Total	Tight Forward	Loose Forward	Total	Scrumhalf	Inside Back Outside Back
<i>Movement Variables</i>						
Low intensity dist. (m.min⁻¹)	58 ± 7*	63 ± 6	55 ± 6 ^a	56 ± 6	61 ± 8	57 ± 6 53 ± 5 ^a
High-intensity dist. (m.min⁻¹)	11 ± 5*	7 ± 3	13 ± 4 ^{a,c}	14 ± 4	20 ± 5 ^a	12 ± 4 ^{a,c} 13 ± 3 ^{a,c}
High-intensity: Low Intensity Running Ratio	1:8*	1:13	1:5	1:4	1:3 ^{a,b,d,e}	1:5 1:4

Low intensity running is $< 4 \text{ m.s}^{-1}$ and high-intensity running is $> 4 \text{ m.s}^{-1}$. *Indicates forwards significantly different ($p < 0.05$) from backs. ^{a,b,c,d,e} indicates significantly different from tight forwards, loose forwards, scrumhalf, inside backs and outside backs respectively.

Figure 6.1 - Relative distances covered in 4 speed zones by forwards and backs. * indicates a significant difference ($p<0.05$)

Figure 6.2 - Relative distances covered in 4 speed zones by tight forwards, loose forwards, scrumhalves, inside backs and outside backs. #, § and θ indicate a significant difference from tight forwards, loose forward and scrumhalf respectively. ($p<0.05$)

6.3.3 High and low intensity running

The time spent in low and high-intensity running zones for backs and forwards, and for positional groups is shown in table 6.3. These results were used to calculate average high-intensity: low intensity running ratios (table 6.3). Analysis revealed that forwards cover more distance than backs in low intensity ranges (forwards 58 ± 7 vs. backs 56 ± 6 m.min⁻¹, ES = *small*), while backs cover more distance in high-intensity ranges (forwards 11 ± 5 vs. backs 14 ± 4 m.min⁻¹, ES = *medium*). Accordingly, the high-intensity: low intensity running ratio was approximately 1:8 for forwards and 1:4 for backs. This indicates that forwards cover double the low intensity distance for each high-intensity run than backs do.

Tight forwards perform the greatest amount of low intensity running (63 ± 6 m.min⁻¹, ES = *small* to *very large*), significantly more than loose forwards and outside backs. They also perform the least high-intensity running (7 ± 3 m.min⁻¹, ES = *large* to *very large*), significantly less than all other position groups. Tight forwards thus have the greatest high-intensity: low intensity running ratio (1:13). Scrumhalves perform the most high-intensity running (20 ± 5 m.min⁻¹, ES = *very large*), and the second lowest intensity running (61 ± 8 m.min⁻¹, ES = *small* to *large*). Scrumhalves have the smallest high-intensity: low intensity running ratio (1:3).

Table 6.4 - Comparison of proportion time spent in four speed zones for forwards and backs, and for five positional groups, during professional rugby union match play.

<i>Proportion time in movement zones</i>	Forwards			Backs			
	Total	Tight Forward	Loose Forward	Total	Scrumhalf	Inside Back	Outside Back
% time walking	80 ± 7*	79 ± 7 ^e	80 ± 6	83 ± 5	80 ± 5	83 ± 4	84 ± 5
% time jogging	17 ± 6*	18 ± 6 ^{d,e}	15 ± 5	13 ± 5	14 ± 5	12 ± 4	13 ± 5
% time striding	3 ± 3	3 ± 4	4 ± 1	4 ± 2	5 ± 1	4 ± 3	3 ± 1
% time sprinting	0.3 ± 0.3*	0.1 ± 0.1 ^{b,c,e}	0.5 ± 0.3 ^e	0.7 ± 0.4	0.7 ± 0.3	0.5 ± 0.5	0.8 ± 0.4

*Indicates forwards significantly different ($p < 0.05$) from backs. ^{a,b,c,d,e} indicates significantly different from tight forwards, loose forwards, scrumhalf, inside backs and outside backs respectively. The total proportion time for each position group is 100%, discrepancies are due to rounding where it was felt that percentage fractions were only relevant in the % time sprinting zone.

Table 6.5 - Comparison of sprint and maximal acceleration frequency for forwards and backs, and for five positional groups.

<i>Sprint Variables</i>	Forwards			Backs			
	Total	Tight Forward	Loose Forward	Total	Scrumhalf	Inside Back	Outside Back
Sprint/min (>6 m.s⁻¹)	1 every 14 ± 17 min*	1 every 33 ± 33 min ^{b,c,e}	1 every 10 ± 17 min ^e	1 every 7 ± 14 min	1 every 9 ± 11 min	1 every 6 ± 6 min	1 every 6 ± 14 min
Accelerations/min (>2.75 m.s⁻²)	1 every 7 ± 8 min*	1 every 14 ± 25 min ^{b,c,e}	1 every 9 ± 13 min ^{c,e}	1 every 5 ± 10 min	1 every 4 ± 14 min	1 every 7 ± 8 min	1 every 5 ± 11 min

*Indicates forwards significantly different ($p < 0.05$) from backs. ^{a,b,c,d,e} indicates significantly different from tight forwards, loose forwards, scrumhalf, inside backs and outside backs respectively.

6.3.4 Proportion time spent in speed zones

The majority of playing time (79 – 84%) was spent walking for all positions. Backs spent a significantly greater portion of time walking (Forwards 80 ± 7 vs. $83 \pm 5\%$, ES = *medium*) and sprinting (forwards 0.3 ± 0.3 vs. backs $0.7 \pm 0.4\%$, ES = *large*) than forwards did (table 6.4). Forwards spent more time jogging than backs (forwards 17 ± 6 vs. backs $13 \pm 5\%$, ES = *medium*). Tight forwards were the most unique positional group, spending the most time jogging ($18 \pm 6\%$, ES = *medium to large*), and the least time walking ($79 \pm 7\%$, ES = *small to medium*) and sprinting ($0.1 \pm 0.1\%$, ES = *large to very large*). There was no significant difference between any position groups for time spent striding, but scrumhalves spent the most time in this speed zone ($5 \pm 1\%$, ES = *medium to very large*). Outside backs spend significantly more time sprinting ($0.8 \pm 0.4\%$, ES = *small to very large*) than tight and loose forwards.

6.3.5 Sprint and acceleration characteristics

Analysis of sprint and acceleration frequency is shown in table 6.5. Backs reached sprint velocity twice as often as forwards (backs 1 every 7 ± 14 min. vs. forwards 1 every 14 ± 17 min., ES = *large*). Backs also performed maximal accelerations 1.5 times more often than forwards did (backs 1 every 5 ± 10 min. vs. forwards 1 every 9 ± 13 min., ES = *large*). Notably, all positions were involved in acceleration actions 30-40% more often than they were involved in sprint actions. Inside and outside backs were the positions most frequently involved in both sprint and acceleration actions. Tight forwards participated the least frequently in sprint and acceleration actions.

Table 6.6 - Comparison of total impact and high-intensity impact frequency for forwards and backs, and for five positional groups.

<i>Impact Variables</i>	Forwards			Backs			
	Total	Tight Forward	Loose Forward	Total	Scrumhalf	Inside Back	Outside Back
Impacts (>5 G.min⁻¹)	10.0 ± 3.0	9.6 ± 3.4	10.6 ± 2.3	9.5 ± 3.2	9.4 ± 3.2	6.5 ± 1.2 ^{a,b,e}	10.9 ± 2.9
High-intensity impacts (>8 G.min⁻¹)	0.9 ± 0.5	0.8 ± 0.3	1.2 ± 0.7	0.9 ± 0.4	0.8 ± 0.3	0.7 ± 0.2	1.1 ± 0.4 ^{a,d}

*Indicates forwards significantly different ($p < 0.05$) from backs. ^{a,b,c,d,e} indicates significantly different from tight forwards, loose forwards, scrumhalf, inside backs and outside backs respectively.

Table 6.7 – Maximum observed values for movement variables during match play and percentage difference from average match play values for five positional groups.

	Tight Forwards	Loose Forwards	Scrumhalves	Inside Backs	Outside Backs
Relative distance (m.min⁻¹)	81 (15%)	86 (25%)	99 (23%)	86 (26%)	78 (17%)
Maximum speed (m.s⁻¹)	9.9 (36%)	10.8 (35%)	9.2 (15%)	9.4 (18%)	11.3 (20%)
Walking distance (m.min⁻¹)	45 (33%)	45 (47%)	41 (15%)	43 (17%)	41 (16%)
Jogging distance (m.min⁻¹)	39 (35%)	33 (37%)	33 (31%)	28 (36%)	25 (41%)
Striding distance (m.min⁻¹)	11 (59%)	20 (75%)	25 (53%)	14 (56%)	15 (71%)
Sprinting distance (m.min⁻¹)	1.5 (198%)	4.8 (128%)	5.8 (85%)	9.1 (276%)	7.3 (87%)
Sprint frequency	1 every 10 minutes (246%)	1 every 4 minutes (175%)	1 every 4 minutes (69%)	1 every 3 minutes (213%)	1 every 4 minutes (73%)
Acceleration frequency	1 every 7 minutes (86%)	1 every 3 minutes (159%)	1 every 3 minutes (41%)	1 every 2 minutes (185%)	1 every 3 minutes (63%)
Impacts (>5 G.min⁻¹)	16 (66%)	16 (55%)	13 (41%)	9 (35%)	17 (58%)
High-intensity impacts (>8 G.min⁻¹)	1.6 (76%)	2.9 (117%)	1.3 (36%)	1.1 (47%)	1.9 (54%)

Relative (m.min⁻¹) rather than absolute distances are reported due to differences in duration of playing exposures. Values are reported as max. (% diff.) The maximum value overall is highlighted in bold.

6.3.6 Impact characteristics

There was no difference in the total number of impacts (backs 9.5 ± 3.2 vs. forwards 10.0 ± 3.0 $>5 \text{ G.min}^{-1}$, ES = *small*), or high-intensity impacts (backs 1.1 ± 0.4 vs. forwards 1.1 ± 0.5 $>8 \text{ G.min}^{-1}$, ES = *trivial*) (table 6.6). Inside backs experienced significantly less total impacts (6.5 ± 1.2 $>5 \text{ G.min}^{-1}$, ES = *small* to *very large*) than tight forwards, loose forwards and outside backs. Inside backs also experienced the least high-intensity impacts (0.7 ± 0.2 $>8 \text{ G.min}^{-1}$, ES *small* to *very large*). Though not statistically significant, loose forwards experienced the most total (10.6 ± 2.3 $>5 \text{ G.min}^{-1}$, ES = *medium* to *very large*) and high-intensity impacts (1.3 ± 0.7 $>8 \text{ G.min}^{-1}$, ES = *small* to *large*).

6.3.7 Maximum match values

Table 6.7 presents the maximum observed value for each movement variable, and the percentage difference from average match performance for each position group. These values provide a perspective on what the extreme range of physical load experienced during match play might be. This analysis revealed that while relative total distance, and distance covered walking and jogging may be increased by a third in the most intense matches, high-intensity running distance (striding and sprinting) can be increased up to 75% and 280% respectively. The factor that showed the highest deviation from match averages was sprint and acceleration frequencies. These showed that in the most intense matches sprint and acceleration exposure could be up to 250% greater than the average.

6.4 Discussion

Movement profile of South African professional rugby union players

This GPS analysis of the movement and impact characteristics of professional rugby union players was the first to be performed in South Africa. The first major finding of this research is that there was no significant difference in the relative distances covered between forwards and backs. This result is in contrast with previous research (Cahill *et al.*, 2013; Coughlan *et al.*, 2011; Cunniffe *et al.*, 2009;

Reid *et al.*, 2013), which has reported backs covering a higher amount of relative distance than forwards.

The results of the movement characteristic analysis in this study tend to agree with those that have been previously reported (Cahill *et al.*, 2013; Deutsch *et al.*, 2007; Duthie *et al.*, 2003; Roberts *et al.*, 2008). The game is played mostly at low speed with players spending the majority of their time standing, walking or jogging. Notably, the forwards covered more distance in low intensity movement zones, while backs covered more distance in high-intensity movement zones. This most likely reflects the influence of positional requirements, where forward players typically contest possession of the ball at close quarters, while backs await possession in wider areas giving them more opportunity and space to run in (Deutsch *et al.*, 2007). Positional analysis revealed that scrumhalves covered the most distance overall ($81 \pm 12 \text{ m}\cdot\text{min}^{-1}$, ES = *medium* to *very large*) and the most distance in high-intensity running zones ($20 \pm 5 \text{ m}\cdot\text{min}^{-1}$, ES = *very large*). These results exceed those reported by Jones *et al.* (2015) (overall distance $72 \pm 7 \text{ m}\cdot\text{min}^{-1}$, high-intensity running $14 \pm 2 \text{ m}\cdot\text{min}^{-1}$), but were similar to those of Cahill *et al.* (2013) (overall distance median $79 \text{ m}\cdot\text{min}^{-1}$, interquartile range (IQR) 7). These results reflect the scrumhalf's unique role in the game where they keep pace with play in order to distribute possession, and as a result are in possession of the ball most often (Deutsch *et al.*, 2007).

Outside backs were the most accomplished sprinters, attaining the greatest maximum speed ($9.4 \pm 0.9 \text{ m}\cdot\text{s}^{-1}$, ES = *small* to *very large*), covering the most distance sprinting ($4 \pm 2 \text{ m}\cdot\text{min}^{-1}$, ES = *small* to *very large*) and performing sprints (1 every 6 min) and maximal accelerations (1 every 5 min) more often than other positions. Outside backs also spent more time walking ($84 \pm 5\%$, ES = *trivial* to *medium*) than other position groups. Cahill *et al.* (2013) also reported outside backs attaining the greatest maximum speed (median $8.8 \text{ m}\cdot\text{s}^{-1}$, IQR = 0.9), and that outside backs spent the most time walking (median 51.9%, IQR = 10.3).

Tight forwards spent more time ($18 \pm 6\%$, ES = *medium* to *large*) and covered more distance ($29 \pm 5 \text{ m}\cdot\text{min}^{-1}$, ES = *medium* to *very large*) jogging than any other positional group. Jones *et al.* (2015) also reported that tight forwards cover the most distance jogging. In match play, the primary responsibility of tight forwards is to contest for and retain possession (Deutsch *et al.*, 2007), a role that results in a great deal of physical contact in scrums, rucks and mauls. As such, tight forwards may be placed at a disadvantage when it comes to attaining high speeds, due to the highly fatiguing nature of these involvements. Johnston *et al.* (2014) has shown that physical contact reduces high-intensity running during game play, and conditioning programmes for tight forwards should reflect this.

Despite falling into different positional groups (backs and forwards), analysis revealed the movement characteristics of loose forwards and inside backs to be similar. There were no significant differences in distance covered jogging (loose forward 24 ± 4 vs. inside back $21 \pm 4 \text{ m}\cdot\text{min}^{-1}$, ES = *large*), striding (loose forward 11 ± 4 vs. inside back $9 \pm 3 \text{ m}\cdot\text{min}^{-1}$, ES = *medium*) or sprinting (loose forward 2 ± 1 vs. inside back $2 \pm 2 \text{ m}\cdot\text{min}^{-1}$, ES = *small*) for these 2 groups. Loose forwards did walk significantly less than inside backs (loose forward 31 ± 5 vs. inside back $36 \pm 4 \text{ m}\cdot\text{min}^{-1}$, ES = *very large*). Time spent in various speed zones and overall high-intensity: low intensity running ratio was the same for loose forwards and inside backs. These results indicate that the typical strategy of grouping forwards and backs during training is most likely incorrect. It may be more prudent to group tight forwards; loose forwards and inside backs; scrumhalves; and outside backs for training. Scrumhalves have highly unique positional requirements and should have individualized programmes, which reflect this. This suggestion is based on the results from this study and the trends point to this grouping in training. Larger samples of elite rugby players may prove otherwise.

Accelerometer data analysis

Analysis of accelerometer data revealed that there was no difference in the number of total (backs 9.5 ± 3.2 vs. forwards $10.0 \pm 3.0 >5 \text{ G.min}^{-1}$, ES = *trivial*), or high-intensity impacts (backs 1.1 ± 0.4 vs. forwards $1.1 \pm 0.5 >8 \text{ G.min}^{-1}$, ES = *trivial*) between backs and forwards. It was notable however, that loose forwards ($1.3 \pm 0.7 >8 \text{ G.min}^{-1}$, ES = *small to large*) and outside backs ($1.2 \pm 0.4 >8 \text{ G.min}^{-1}$, ES = *small to very large*) were the positions most likely to be involved in high-intensity impacts. These results may reflect the greater speeds that outside backs are capable of resulting in a preponderance of high-speed collisions. Loose forwards are typically involved in a higher number of tackles and rucks than other positions (Deutsch *et al.*, 2007), which may result in a greater number of high-intensity impacts. Accelerometer measures have been shown to be reasonably reliable (Waldron *et al.*, 2011), while validity of these measures is still to be established. Contact exposure significantly increases the physical load of rugby participation and the accelerometer data available are reported here to provide normative data for practitioners using these GPS devices.

Overall, the results of this research tend to agree with previous GPS research in professional rugby teams (Cahill *et al.*, 2013; Jones *et al.*, 2015). A notable exception to this is the difference in relative distance covered by backs and forwards found by Cahill *et al.* (2013) study, which was not found here.

Maximum observed values

A unique aspect of this study was the reporting of maximum observed values during match play. These values provide a perspective on what the extreme range of physical load experienced during match play might be. This analysis revealed that while relative total distance, and distance covered walking and jogging may increase by a third in the most intense matches, high-intensity running distance (striding and sprinting) can be tripled. This indicates that players should regularly be exposed to high-intensity running training, to allow

them to cope with the extreme demands of match play should the need arise. Following matches, GPS data should be compared to team norms to determine whether the players were exposed to greater than normal loads. If so, additional management and recovery strategies may be required to assist players during the subsequent recovery period.

A limitation of this study was that it only examined one team, with multiple measures performed on the same players. As a result of this, some of the results reflected here will be accounted for by individual player abilities, team tactics and prevailing playing conditions. These results will be highly valid within this playing group, but may not be easily generalisable to other teams or larger samples of players.

6.5 Conclusion

This investigation provided information on the movement and physical exertions that players would typically be exposed to when participating in a professional rugby union match in South Africa. This research reemphasizes the variation in movement patterns of players playing in different positions. These data trends provide a starting point for the design of position specific training programmes, and against which the specificity of training should be assessed. These data also show contrasts to similar studies done internationally, indicating that different playing styles and environments will affect the physical demands of the game. This study provides further foundation for future studies in positional exertions in rugby players, and will likely affect future thinking for fitness and conditioning in rugby union players.

CHAPTER 7 – SPECIFICITY OF RUGBY UNION TRAINING ACTIVITIES FOR PLAYERS IN DIFFERENT POSITIONS

7.1 Introduction

The principle of specificity of training states that maximum training benefits will be gained when the training stimulus closely matches the movement and physiological demands of the sport (Roberts *et al.*, 2008; Smith, 2003). To this end, time motion analysis of players during matches is of great value to sports scientists and conditioning coaches in the production of game specific training programmes (Spencer *et al.*, 2005). In accordance with the teams' proposed injury risk mitigation strategy (Chapter 3), to improve the specificity of training to reduce player fatigue, this study was initiated to determine how closely training practices mimic actual match demands.

Rugby union is played primarily at low speeds (walking and jogging), but interspersed with high-intensity periods where players sprint and are involved in physical collisions (Austin *et al.*, 2011a; Cahill *et al.*, 2013; Deutsch *et al.*, 2007; Duthie *et al.*, 2005; Quarrie *et al.*, 2012; Roberts *et al.*, 2008). There are significant differences in the physical requirements of different playing positions (Chapter 6). For example, scrumhalves cover the most total distance, tight forwards the least total distance and outside backs attain the highest speeds while also spending the most time walking (Cahill *et al.*, 2013). Based on these positional idiosyncrasies, researchers have called for increased specialisation of rugby union training programmes to ensure that training is specific for the varying demands of different positions during matches (Deutsch *et al.*, 2007; Quarrie *et al.*, 2012; Roberts *et al.*, 2008).

Rugby union coaches typically utilise a combination of training methodologies to prepare players for competition. Common practices include the use of traditional

endurance conditioning (TEC) training (running without the ball for bouts >3 min duration), high-intensity interval training (HIIT) (high-intensity efforts <2.5 min duration and interspersed with low-intensity recovery periods), game based training (GBT) and game skills training (ST) (match related drills that simulate game scenarios) (Argus *et al.*, 2010). The typical physical demands of these training practices, and how well they relate to actual in-match movement demands is largely undetermined.

Within rugby union, there has been a movement toward game-based training as a method of player preparation, due to the ability to improve physical fitness and skill factors simultaneously (Gamble, 2004b; Kennett, Kempton & Coutts, 2012). Research in other team sports has indicated that game-based training generally replicates the physical demands of elite competition (Gabbett & Mulvey, 2008c), but may fall short of replicating the most high-intensity periods of match play (Gabbett *et al.*, 2008c; Gabbett, 2010c). Similarly, it is unclear how well other training activities (TEC, HIIT and ST) prepare players for the demands of match play in rugby union. Only one research study has previously compared the demands of rugby union training and matches (Hartwig, Naughton & Searl, 2011), showing that rugby training did not meet the demands of match play in adolescent players. No research exists comparing training and match demands in senior professional players.

While specificity of training is desirable, it may be unrealistic to expect training sessions to regularly reproduce match intensities and loads (Dawson *et al.*, 2004). Increased training loads have been associated with increased injury rates in rugby league (Gabbett *et al.*, 2011c). In addition, participation in rugby union match play is known to cause significant muscle damage (Twist & Highton, 2015; West *et al.*, 2013) and if this were replicated too often in training players would not recover in time for the next match. As such, the need to balance training loads required to maintain or improve performance with injury risk requires

careful consideration. Furthermore, the diversity of physical attributes (Duthie *et al.*, 2003) and movement patterns (Cahill *et al.*, 2013; Deutsch *et al.*, 2007; Roberts *et al.*, 2008) among different positions in rugby union, will result in different physical loads experienced among players from different positions participating in the same training session. A one-size fit all approach to training is unlikely to illicit optimal adaptations from players across a range of positions.

The aim of this study was to determine the specificity of typical training activities in rugby union, by comparison with the demands of match play. The specificity of each training method for players in different positional groups will be assessed. Knowing the movement demands of various training activities, and understanding how these may differ from actual match demands for players in different positions will provide valuable information to coaches for prescribing position specific training plans.

7.2 Methods

7.2.1 Experimental approach to the problem

A prospective, observational study was conducted to determine the movement demands of typical training activities of a professional rugby union team. Players' movement patterns were observed during training sessions and then compared with the match-play demands of professional competition.

7.2.2 Participants

Fifty-three players (Age 25 ± 3 years, stature 186 ± 7 cm and body mass 101.5 ± 12.2 kg), volunteered to participate in this portion of the research project between 2011 and 2013. These players were from the same professional rugby team described in Chapters 3 – 6 of this thesis. The study was performed according to the directives of the Declaration of Helsinki (World Medical Association, 2013), and all players signed informed consent. Players were divided into positional groups; tight forwards (props and locks), loose forwards (hookers,

flanks and eighth men), scrumhalves, inside backs (fly halves and centres) and outside backs (wings and fullbacks); based on previously determined similarities in positional demands (Deutsch *et al.*, 2007; Roberts *et al.*, 2008). The descriptive characteristics of each of these positional groups are detailed in table 6.1 (Chapter 6 pg. 124).

7.2.3 Experimental procedure

Players were monitored during 96 training sessions over a 25-month period from November 2011 to October 2013 that included two pre-season and two in-season training phases. Training sessions were classified in consultation with the team strength and conditioning coach into one of four types of training activities, indicated in table 7.1.

Table 7.1 – Characteristics and number of observations of the four training activities examined in this study.

Training Activity	Activity Description	Observations (N)
Traditional endurance conditioning - TEC	Maximal aerobic speed and interval running activity on a track without the ball. Individual activity bouts ranged between 3-15 minutes. Work to rest ratios ranged from 2:1 to 1:3	96 during 8 training sessions
High-intensity interval training - HIIT	Short burst high-speed activity bouts without the ball of between 20 seconds and 2.5 minutes, generally including a number of changes of direction and acceleration and deceleration components. Work to rest ratios ranged from 1:1 to 1:10	125 during 13 training sessions
Game-based training - GBT	Training games designed to improve physical qualities, skills and decision-making. Pitch size and player numbers were varied to effect training intensity.	86 during 8 training sessions
Skills training - ST	Training sessions in which match specific skill components are practiced to develop proficiency under pressure and coordinated patterns of play.	324 during 67 training sessions

Pre-season training phases included more traditional endurance conditioning and high-intensity interval training type sessions, while in-season phases were dominated by skills training sessions. All training activities were performed in both pre-season and in-season phases, and the movement profile of these activities was similar in different phases of the season. Unit specific skill sessions such as lineouts and scrums, captain's run and recovery sessions were excluded from the analysis.

Training session activities were compared to data from 24 matches played by the same team during the 2013 rugby season and detailed in chapter 7. These data were used to make magnitude-based inferences regarding the degree that common training activities differ from match demands by. Any training or match observation < 30 minutes in duration was excluded from the analysis. Training movement patterns were assessed using the same GPS devices and according to the same methods described in Chapter 6 (pg. 120-121).

Total distance, session duration and maximum speed attained were recorded for each training session and match. Movement data were categorized into movement speed bands corresponding to walking ($0-2 \text{ m}\cdot\text{s}^{-1}$), jogging ($2-4 \text{ m}\cdot\text{s}^{-1}$), striding ($4-6 \text{ m}\cdot\text{s}^{-1}$) and sprinting ($>6 \text{ m}\cdot\text{s}^{-1}$). Total distance and distance covered in each speed band was normalized to time spent training or in match play to account for variations in session length. Sprint and acceleration characteristics were assessed as the frequencies with which players performed sprints ($>6 \text{ m}\cdot\text{s}^{-1}$) and maximal accelerations ($>2.75 \text{ m}\cdot\text{s}^{-2}$) for a minimum duration of 1 s. Accelerometer data are not reported in this study due to inconsistencies in the measurement, with far larger values being recorded in some training sessions than in matches. This may have occurred due to incorrect use of the device with players carrying it in a hip pocket or sock after forgetting to bring their harness to training. Maximum observed values for all training sessions were reported, to

allow practitioners to assess the upper range of movement requirement for training activities. These are compared with maximum observed match values, previously reported in Chapter 6 (table 6.7), to determine whether training addresses the most extreme demands of match play.

7.2.4 Statistical analysis

All statistical analyses were performed using SPSS analytics software (version 22, IBM.com). Descriptive statistics (Mean $\pm$ SD) were reported for most movement variables. Sprint and acceleration characteristics were reported as frequencies (1 every N $\pm$ SD minutes). Maximum values of all variables were reported to provide perspective on the most extreme demands of training. Differences in movement variables between training activities and match play were assessed using a one-way ANOVA. A Levene's test for homogeneity of variance was utilised. The majority of cases were not normally distributed, and in these instances a Welch robust test of equality of means and Games-Howell *post hoc* test were applied. In the case of normally distributed data, a Tukey's *post hoc* test was utilized. Statistical significance was set at $p < 0.05$. Practical relevance of observed differences was determined by calculating Cohen's effect size statistic. These were calculated for each position group for all movement variables. Effect sizes were determined as the standardised mean difference from match play, meaning that negative and positive effect sizes indicate that variables are less than or greater than match play variables respectively. Due to the large data set and large differences and effect sizes observed, larger effect sizes ranges were applied in this study than elsewhere in this thesis. Effect sizes of 0.2, 0.6, 1.2 and 2.0 were considered *small*, *medium*, *large* and *very large* respectively (Hopkins, 2015). Effect sizes >0.6 (*medium*) were considered practically meaningful in this analysis. 95% Confidence intervals for effect sizes were calculated using a excel spreadsheet designed for this purpose (retrieved from www.cem.org/effect-size-calculator Nov 23 2014).

7.3 Results

7.3.1 Comparison between training activities and mean match exertion

The movement profiles of training activities, and professional match play are presented in table 7.2. Figure 7.1 a and b shows the magnitude of difference from match play of the various training activities for all of the movement variables and positional groups. The relative intensity ($\text{m}\cdot\text{min}^{-1}$) of traditional endurance conditioning (ES = *large*) training sessions was higher than match play, while game-based training (ES = *medium*) and skills (ES = *large*) training was lower. The maximum speed attained during traditional endurance conditioning (ES = *large*) was lower than in matches. There was no meaningful difference in maximal speed between matches and game-based training, high-intensity interval training or skills training sessions.

Players covered more distance walking during matches than during any training activity (ES = *medium* to *very large*). Traditional endurance conditioning training exceeded match requirements for jogging and striding distance (ES = *medium*), while skills training failed to meet match requirements in these movement bands (ES = *medium* to *large*). High-intensity interval training exceeded match requirement for striding (ES = *medium*), but not for any other movement category. Most training activities were able to match game intensity in the sprinting distance and sprint and acceleration frequency categories. Traditional endurance conditioning displayed meaningful differences below match play for sprint distance (ES = *medium*) and acceleration frequency (ES = *large*).

High-intensity interval training was the training activity that was most similar to match requirements overall. Only distance covered walking was significantly lower than match play (ES = *very large*), and striding distance exceeded match play (ES = *medium*). After high-intensity interval training, game-based training was the next most specific activity with *trivial* to *small* differences in all movement categories except relative, walking and jogging distance (ES =

Table 7.2 – Movement characteristics of common rugby union training activities and match play.

	Match Play	TEC	HIIT	GBT	ST
Session duration (min)	73 ± 24	53 ± 22* (Medium)	74 ± 25# (Trivial)	99 ± 19*# ^{\$} (Medium)	111 ± 28*# ^{\$%} (Large)
Total distance (m)	5050 ± 1636	4479 ± 1804 (Small)	5204 ± 1805# (Trivial)	5787 ± 1212*# ^{\$} (Small)	5300 ± 1328# [%] (Trivial)
Relative distance (m.min⁻¹)	69 ± 8	92 ± 34* (Very Large)	71 ± 21# (Trivial)	59 ± 9*# ^{\$} (Medium)	49 ± 11*# ^{\$%} (Large)
Maximum speed (m.s⁻¹)	8.2 ± 1.3	6.2 ± 1.8* (Large)	7.5 ± 1.6*# (Small)	8.4 ± 1.3# ^{\$} (Trivial)	7.9 ± 1.3# [%] (Small)
Walking distance (m.min⁻¹)	34 ± 5	22 ± 9* (Large)	22 ± 5* (Very large)	29 ± 5*# ^{\$} (Medium)	27 ± 5*# ^{\$} (Large)
Jogging distance (m.min⁻¹)	23 ± 6	44 ± 28* (Medium)	27 ± 16*# (Small)	19 ± 6*# ^{\$} (Medium)	14 ± 5*# ^{\$%} (Large)
Striding distance (m.min⁻¹)	10 ± 4	25 ± 23* (Medium)	20 ± 14* (Medium)	9 ± 3# ^{\$} (Small)	6 ± 3*# ^{\$%} (Medium)
Sprinting distance (m.min⁻¹)	2.4 ± 1.9	0.9 ± 2.3* (Medium)	2.4 ± 3.1# (Trivial)	2.6 ± 2.3# (Trivial)	1.4 ± 1.4*# ^{\$%} (Medium)
Sprint frequency	1 every 9 ± 13 min	1 every 22 ± 8 min* (Small)	1 every 12 ± 9 min (Small)	1 every 9 ± 11 min# (Trivial)	1 every 14 ± 14 min*# [%] (Small)
Acceleration frequency	1 every 6 ± 10 min	1 every 23 ± 11 min* (Large)	1 every 7 ± 9 min# (Trivial)	1 every 6 ± 11 min# (Trivial)	1 every 7 ± 8 min# (Trivial)

TEC = traditional endurance conditioning, HIIT = high-intensity interval training, GBT = game based training and ST = skills training. Data are reported as mean ± SD (ES). Relative (m.min⁻¹) rather than absolute distances are reported due to differences in duration of training and match exposures. *, #, \$ and % represent significant difference (ANOVA) from match play, TEC, HIIT and GBT respectively (p < 0.05). Effect size (ES) represents difference from match play.

medium). Traditional endurance conditioning was the training activity that was most different to match play, with *medium* to *large* differences in every movement variable, except sprint frequency. Skills training falls short of match intensity (ES = *medium* to *large*) for relative, walking, jogging, striding and sprinting distance.

7.3.2 Comparison between training activities and mean match exertion for different positional groups

Figures 7.1a and 7.1b present comparisons of the standardised differences of movement variables from match play for each of the 5 positional groups. There are differences in the specificity of training activities to match play for each of the different positional groups. Figure 7.1a indicates that for tight forwards, high-intensity interval training, game-based training and traditional endurance conditioning training sessions all meet or exceed match play requirements for striding, sprinting, sprint frequency and acceleration frequency. There were only *small* to *medium* differences in these parameters between match play and skills training. This indicates that the sprint and high speed running requirements of tight forwards would be met during most training sessions. However, game-based training (ES = *large*) and skills training (ES = *very large*) training did not meet match running requirements in the jogging speed zone.

Similarly, the sprint distance and sprint and acceleration frequency requirements of loose forwards (figure 7.1a) seem to be adequately met by all training activities. However, game-based training does not reach match intensity for striding (ES = *medium*) and skills training falls short of match play jogging and striding distances (ES = *large*).

There are a number of *large* differences in movement patterns during training activities and match play for scrumhalves (figure 7.1b). Skills training does not meet match intensity in any movement category except acceleration frequency

Error bars represent 95% confidence intervals. Greyed out section represents trivial differences. TEC = Traditional endurance conditioning, HIIT = high-intensity interval training, GBT = game based training and ST = skills training. Distances are reported relative to activity time due to differences in duration of match and training exposures.

Figure 7.1a – Comparison of standardized differences in movement characteristics between training activities and professional rugby union match play for all players, tight forwards and loose forwards.

Error bars represent 95% confidence intervals. Greyed out section represents trivial differences. TEC = Traditional endurance conditioning, HIIT = high-intensity interval training, GBT = game based training and ST = skills training. Distances are reported relative to activity time due to differences in duration of match and training exposures.

Figure 7.1b – Comparison of standardized differences in movement characteristics between training activities and professional rugby union match play for scrumhalves, inside backs and outside backs.

(ES = *medium* to *very large*). Game-based training is the only training activity that matches match play in maximum speed obtained for scrumhalves, but there are *medium* to *large* differences in relative, walking, striding and sprint distance and sprint frequency. Traditional endurance conditioning exceeds match play requirement for scrumhalves in relative distance (ES = *medium*), jogging distance (ES = *medium*) and striding distance (ES = *large*), but falls short of the maximum speed (ES = *large*), sprint distance (ES = *very large* (4.6, not accommodated on graph)) and sprint (ES = *large*) and acceleration (ES = *very large*) frequency required. High-intensity interval training is the most specific training activity for scrumhalves with differences in most movement categories ranging from *trivial* to *medium*, but there is a *very large* difference in walking distance.

For inside backs, game-based training seems is a highly appropriate training activity, with only *small* differences from match play in every movement category except walking distance (ES = *large*) (figure 7.1b). High-intensity interval training and traditional endurance conditioning exceeds the match intensity requirements of inside backs by exceeding the amount of jogging (ES = *medium*) and striding (ES = *medium* to *large*) required. Traditional endurance conditioning fails to meet maximum speed, sprint distance and sprint and acceleration frequency requirements for inside backs (ES = *medium* to *large*). Skills training falls short of match intensity (ES = *medium* to *very large*) in every parameter except acceleration frequency.

No training activity satisfies match demands of outside backs for maximum speed (figure 7.1b). Game-based training is a largely specific activity for outside backs as it meets match play requirements in most movement categories, except relative and walking distance and maximum speed (ES = *medium*). Skills training displays *medium* sizes deficits in all movement categories except sprint and acceleration frequency (ES = *small*). High-intensity interval training exceeds match play requirements for outside backs in total relative, jogging and striding

(ES = *medium* to *large*) distance, but also demonstrates *large* to *very large* deficits in maximum speed and acceleration frequency.

7.3.3 Comparison of maximum values for training activities and match play

Table 6.7 (Chapter 6, pg. 131) presents the maximum observed values during match play for each movement variable across all position groups. Table 7.3 presents the maximum observed values for all movement variables during training activities and the percentage difference from maximal match values. These maximum values indicate that it is possible to simulate even the most extreme match intensities within the training environment. Traditional endurance conditioning was the training activity that produced the highest values in most movement variables, indicating that this training activity may have value in training players for matches with the highest intensity. Both game-based training and skills training are unlikely to prepare players for the most high-intensity matches indicating the value of including regular traditional endurance conditioning or high-intensity interval training sessions in the training programme.

Table 7.3 – Maximum observed values for movement variables during training activities and percentage difference from maximum match value.

	TEC	HIIT	GBT	ST
Relative distance (m.min⁻¹)	189 (91%)	116 (17%)	87 (-12%)	80 (-19%)
Maximum speed (m.s⁻¹)	11.6 (3%)	11.4 (1%)	11.3 (0%)	12.1 (7%)
Walking distance (m.min⁻¹)	50 (11%)	45 (0%)	42 (-7%)	39 (-13%)
Jogging distance (m.min⁻¹)	106 (172%)	80 (105%)	57 (46%)	34 (-13%)
Striding distance (m.min⁻¹)	91 (264%)	69 (176%)	15 (-40%)	25 (0%)
Sprinting distance (m.min⁻¹)	16 (76%)	13 (43%)	10 (10%)	8 (-12%)
Sprint frequency	1 every 1.5 min (100%)	1 every 2.5 min (20%)	1 every 2.5 min (20%)	1 every 2.5 min (20%)
Acceleration frequency	1 every 2 min (0%)	1 every 2 min (0%)	1 every 2.5 min (-20%)	1 every 1 min (100%)

TEC = traditional endurance conditioning, HIIT = high-intensity interval training, GBT = game based training and ST = skills training. Relative (m.min⁻¹) rather than absolute distances are reported due to differences in duration of training exposures. Percentage difference from match maximums are presented in brackets. The highest value in each movement category is highlighted in bold.

7.4 Discussion

The purpose of any sport specific physical training programme should be to optimally prepare players for the demands of competition. This is achieved by maximising training specificity through the manipulation of training activities to simulate or exceed the skill and physical demands of competitive match play. Relatively few studies have previously attempted to utilize GPS to assess the appropriateness of training activities (Gabbett, 2010c)(Higham *et al.*, 2013). This study is the first to compare the movement characteristics of contemporary training activities in professional rugby union with match play demands using GPS technology. Based on the widely acknowledged differences in movement patterns of players in different positions (Cahill *et al.*, 2013; Deutsch *et al.*, 2007; Quarrie *et al.*, 2012; Roberts *et al.*, 2008), this study also assessed the appropriateness of different training activities for players in different positions. A major finding of this study was the substantial differences in the typical movement patterns of players involved in match play and during training activities. Conditioning coaches can use the results of this study to develop position specific training programmes for professional rugby union players.

7.4.1 General comparisons between training activities and match play

Players walked more during match play than during any training activity (ES = *medium to very large*) (table 7.2). This finding likely reflects the intermittent nature of rugby union match play, with regular stoppages to contest first phase possession. During these stops in play, players typically walk to the following phase of play, allowing an opportunity for active recovery to take place. World Rugby game analysis reports suggest that the ball is only in play between 42 and 46% of the time during rugby matches (World Rugby, 2015b). It seems that players are afforded more opportunity to walk during match play than during training sessions, which may assist players in maintaining intensity throughout the game when the ball is in play. Coaches and trainers should be aware that

reduced walking distance during training limits opportunities for active recovery, and may make it difficult for players to perform the most high-intensity activities optimally.

High-intensity interval training was shown to be the training activity that is most specific to match play for all positions combined, with differences only present in the walking (ES = *very large*) and striding (ES = *medium*) movement categories (table 7.2). High-intensity interval training met or exceeded match play requirements for tight and loose forwards in all movement categories except walking (ES = *large* to *very large*), and is highly specific for these positions (figure 7.1a). High-intensity interval training is the most specific training activity for scrumhalves, with *small* to *medium* differences from match play in most movement categories (figure 8.1b), but did not satisfy scrumhalves match requirements for walking and jogging distance (ES = *large* to *very large*). The maximum speed and sprint and acceleration frequency requirements of inside and outside backs are not met by high-intensity interval training (ES = *small* to *large*) (figure 7.1b).

Game-based training was specific to match requirements in terms of speed and acceleration variables (*trivial* to *small* differences in maximum speed, sprint distance, sprint and acceleration frequency) (table 7.1). This result agrees with the findings of Gamble *et al.* (2004) and Kennett *et al.* (2012) that show that game-based training is an effective method of training for rugby union. However, a *medium* sized difference in relative distance covered, which resulted from differences in walking and jogging distances, between game-based training and match play, indicates that game-based training does not replicate match intensities.

This result contrasts slightly with that of Gabbett *et al.* (2010c) which also showed that game-based training didn't replicate match demands in female field

hockey players, but that the area of discrepancy was high-intensity running, not low-intensity running distance as indicated here. In a study of rugby sevens training activities, Higham *et al.*, 2013 showed that game-based training and high-intensity skills drills replicated match demands more closely than low-intensity skills drills, but still did not meet absolute match demands in any velocity zone. Overall, it would seem that both high-intensity interval training and game-based training satisfy a number of the requirements for team intermittent high-intensity sports and as such are worthwhile activities for training. However, neither of these activities will adequately prepare players for the most high-intensity periods of match play and training activities specifically designed to address these highest demand periods should be performed periodically.

7.4.2 Position specific comparisons between training activities and match play

When compared with individual position requirements, game-based training was shown to be highly appropriate in some positions, but fell short of replicating match intensity for others. Game-based training does not meet the relative distance and jogging requirements of tight forwards, or the relative distance and striding requirements of loose forwards (figure 7.1a). This indicates that if game based training were used and the only form of conditioning for these position groups, they would be underprepared for match play. Game-based training is a non-specific activity for scrumhalves as it does not meet match requirements for any movement category except maximum speed (figure 7.1b). Game-based training is a highly appropriate form of training for outside backs as it meets match play requirements in all movement categories except relative distance, maximum speed and walking (ES = *medium*). For inside backs, game-based training was mostly specific, but falls short of match requirements for relative, walking and jogging distance (ES = *medium* to *very large*). Coaches and trainers should therefore, be wary of the one-size fits all approach. While game-based training is an effective training strategy, particularly in light of the potential to

improve skill components in conjunction with physical conditioning (Gamble, 2004b; Kennett *et al.*, 2012), coaches and trainers must be aware of the need to supplement game-based training with other training activities that complement the specific needs of players in different positions. Alternatively, clever manipulation of training variables within game-based training may make it possible to better simulate match demands for all positions (Kennett *et al.*, 2012), but these would need to be monitored carefully.

Options available to coaches to supplement game-based training for position specific training are traditional endurance conditioning and high-intensity interval training. Traditional endurance conditioning exceeds match intensity in relative (ES = *large*), jogging (ES = *medium*) and striding (ES = *medium*) distance, but falls short for maximum speed (ES = *large*), sprint distance (ES = *medium*) and acceleration frequency (ES = *large*) (table 7.2). High-intensity interval training is effective for achieving adequate jogging, striding and sprinting intensities during training. The use of traditional endurance conditioning or high-intensity interval training in combination with game-based training would ensure that players are able to sustain match running intensities (figure 7.1a and b).

Skills training sessions had the lowest mean intensity of all training activities, with *large* to *very large* differences from match play for all position groups. This reduction in relative distance covered can be explained by *medium* to *very large* differences in the jogging and striding speed zones. There were similarities between skills training and match play in maximum speed, sprint distance and sprint and acceleration frequency for forwards (tight forwards and loose forwards), but this was not apparent for backs (scrumhalf, inside back, outside back).

Skills training was the most regularly prescribed training activity over the course of this study, and players participated in skills training sessions at least twice

every week. Coaches should note that participation in skills training only will not adequately prepare players for the physical demands of match play. However, it is not desirable to reproduce match intensity in every training session (Dawson *et al.*, 2004), as this would interfere with the recovery process and could lead to over-training (Gabbett *et al.*, 2011c). Training should be targeted to develop all of the physical characteristics associated with success in rugby union (Duthie, 2006), not just repetitively replicate game demands. The reduced intensity of skills training therefore, serves a practical purpose in creating an environment where workloads can be sustained through training sessions to allow gains in other areas such as tactical awareness and skill development.

An additional finding of this study was that no training activity studied here managed to simulate the maximum speed requirements of outside backs during match play (ES = *medium to very large*) (figure 7.1b). This indicates that outside backs should be regularly exposed to maximum speed training to maintain and develop this important attribute for performance. In addition, none of the training activities studied here adequately prepare scrumhalves for match play. These findings, once again, illustrate the uniqueness of the scrumhalf position within rugby union (Deutsch *et al.*, 2007). Scrumhalves would be best served by training with a combination of game-based training, traditional endurance conditioning and high-intensity interval training, but more position specific training protocols should be developed.

7.4.3 Maximum match and training values

Analysis of maximum observed values during match play (table 6.7 – Chapter 6, pg. 131) and training (table 7.3) indicate that it is possible to meet and even exceed the movement characteristics of professional rugby union match play during training. This result is in contrast with previous research in adolescent rugby union (Hartwig *et al.*, 2011), international rugby sevens (Higham *et al.*, 2013), professional rugby league (Gabbett *et al.*, 2012b), Australian rules football

(Dawson *et al.*, 2004) and elite women's field hockey (Gabbett, 2010c), which all showed that contemporary training practices failed to replicate match demands. The low ball-in-play time of professional rugby union (42-46%) (World Rugby, 2015b), presumably lowers overall match intensity making it possible to achieve these intensities during training. Attention should be paid to the high-intensity periods of play that occur between stoppages and ensuring that players are conditioned to perform at an adequate level during these repeated high-intensity bouts.

An important factor to consider is that peak values of movement characteristics measured during training were similar to or exceeded the most extreme match demands, most notably for traditional endurance conditioning and high-intensity interval training sessions. This indicates that some training sessions could be as demanding, or more demanding than matches. Caution should be applied when prescribing training sessions to ensure that the training load is not overly demanding. This is especially important in situations where players in different positions complete the same training session but may experience vastly different physical loads. Training sessions should be carefully monitored (with GPS or other methods) to ensure that the desired intensities and training objectives are achieved. Furthermore, individual response to these sessions should be assessed through player monitoring programmes (Halson, 2014).

7.4.4 Contact demands of training

A limitation of this study is the inability to accurately measure contact demands of training with the GPS devices used (Gabbett, 2012c). Physical contact reduces both total running distance (Johnston *et al.*, 2014d) and high-intensity running during game based activities (Johnston, Gabbett & Jenkins, 2014b). Since rugby union players frequently engage in physical contact and static exertions (tackling, rucking, scrumming etc.) during match play, the influence of these contact factors on fatigue cannot be ignored (Deutsch *et al.*, 2007; Duthie *et al.*, 2006).

Research from rugby league indicates that exposure to contact training is an important factor for success during match play (Gabbett, Jenkins & Abernethy, 2010a). Players were regularly exposed to physical contact during skills training sessions in this study, but not during traditional endurance conditioning and high-intensity interval training activities. During game-based training players were occasionally exposed to light contact. Due to inconsistencies apparent in the accelerometer data collected, no attempt was made to quantify the effects of contact on movement characteristics of the various training activities. Exposure to physical contact may have affected movement characteristics during skills training. Improvement in the ability of GPS devices to monitor contact involvements will further improve our understanding of the effects of contact on training load.

7.5 Conclusion

The findings of this study illustrate that training practices of the rugby union team studied were not highly specific to match play. High training volumes are associated with increased injury risk in contact sports (Gabbett *et al.*, 2011c), but probably do not confer any additional performance advantage (Brooks *et al.*, 2008a). Therefore improved training efficiency will maintain and possibly improve physical performance while reducing the injury risk associated with high training volumes. This research study has demonstrated how training prescription can be improved through the use of GPS time-motion analysis as part of an injury risk mitigation strategy.

CHAPTER 8 - DETERMINING ACTIVITY-RELATED FATIGUE IN RUGBY UNION MATCH PLAY

8.1 Introduction

In team sports, fatigue can be broadly identified by reductions in self-regulated movement distance and/or intensity during a match (Waldron & Highton, 2014). Accordingly, activity-related fatigue in team sports has been evidenced by a decline in total and high-intensity ($>3.6 \text{ m.s}^{-1}$) running distance across progressive game segments in soccer (Bradley & Noakes, 2013), rugby league (Kempton *et al.*, 2013), Australian rules football (Wisbey *et al.*, 2010), rugby sevens (Higham *et al.*, 2011) and rugby union (Jones *et al.*, 2015; Lacombe *et al.*, 2013; Roberts *et al.*, 2008). In addition to the gradual decline in running performance over the course of a match, acute-fatigue also occurs in “transient” periods. These periods of transient fatigue occur immediately following the most high-intensity periods of matches, and are evidenced by the reduction of running intensity below match average (Mohr, Krstrup & Bangsbo, 2003). Total recovery of running intensity following periods of transient fatigue has been shown in soccer players (Mohr *et al.*, 2003).

Contemporary models of pacing in team sport suggest that players regulate their efforts based on macro-, meso- and micro-pacing strategies (Edwards & Noakes, 2009). The macro-pacing strategy is determined prior to the start of the match based on intrinsic (hydration, fuel availability, motivation) and extrinsic (ambient temperature, opposition) factors. This macro pacing ‘schema’ is then modified between halves (meso-pacing) and continuously (micro-pacing) in response to in-match factors such as exertion, opposition and score line (Edwards *et al.*, 2009). The net result of this type of strategy is that players regulate exercise intensity throughout matches to ensure sufficient physiological reserves to complete that match, as well as to be able to up-regulate activity levels during the most intense periods of match play.

To the researcher's knowledge, only 3 studies have reported changes in temporal patterns of movement within rugby union matches. Analysis from successive 10 minutes periods of matches indicate that rugby union players typically adopt a 'slow-positive' (Waldron *et al.*, 2014) pacing strategy in terms of total distance covered, starting games at higher running intensities with a gradual decline ($\approx 10\%$) throughout each half (Jones *et al.*, 2015; Roberts *et al.*, 2008). Roberts *et al.* (2008) reported that high-intensity running distance remained consistent throughout match segments. In contrast, Jones *et al.* (2015) showed large reductions ($\approx 50\%$) in high-intensity running in periods 30-40 minutes and 50-60 minutes during match play. Lacome *et al.* (2013) found no change in exercise to rest ratios from 1st to 2nd half in international rugby players, concluding that there was not an obvious decrease in performance due to fatigue (Lacome *et al.*, 2013), indicating a 'flat' (Waldron *et al.*, 2014) pacing strategy.

An important consideration in determining pacing and fatigue in rugby union is the presence of physical contact. Physical contact reduces total running performance in rugby league players participating in small-sided games (Johnston *et al.*, 2014a; Johnston *et al.*, 2014b; Johnston *et al.*, 2014d). In limited contact situations, total running distance is decreased, but high-intensity running distance is maintained (Johnston *et al.*, 2014a; Johnston *et al.*, 2014b). However, when players were exposed to multiple contact efforts, both total running and high-intensity running are reduced (Johnston *et al.*, 2014d). These results suggest that players adjust their pacing 'schema' in response to the prevailing contact demands. In the presence of lighter contact loads players will reduce low-intensity running distance in an attempt to maintain the ability to perform high-intensity efforts, but that if the contact load is sufficient both total and high-intensity running will be reduced.

Rugby union forwards are exposed to more contact activities than backs during match play (Deutsch *et al.*, 2007; Duthie *et al.*, 2005; Roberts *et al.*, 2008), and as such may be more likely to display signs of activity-related fatigue (reduced total or high-intensity running). This may be the reason why forwards are substituted more often than backs during rugby union matches (Waldron *et al.*, 2014). No study has previously assessed whether the fatigue pattern of rugby union players is affected by position.

Injury incidence is highest among starting players in the fourth quarter of matches (Brooks *et al.*, 2005a) suggesting that as players begin to suffer higher levels of activity-related fatigue, their injury risk increases. Therefore, if the presence of activity-related fatigue could be clearly identified in players on the field, injury risk could be mitigated through substitution of the fatigued player/s.

Starting players are often substituted before the end of the match in rugby union. Teams are allowed to substitute seven, and in international competition eight players during the course of the game for tactical reasons or injury. Soccer (Carling *et al.*, 2010), rugby league (Black & Gabbett, 2014; Waldron *et al.*, 2013) and rugby sevens (Higham *et al.*, 2011) have all reported greater high-intensity running distance covered by substitutes. Since most rugby union substitutions occur in the second half of games, it would be valuable to contrast the performance of substitutes with the second half performance of whole game players to determine the impact of substitutes on match intensity.

The aim of this study is to report the influence of match period, playing position and the introduction of substitutes on the movement patterns of professional rugby union players. This information will be useful for identifying activity-related fatigue, and could be used by rugby union coaches to protect fatigued players from injury, and to optimise the impact of substitutes during matches.

8.2 Methods

8.2.1 Experimental approach to the problem

In this observational design study, GPS data files were collected from professional rugby union players during match play. The data contained in these files was divided into quartiles for each match period. Movement data was then compared across match period, position groups and starting and substitute to determine indicators on activity-related fatigue.

8.2.2 Participants and GPS data

The same GPS data set as used in Chapter 6 was used to assess the occurrence of fatigue and the introduction of substitutes on movement characteristics of rugby union players. In brief, 19 players (age 26 ± 2 years; body mass 101.5 ± 12.2 kg, stature 1.86 ± 0.07 m) contributed 102 individual GPS match participation files from 24 professional matches. Data from these files was analysed to determine total distance (m) covered, maximum speed (m.s^{-1}) attained, the distance covered in differentiated speed zones (walking – $0-2 \text{ m.s}^{-1}$, jogging – $2-4 \text{ m.s}^{-1}$, striding – $4-6 \text{ m.s}^{-1}$, and sprinting – $>6 \text{ m.s}^{-1}$), and impact (total >5 G and high intensity >8 G), sprint ($>6 \text{ m.s}^{-1}$) and acceleration counts ($>2.75 \text{ m.s}^{-2}$).

8.2.3 GPS data analysis

The raw data files were designated as 1st half starter, 2nd half starter and 2nd half substitute files, and were separated according position group (forward or back). Players who started matches and completed at least 35 minutes in the 2nd half (N = 46) were designated “whole game” players. Players who replaced starting players in the 2nd half were designated as substitutes (N = 20). Only “whole game” players and second half substitutes were included in this study. Temporal analysis of movement patterns was investigated by dividing each 1st half starter, 2nd half starter and 2nd half substitute file into quartiles.

8.2.4 Statistical Analysis

Assessment of changes in movement characteristics of whole game backs and forwards across match halves was performed using a paired samples t-test. Time-course changes in movement patterns were examined for each position group using separate mixed design factorial analysis of variance (ANOVA), to compare position (back, forward) by match period (1st half quartile 1-4 and 2nd half quartile 1-4). Assumptions of sphericity were assessed using the Mauchly test of sphericity, with any violations adjusted by use of the Greenhouse-Geisser correction. No significant interaction (position x quartile) effects were found. Where significant effects of position were observed, independent samples t-tests with Bonferroni corrections were used to determine difference in position per quartile. Where significant effect of quartile was present, the magnitude of difference was determined by comparing quartiles through a series of paired sample t-tests with Bonferroni corrections.

The effect of substitutes was determined by comparing the second half performances of “whole game” players (n = 46, forwards = 19, backs = 27) versus players who came on as second half substitutes (n = 20, forwards = 17, backs = 3), via independent samples t-test. Time course comparison of the second half performance of “whole game” players and substitutes was only conducted for forwards, due to the small sample of back substitutes (n = 3). A similar factorial ANOVA was used for this comparison, with bout (whole game, substitute) utilised as a grouping variable rather than position.

All data are reported as mean $\pm$ SD and level of significance was set at $p < 0.05$. Precision of estimates is indicated with 95% confidence limits (95%CI). Given the practical nature of this study differences were also analysed using Cohen’s effect size (ES) statistic. Effect sizes of 0.2, 0.5, 0.8 and 1.2 were considered *small*, *medium*, *large* and very large respectively (Hopkins *et al.*, 2009). Effect sizes >0.5 were considered practically meaningful.

8.3 Results

8.3.1 Effect of half on movement variable

Table 8.1 presents the differences in the movement variables from the first to second half for “whole game” players. The relative distance covered in the 2nd half was decreased for both forwards ($-13 \pm 18\%$, ES = *large*) and backs ($-9 \pm 22\%$, ES = *large*) indicating an overall reduction in match intensity of $\approx 10\%$. Backs and forwards differed in their movement profile across halves in terms of low intensity and high-intensity running. Both position groups displayed significant, *large* reductions in low intensity running distance between halves (forwards $-10 \pm 13\%$, ES = *large*; backs $-7 \pm 10\%$, ES = *large*). Forwards showed a significant, *medium* sized reduction in high-intensity running from 1st to 2nd half ($-27 \pm 36\%$, ES = *medium*), while backs only showed a *small*, non-significant reduction ($-10 \pm 8\%$, ES = *small*).

Forwards also differed from backs in the rate of decline in sprint and acceleration frequency. Forwards performed significantly less sprints ($-29 \pm 29\%$, ES = *small*) and less accelerations ($-27 \pm 32\%$, ES = *medium*) in the 2nd half compared to the first, while there were no notable changes in sprint ($-13 \pm 7\%$, ES = *small*) or acceleration frequency ($-5 \pm 15\%$, ES = *trivial*) for backs. Both backs and forwards displayed *small* reductions in the total number of impacts sustained between halves (forwards $-9 \pm 7\%$, ES = *small*; backs $-10 \pm 9\%$, ES = *small*), but only forwards showed a *small* decrease in high-intensity impacts (forwards $-9 \pm 1\%$, ES = *small*; backs $-2 \pm 9\%$, ES = *trivial*).

Table 8.1 – Movement variables of 1st half, 2nd half and substitute players from different position groups in professional rugby union matches.

	Forwards					Backs				
	Whole Game (N=19)			Substitute (N=17)		Whole Game (N=27)			Substitute (N=3)	
	1 st Half	2 nd Half	ES	2 nd Half	ES	1 st Half	2 nd Half	ES	2 nd Half	ES
Time Playing (mins)	47 ± 7	50 ± 8	<i>small</i>	36 ± 14*	<i>very large</i>	46 ± 3*	50 ± 7	<i>medium</i>	33 ± 2*	<i>very large</i>
Total Distance (m)	3485 ± 696	3163 ± 391	<i>medium</i>	2403 ± 955*	<i>large</i>	3160 ± 275	3129 ± 394	<i>trivial</i>	1958 ± 99*	<i>very large</i>
Relative Distance (m.min⁻¹)*	74 ± 11*	65 ± 8	<i>large</i>	67 ± 10	<i>small</i>	70 ± 8*	63 ± 5	<i>large</i>	59 ± 10*	<i>large</i>
Maximum Speed (m.s⁻¹)	7.3 ± 0.9	7.3 ± 1.3	<i>trivial</i>	7.1 ± 1.4	<i>trivial</i>	8.6 ± 1.2	8.6 ± 1.0	<i>trivial</i>	8.9 ± 1.0	<i>small</i>
Low intensity distance <4 m.s⁻¹ (m.min⁻¹)	62 ± 8*	56 ± 8	<i>large</i>	55 ± 5	<i>trivial</i>	56 ± 4*	52 ± 4	<i>large</i>	48 ± 2	<i>very large</i>
High intensity distance >4 m.s⁻¹ (m.min⁻¹)	12 ± 6*	9 ± 4	<i>medium</i>	12 ± 6*	<i>medium</i>	13 ± 4	11 ± 3	<i>small</i>	12 ± 2	<i>trivial</i>
Sprint frequency (>6 m.s⁻¹)	1 every 14 ± 14 min*	1 every 20 ± 25 min	<i>small</i>	1 every 13 ± 25 min	<i>medium</i>	1 every 7 ± 5 min	1 every 8 ± 17 min	<i>small</i>	1 every 10 ± 2 min	<i>small</i>
Acceleration frequency (>2.75 m.s⁻²)	1 every 9 ± 17 min*	1 every 13 ± 7 min	<i>medium</i>	1 every 7 ± 9 min*	<i>large</i>	1 every 5 ± 10 min	1 every 5 ± 9 min	<i>trivial</i>	1 every 5 ± 2 min	<i>trivial</i>
Total impacts (>5 G.min⁻¹)	8.7 ± 2.4	7.9 ± 3.2	<i>small</i>	9.7 ± 2.4	<i>medium</i>	10.0 ± 3.5	9.0 ± 3.0	<i>small</i>	6.2 ± 3.4	<i>large</i>
High intensity impacts (>8 G.min⁻¹)	0.8 ± 0.3	0.7 ± 0.3	<i>small</i>	1.2 ± 0.7*	<i>large</i>	1.1 ± 0.3	1.1 ± 0.4	<i>trivial</i>	0.9 ± 0.5	<i>small</i>

Note: Data presented as mean ± SD. * indicates significant difference from 2nd half whole game players (P < 0.05). ES indicates effect size of difference from 2nd half whole game players. Sprint and acceleration frequency indicate how regularly players exceeded the speed and acceleration thresholds indicated

Table 8.2 – Temporal changes in movement patterns throughout match play for whole game forwards and backs.

	Pos.	1 st Half				2 nd Half			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Total Distance (m)	Fwd	874 ± 163	875 ± 200	866 ± 285	832 ± 221	736 ± 183	801 ± 175	771 ± 160	786 ± 133
	Back	795 ± 121* (medium)	761 ± 107 (medium)	783 ± 103 (small)	784 ± 123 (small)	819 ± 143* (medium)	805 ± 144* (trivial)	806 ± 164 (small)	693 ± 126 (medium)
Relative Distance (m.min⁻¹)	Fwd	74 ± 14	73 ± 11	71 ± 17	69 ± 15	64 ± 13	69 ± 11	67 ± 11	69 ± 13 [#]
	Back	69 ± 10* (small)	67 ± 11* (medium)	68 ± 10* (small)	68 ± 10* (trivial)	66 ± 9* (trivial)	65 ± 7* (small)	66 ± 12* (trivial)	56 ± 10 (large)
Maximum Speed (m.s⁻¹)	Fwd	6.8 ± 0.7	6.9 ± 1.1	6.2 ± 0.8 [#]	6.3 ± 1.4	6.1 ± 0.7 [#]	6.3 ± 1.0 [#]	6.5 ± 1.4 [#]	6.2 ± 1.3 [#]
	Back	7.5 ± 1.6 (medium)	7.7 ± 1.3 (medium)	7.5 ± 1.4 (large)	7.4 ± 1.3 (large)	7.8 ± 1.1 (very large)	7.3 ± 1.4 (large)	7.8 ± 1.1 (large)	7.2 ± 1.4 (medium)
Low intensity distance <4 m.s⁻¹ (m.min⁻¹)	Fwd	60 ± 11	61 ± 9	61 ± 14	60 ± 11	56 ± 11	60 ± 8 [#]	57 ± 10	59 ± 10 [#]
	Back	57 ± 7* (small)	54 ± 8 (large)	55 ± 7* (medium)	56 ± 7* (small)	54 ± 7 (small)	54 ± 6 (large)	53 ± 9 (small)	48 ± 7 (very large)
High intensity distance >4 m.s⁻¹ (m.min⁻¹)	Fwd	13 ± 7	12 ± 6	10 ± 8	10 ± 7	8 ± 4 [#]	9 ± 6	10 ± 5	9 ± 7
	Back	12 ± 6 (trivial)	13 ± 6* (trivial)	14 ± 6 (medium)	12 ± 5* (small)	13 ± 4 (very large)	11 ± 5* (small)	13 ± 5 (medium)	9 ± 5 (trivial)

Table 8.2 continued – Temporal changes in movement patterns throughout match play for whole game forwards and backs.

	Pos.	1 st Half				2 nd Half			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Sprint frequency ($>6 \text{ m.s}^{-1}$)	Fwd	1 every 14 $\pm$ 11 min	1 every 13 $\pm$ 11 min	1 every 15 $\pm$ 8 min	1 every 21 $\pm$ 17 min [#]	1 every 33 $\pm$ 16 min [#]	1 every 29 $\pm$ 24 min [#]	1 every 20 $\pm$ 15 min [#]	1 every 16 $\pm$ 11 min
	Back	1 every 7 $\pm$ 7 min (<i>medium</i>)	1 every 5 $\pm$ 6 min (<i>small</i>)	1 every 6 $\pm$ 9 min (<i>large</i>)	1 every 7 $\pm$ 8 min (<i>large</i>)	1 every 6 $\pm$ 9 min (<i>very large</i>)	1 every 9 $\pm$ 11 min (<i>medium</i>)	1 every 7 $\pm$ 10 min (<i>large</i>)	1 every 8 $\pm$ 8 min (<i>medium</i>)
Acceleration frequency ($>2.75 \text{ m.s}^{-2}$)	Fwd	1 every 7 $\pm$ 8 min	1 every 9 $\pm$ 10 min	1 every 15 $\pm$ 14 min [#]	1 every 13 $\pm$ 16 min [#]	1 every 13 $\pm$ 16 min [#]	1 every 14 $\pm$ 12 min [#]	1 every 14 $\pm$ 9 min [#]	1 every 12 $\pm$ 11 min
	Back	1 every 6 $\pm$ 8 min (<i>small</i>)	1 every 5 $\pm$ 6 min (<i>medium</i>)	1 every 5 $\pm$ 7 min (<i>large</i>)	1 every 5 $\pm$ 7 min (<i>large</i>)	1 every 4 $\pm$ 7 min (<i>very large</i>)	1 every 6 $\pm$ 8 min (<i>large</i>)	1 every 5 $\pm$ 7 min (<i>large</i>)	1 every 7 $\pm$ 6 min (<i>medium</i>)
Total impacts ($>5 \text{ G.min}^{-1}$)	Fwd	9.3 $\pm$ 4.5	9.2 $\pm$ 2.4	8.2 $\pm$ 3.7	7.4 $\pm$ 2.1 [#]	8.2 $\pm$ 3.7	9.4 $\pm$ 4.8	8.2 $\pm$ 3.1	8.7 $\pm$ 4.0
	Back	10.4 $\pm$ 5.3 (<i>small</i>)	10.0 $\pm$ 3.9 (<i>small</i>)	10.4 $\pm$ 4.1 (<i>medium</i>)	9.6 $\pm$ 4.8 (<i>medium</i>)	9.7 $\pm$ 3.7 (<i>small</i>)	9.4 $\pm$ 3.3 (<i>trivial</i>)	10.0 $\pm$ 3.6 (<i>medium</i>)	7.1 $\pm$ 4.0 (<i>small</i>)
High intensity impacts ($>8 \text{ G.min}^{-1}$)	Fwd	0.8 $\pm$ 0.6	0.9 $\pm$ 0.4	0.6 $\pm$ 0.3 [#]	0.8 $\pm$ 0.5	0.8 $\pm$ 0.5	0.8 $\pm$ 0.4	0.7 $\pm$ 0.4	0.8 $\pm$ 0.4
	Back	1.0 $\pm$ 0.5 (<i>small</i>)	1.1 $\pm$ 0.4 (<i>medium</i>)	1.1 $\pm$ 0.4 (<i>very large</i>)	1.1 $\pm$ 0.7 (<i>small</i>)	1.1 $\pm$ 0.5 (<i>medium</i>)	1.2 $\pm$ 0.6 (<i>medium</i>)	1.1 $\pm$ 0.5 (<i>large</i>)	0.9 $\pm$ 0.7 (<i>trivial</i>)

Note: Data presented as mean $\pm$ SD (effect size). Effect size indicates magnitude of difference between forwards and backs during each time period. Pos. indicates position group forward (Fwd) or back. Q1-4 indicate quartiles for each half, mean duration of each quartile was 12 ± 2 min for backs and forwards. Sprint and acceleration frequency indicate how regularly players exceeded the speed and acceleration thresholds indicated. [#] indicates significant difference from back position group during the same time period, * indicates significant difference from 2nd half Q4.

Figure 8.1 – Relative total (a.), low-intensity (b.) and high-intensity (c.) distance covered by backs and forwards in each quartile of 2 halves of rugby union matches. # indicates significant difference between positions for a match period and * indicates significant difference for backs from 2nd half Q4.

8.3.2 Temporal changes in movement patterns

A number of significant effects of position (back, forward) and match period (1st half Q 1-4, 2nd half Q 1-4) occurred across movement variables, and these are illustrated in figure 8.2a and b, and in table 8.2. Significant effects of position were present for relative distance, maximum speed, low- and high-intensity distance, sprint and acceleration frequency and total and high-intensity impacts.

It was notable that there was that there was a decrease in maximum speed of forwards from 1st half Q1 to 2nd half Q1 ($-10 \pm 13\%$). During the same time period, backs maintained their maximum speed ($4 \pm 2\%$), changing the difference in maximum speed from *medium* to *large* or *very large* for most of the second half. Similar effects were present for sprint and acceleration frequency, where difference between forwards and backs were *small* to *medium* during the early periods of the match, but progressed onward to become *large* to *very large* differences.

There was no statistical difference in the relative distance covered by backs and forwards until the final match period (2nd half Q4), where forwards covered significantly more distance (forwards 69 ± 13 vs. backs 56 ± 10 , ES = *large*). Forwards covered more low-intensity distance than backs during the 2nd half Q2 and Q4 (*large* to *very large* differences) (figure 9.1b). There was a significant difference in high-intensity running distance between backs and forwards in the first period of the second half (forwards 8 ± 4 vs. backs 13 ± 4 m.min⁻¹, ES = *very large*). It was notable that both forwards and backs experienced declines in high-intensity running distance of $\approx 35\%$ over the course of the match, but these declines followed different patterns. Forwards high-intensity running distance declined $23 \pm 15\%$ from Q1 to Q4 during the 1st half, while backs maintained their high-intensity running distance ($-2 \pm 13\%$) during the same period. Thereafter, forwards maintained their high-intensity running distance from 1st half Q4 to 2nd half Q4 ($-7 \pm 25\%$). Backs maintained similar high-intensity running

distances from 1st half Q1 to 2nd half Q3 before a dramatic drop off in the last quartile of the 2nd half ($-35 \pm 51\%$).

A significant effect of position was present for both total and high-intensity impacts, with significant differences between forwards and backs in 1st half Q3 (high-intensity impacts forwards 0.6 ± 0.3 vs. backs $1.1 \pm 0.4 >8 \text{ G.min}^{-1}$, ES = *very large*) and Q4 (total impacts forwards 7.4 ± 2.1 vs. $9.6 \pm 4.8 >5 \text{ G.min}^{-1}$, ES = *medium*). Overall, backs typically exceeded forward measures for both accelerometer measures (*small* to *very large* differences), but no clear time course was apparent for these differences.

No statistically significant effect of match period was observed in any movement category for forwards. Backs demonstrated a reduction in activity levels in the final quartile of the 2nd half, resulting in significant differences from other match periods for total, relative, low- and high-intensity distance.

8.3.3 Effect of substitutes

The difference in movement variables of whole game players in the second half and substitute players is presented in table 8.3. Substitutes spent significantly less time on the field and covered significantly less distance than whole game players. Forward substitutes covered a *small* amount more relative distance than whole game players ($4 \pm 2\%$, ES = *small*) and achieved this by covering significantly more high-intensity distance ($30 \pm 29\%$, ES = *medium*). Forward substitutes also displayed greater sprint ($38 \pm 25\%$, ES = *medium*) and acceleration ($47 \pm 40\%$, ES = *large*) frequency, and were involved in more total ($19 \pm 28\%$, ES = *medium*) and high-intensity ($42 \pm 33\%$, ES = *large*) impacts in the second half than whole game forward players.

In contrast, the appearance of backline substitutes did not have a great effect on the intensity of the game. Back replacements covered significantly less relative

distance ($-7 \pm 9\%$, ES = *large*), as a result of covering a *very large* amount less distance at low intensity ($-9 \pm 10\%$, ES = *very large*), compared to whole game backline players. There were no differences between whole game backline players and substitutes for high-intensity distance, sprint or acceleration frequency. There was a *large* difference in total impacts ($-45 \pm 61\%$, ES = *large*) and a *small* difference in high-intensity impacts ($-17 \pm 60\%$, ES = *small*), with substitutes sustaining fewer impacts than whole game players.

Table 8.3 – Temporal changes in movement patterns during the 2nd half for whole game forwards and forward substitutes.

	Bout	2 nd Half			
		Q1	Q2	Q3	Q4
Time Playing (mins)	WG	12 $\pm$ 2	12 $\pm$ 2	12 $\pm$ 2	12 $\pm$ 2
	Sub	9 $\pm$ 3 [#] (<i>large</i>)	9 $\pm$ 3 [#] (<i>large</i>)	9 $\pm$ 3 [#] (<i>large</i>)	9 $\pm$ 3 [#] (<i>large</i>)
Total Distance (m)	WG	736 $\pm$ 183	801 $\pm$ 175	771 $\pm$ 160	786 $\pm$ 133
	Sub	576 $\pm$ 210 [#] (<i>large</i>)	651 $\pm$ 268 (<i>medium</i>)	598 $\pm$ 261 (<i>large</i>)	577 $\pm$ 225 [#] (<i>large</i>)
Relative Distance (m.min⁻¹)	WG	64 $\pm$ 13	69 $\pm$ 11	67 $\pm$ 11	69 $\pm$ 13
	Sub	67 $\pm$ 23 (<i>trivial</i>)	75 $\pm$ 14 (<i>small</i>)	67 $\pm$ 14 (<i>trivial</i>)	68 $\pm$ 17 (<i>trivial</i>)
Maximum Speed (m.s⁻¹)	WG	6.1 $\pm$ 0.7	6.3 $\pm$ 1.0	6.5 $\pm$ 1.4	6.2 $\pm$ 1.3
	Sub	5.8 $\pm$ 1.4 (<i>small</i>)	6.1 $\pm$ 0.7 (<i>small</i>)	6.1 $\pm$ 1.1 (<i>small</i>)	6.3 $\pm$ 1.7 (<i>trivial</i>)
Low intensity distance <4 m.s⁻¹ (m.min⁻¹)	WG	56 $\pm$ 11	60 $\pm$ 8	57 $\pm$ 10	59 $\pm$ 10
	Sub	55 $\pm$ 16 (<i>trivial</i>)	61 $\pm$ 12 (<i>trivial</i>)	56 $\pm$ 10 (<i>trivial</i>)	56 $\pm$ 13 (<i>small</i>)
High-intensity distance >4 m.s⁻¹ (m.min⁻¹)	WG	8 $\pm$ 4	9 $\pm$ 6	10 $\pm$ 5	9 $\pm$ 7
	Sub	12 $\pm$ 10 (<i>medium</i>)	15 $\pm$ 8 [#] (<i>large</i>)	11 $\pm$ 8 (<i>trivial</i>)	12 $\pm$ 9 (<i>small</i>)

Note: Data presented as mean $\pm$ SD (effect size). Q1-4 indicate quartiles for 2nd half. Bout indicates whole game (WG) or substitute (sub) players. Sprint and acceleration frequency indicate how regularly players exceeded the speed and acceleration thresholds indicated. [#] indicates significant difference between whole game players and substitutes during the same time period.

Table 8.3 continued – Temporal changes in movement patterns during the 2nd half for whole game forwards and forward substitutes.

	Bout	2 nd Half			
		Q1	Q2	Q3	Q4
Sprint frequency (>6 m.s⁻¹)	WG	1 every 33 ± 16 min	1 every 29 ± 24 min	1 every 20 ± 15 min	1 every 16 ± 11 min
	Sub	1 every 10 ± 6 min (<i>medium</i>)	1 every 21 ± 14 min (<i>small</i>)	1 every 22 ± 12 min (<i>trivial</i>)	1 every 16 ± 11 min (<i>small</i>)
Acceleration frequency (>2.75 m.s⁻²)	WG	1 every 13 ± 16 min	1 every 14 ± 12 min	1 every 14 ± 9 min	1 every 9 ± 11 min
	Sub	1 every 6 ± 5 min (<i>medium</i>)	1 every 6 ± 7 min [#] (<i>large</i>)	1 every 6 ± 5 min (<i>medium</i>)	1 every 8 ± 7 min (<i>small</i>)
Total impacts (>5 G.min⁻¹)	WG	8.2 ± 3.7	9.4 ± 4.8	8.2 ± 3.1	8.7 ± 4.0
	Sub	8.7 ± 4.7 (<i>trivial</i>)	12.6 ± 4.0 (<i>medium</i>)	9.8 ± 3.9 (<i>small</i>)	10.4 ± 5.4 (<i>small</i>)
High-intensity impacts (>8 G.min⁻¹)	WG	0.8 ± 0.5	0.8 ± 0.4	0.7 ± 0.4	0.8 ± 0.4
	Sub	0.8 ± 0.4 (<i>trivial</i>)	1.4 ± 0.9 [#] (<i>large</i>)	1.2 ± 0.9 (<i>medium</i>)	1.5 ± 1.2 (<i>large</i>)

Note: Data presented as mean ± SD (effect size). Q1-4 indicate quartiles for 2nd half. Bout indicates whole game (WG) or substitute (sub) players. Sprint and acceleration frequency indicate how regularly players exceeded the speed and acceleration thresholds indicated. [#] indicates significant difference between whole game players and substitutes during the same time period.

The temporal relationship between whole game forwards and forward substitutes was examined and is presented in table 8.3. No main effects of match period were present in any of the movement variables. Quartile length for substitutes was shorter than that of whole game players (whole game 12 ± 2 vs. 9 ± 3 min, ES = *large*), and as a result whole game players covered more total distance in each quartile (ES=*medium* to *large*). There was however, no significant effect of bout (whole game vs. substitute) for relative or low-intensity distance (ES = *trivial* to *small*), indicating a similar total work rate for whole game players and substitutes.

Substitutes set a higher pacing strategy than whole game players for high-intensity distance, with *medium* to *large* differences from whole game players in 2nd half Q1 and Q2. Substitutes covered more high-intensity distance than whole game players throughout, but the magnitude of these differences was reduced in the last two periods of the 2nd half (ES=*trivial* to *small*).

There was a *medium* sized, non-significant difference in sprint frequency in 2nd Q1, which was reduced to *trivial* to *small* differences in subsequent quartiles. Acceleration frequency was higher for substitute players in the first 3 quartiles (Q1-3) of the 2nd half. These results indicate that substitutes are more likely to be involved in sprints and maximal accelerations than whole game players during the initial match periods following substitution.

Substitutes experienced more high-intensity impacts than whole game players during the latter periods of the second half (Q2-4) (ES = *medium* to *large*). Substitutes also tended to experience more overall impacts; this difference was not significant at any stage (ES = *trivial* to *medium*).

8.4 Discussion

8.4.1 Effect of half on player movement patterns

The purpose of this study was to report the effects of match related fatigue on the physical performance of professional rugby union players in different position groups (backs vs. forwards). The main finding of this study was that both backs and forwards decreased the distance covered in the second half by $\approx 10\%$. This change was attributable to a $10 \pm 13\%$ (ES = *large*) decrease in low intensity running distance and a $27 \pm 36\%$ (ES = *medium*) decrease in high-intensity distance across halves for forwards. For backline players, a similar size decrease was present for low intensity running ($-7 \pm 10\%$, ES = *large*) across halves, but a much smaller decrease in high-intensity running was observed ($-10 \pm 8\%$, ES = *small*). Sprint ($-29 \pm 29\%$, ES = *small*) and acceleration frequency ($-27 \pm 32\%$, ES =

medium) were significantly reduced across halves for forwards, but remained consistent for backs (sprint frequency $-13 \pm 7\%$, ES = *small*; acceleration frequency $-5 \pm 15\%$, ES = *trivial*). Reductions in magnitude of accelerations in relation to match period have previously been described in elite rugby union players (Lacome *et al.*, 2013).

These findings are similar to those that have been previously reported in other high-intensity, intermittent running team sports. Soccer (Mohr *et al.*, 2003), Rugby League (Sirotic *et al.*, 2013) and Australian Rules Football (Wisbey *et al.*, 2010) all display similar $\approx 10\%$ reductions in total running distance of players from first to second half. High-intensity running distance is typically reduced by $\approx 20\text{--}30\%$ across halves in these sports (Mohr *et al.*, 2003; Sirotic *et al.*, 2013; Wisbey *et al.*, 2010). Rugby union displays a remarkably similar pacing profile to these other sports when it is considered that the relative distance covered is much less in rugby union ($60\text{--}80\text{m}\cdot\text{min}^{-1}$) (Cahill *et al.*, 2013) than the other sports (soccer $\approx 120\text{ m}\cdot\text{min}^{-1}$, rugby league $109\text{ m}\cdot\text{min}^{-1}$, Australian Rules Football $124\text{m}\cdot\text{min}^{-1}$) (Mohr *et al.*, 2003; Sirotic *et al.*, 2013; Wisbey *et al.*, 2010). An explanation for this phenomenon may be that rugby union players utilize a macro-pacing strategy that reduces running intensity in order to maintain the ability to perform repeated high-intensity contact efforts.

This is the first study on fatigue in rugby union to include position groups as a factor in the analysis of movement patterns during a match. Roberts *et al.* (2008) reported no difference in total distance or high-intensity running distance between match halves for all players. Jones *et al.* (2015) also reported no difference in total, high or low speed distance per half, although there were reductions in cruising ($2.7\text{ to }3.8\text{ m}\cdot\text{s}^{-1}$) and striding ($3.8\text{ to }5.0\text{ m}\cdot\text{s}^{-1}$) distance for all players. The findings of this study show that there were reductions in total running distance between halves in both position groups, and a significant reduction in high-intensity running in the 2nd half for forwards. Furthermore,

these findings suggest that fatigue may manifest differently for players in different positions.

It has been regularly reported that team sport players in different positions display different movement patterns. Despite this, limited evidence is currently available comparing the pacing profiles of high-intensity intermittent team sport players in different positions. Pacing studies have thus far focused on differences in pacing according to playing level or the impact of substitutes or interchange players (Waldron *et al.*, 2014). This studies finding that pacing profiles may differ by position opens up an interesting new line of enquiry for pacing research.

8.4.2 Temporal movement patterns during match play

When each half was divided into quartiles, it was apparent that forwards have a “slow-positive” (Waldron *et al.*, 2014) pacing strategy with regard to total relative and high-intensity running distance. This indicates that forwards start out the match at a high level of running intensity and gradually decline throughout the match. In contrast, the backs displayed a “flat” pacing strategy, maintaining total relative and high-intensity running distance throughout the match until a large drop-off in the final quartile (2nd half 2Q). It is unclear whether the large decrement in movement variables for backs in the final quartile was due to fatigue or pacing. It is likely that the outcome (win/lose) of the match was already apparent in the final quartile and as a result players may have reduced intensity, or team tactics may have changed.

The differing pacing strategies or fatigue profiles of backs and forwards is also apparent in maximum speed, sprint and acceleration frequency variables. Although, backs clearly out perform forwards in these movement categories (Chapter 6), the differences in these movement categories between backs and forwards are *small* to *medium* in the early periods of the game (1st half Q1-2), but become *large* to *very large* during the middle periods (1st half Q3 to 2nd half Q3).

This indicates that the differences in maximum speed, high-intensity running and acceleration ability between forwards and backs becomes more exaggerated as match duration increases. This growing disparity in the physical attributes of players in different positions as match duration increases may explain why more tries are scored in the second half of games (WorldRugby.org, 2015b). This also represents an interesting line of enquiry for other sports, where similar differences in the pacing strategies of players in different positions may be discovered.

8.4.3 The effect of contact on pacing strategies

Investigations into pacing strategies of team sports suggest that when players are exposed to multiple contact efforts, total and high-intensity movement rates cannot be maintained (Johnston *et al.*, 2014b). The findings of this research suggest that for players completing a whole match, forwards experience greater fatigue than backs based on reductions in high-intensity running, maximal speed, sprint and acceleration frequency. This may be because forwards are exposed to a larger number of contact involvements than backs during rugby union match play (Deutsch *et al.*, 2007; Duthie *et al.*, 2005; Roberts *et al.*, 2008).

For backs the rate of overall and high-intensity movement was reduced between halves, but this was the result of a *large* reduction in the final quarter of the 2nd half. Total and high-intensity running distance was essentially maintained for backs throughout the first seven match periods (1st half Q1 to 2nd half Q7). This is in contrast to most team sports where there is a significant reduction in high-intensity running distance in the second half (Higham *et al.*, 2011; Mohr *et al.*, 2003; Sirotic *et al.*, 2009). The relative distance per match for backs in this study ($67 \pm 6 \text{ m}\cdot\text{min}^{-1}$), is lower than that of other team sports ($\approx 110 \text{ m}\cdot\text{min}^{-1}$) (Higham *et al.*, 2011; Mohr *et al.*, 2003; Sirotic *et al.*, 2009), and is perhaps not high enough to elicit a fatigue-related reduction in high-intensity running distance in the absence of large contact demands.

Since contact involvement is such an important factor in determining fatigue, it was hoped that the accelerometer data provided by the GPS units would provide an insight into the contact loads that player's experience. Analysis of accelerometer data indicates that backs experience more total and high-intensity G-forces than forwards. Therefore, referring to these G-forces as impacts is likely incorrect as it is known that forwards experience more physical contacts than backs (Deutsch *et al.*, 2007; Duthie *et al.*, 2005; Roberts *et al.*, 2008) during match play. Since backs sprint and accelerate more frequently than forwards, it is likely that the accelerometer data reported here is reflective of acceleration/deceleration forces of running as well as actual physical collisions. The accelerometer data presented does not explain the difference in fatigue profile between backs and forwards according to the proposed model.

Research in rugby league has shown no relationship between contact events (tackles and hit-ups) and accelerometer measures (McLellan *et al.*, 2012). However, research did show that accelerometer measurements were correlated with decreases in peak rate of force development and peak power for up to 24 h post match (McLellan *et al.*, 2011b). Accelerometer measures were also correlated with elevated creatine kinase concentrations up to 120 h post match (McLellan *et al.*, 2011a). These findings indicate that even though accelerometer measures do not match up with the number of contact events that players are exposed to during rugby union match play, they may be an important indicator of physical load. Measurement of G-forces may provide a perspective on muscle damage as result of acceleration/deceleration during match play.

8.4.4 Substitute movement patterns

The movement patterns of substitute players were examined to determine if they would set a significantly higher pacing strategy based on their shorter time on the field. Forward substitutes had a slightly higher rate of movement than

whole game players in the second half ($4 \pm 2\%$, ES = *small*), due to a *medium* sized difference in high-intensity running distance ($30 \pm 29\%$, ES = *medium*). This effect occurred primarily in the first two quartiles (2nd half Q1 – Q2) of the substitutes inclusion, indicating that substitutes may follow the previously described “one-bout, all-out” pacing strategy (Waldron *et al.*, 2014). The forward substitutes cover as much high-intensity distance as whole game players did in the 1st half of the game (whole game 12 ± 6 vs. sub. 12 ± 6 , ES = *medium*). As such, it seems that the introduction of forward substitutes does not significantly speed up the game, as it does in other team sports (Carling *et al.*, 2010; Higham *et al.*, 2011; Waldron *et al.*, 2014). This may be due to the linear nature of the defence in rugby union that does not allow the freedom of movement that is afforded to substitutes in sports like soccer or Australian Rules football. Where forward substitutes did excel was in the frequency of accelerations ($47 \pm 40\%$, ES = *large*) and high-intensity impacts ($42 \pm 33\%$, ES = *large*). Differences in acceleration frequency between whole game players and substitutes were highest in the early periods on the field (2nd half Q1-3, ES = *medium* to *large*). Differences in high-intensity impacts were greater towards the end of the game (2nd half Q2-4, ES = *medium* to *large*). If substitutes are limited by the presence of the defensive line in terms of the distance that they can run, they may instead expend energy through a greater intensity of acceleration and contact work.

Only 3 back substitute files were available for study and accordingly caution is recommended in interpreting the analysis from such a small sample size. Back substitutes did not improve on whole game players’ intensity in any movement categories.

8.4.5 Practical applications

Activity-related fatigue may be a risk factor for injury in professional rugby union, and as such it is prudent to monitor players on-field to determine if their performance is inhibited by fatigue. The results of this study suggest that

decreased high-intensity running distance and decreased sprint and/or acceleration frequency are indicators of activity-related fatigue. For practitioners hoping to determine fatigue via live monitoring within games, sprint and acceleration frequency would not be sensitive markers of fatigue because they occur too infrequently in forwards (1 every 9 to 20 minutes). This research suggests that measuring high-intensity running distance per minute would be the best, most sensitive measure for determining activity-related fatigue. A suggestion for a practical starting point for investigation would be that any player who does not complete at least 8 m.min⁻¹ high-intensity running within a 10-minute period be judged as fatigued.

Accordingly, if a player displays this change in movement pattern and it cannot be explained by pacing or in-match conditions, substitution should be considered. Recent research suggests that the degree of fatigue experienced by players can be limited by improving physical qualities like high-intensity running ability and lower body strength (Johnston *et al.*, 2014c), improvements in this quality reduce injury risk (Gabbett *et al.*, 2012). This fitness component should be adequately addressed through the player's physical training programme.

It should be noted that while the changes in movement patterns observed in this study have been attributed to player fatigue, there are alternative explanations. Players could alter their pacing strategy within the game based on the match situation or score line. If the outcome of the game was secure, players could reduce running intensity to conserve themselves for the following game, or team tactics could be adjusted to those that require less running. Ambient conditions such as the presence of rain or heat and humidity would also affect pacing. These in-match factors should be taken into account when considering match related fatigue.

8.4.6 Directions for future research

This study provides a departure point for future analysis of fatigue and pacing in rugby union matches, but there are a number of aspects that should be improved upon. Firstly, assessment did not reveal transient fatigue and subsequent reduced performance following the most intense periods of matches. It is likely that, high-intensity bursts and transient fatigue likely account for the high degree of variability around most measurements. A second concern is that there are differences in the physical profiles of players within the back and forward positional groups. Insufficient data were available in this study to assess individual positions, but future research should aim to establish the whole match and transient fatigue profiles of players in individual positions. Finally, this research was conducted on players representing a single team and may only reveal the results of their particular conditioning programme or playing style. Further research should make comparisons across teams at different playing standards to determine how pacing strategies may differ.

8.5 Conclusion

This research provides evidence that rugby union forwards experience decreases in total and high-intensity running, sprint and acceleration frequency in the second half of matches. It is proposed that these changes in movement patterns occur due to activity-related fatigue resulting from running and contact involvements during match play. Backs displayed reductions in low intensity running distance, but were able to maintain high-intensity running distance as well as sprint and acceleration frequency for the majority of the match. This difference in the fatigue profile of backs and forwards may reflect that backs experience a lesser degree of fatigue during match play due to lower running loads and contact involvements. These findings may assist in reducing injuries resulting from activity-related fatigue by providing information for coaches about the symptoms of this fatigue. Early substitution of forwards and the inclusion of additional forward substitutes on the bench are likely effective injury risk

mitigation strategies, and would assist in maintaining the intensity of team performance throughout the 80 minutes of play. These substitutions must be well planned in order to be effective.

CHAPTER 9 – CONCLUSION

9.1 Summary and conclusions

The aim of this thesis was to utilise an existing injury risk management model to positively influence the management of injury and its related risk factors within a professional rugby union team. To lay the foundation for the project, an injury risk assessment was performed on the team. This assessment revealed that the team injury burden was higher than expected for a professional team.

One of the key components of a risk management model is the reporting of risk to the various stakeholders, in this case the players, coaches, strength and conditioning, medical and management staff. Once the stakeholders are aware of the intrinsic risks, they can make decisions about whether those risks are acceptable to the individuals or organisation concerned (Fuller *et al.*, 2012). Following this report, consensus was gained among stakeholders that the injury risk within the organisation was too high, and accordingly the injury risk identification and mitigation processes were initiated.

The risk identification process aimed at identifying injury risk factors that may contribute to the high incidence of injury within the team. A low score in the pre-season FMS test was associated with increased risk of both contact and non-contact injury. Furthermore, both high and low training volumes and high training intensity were established as risk factors for injury.

The risk mitigation process attempted to minimise injury risk through the implementation and assessment of preventative interventions. Perceptual fatigue questions related to sleep quality and wellness showed no relationship with either training volume or injury incidence, and were therefore shown to be inadequate as markers of player fatigue. Counter movement jump tests were

shown to be the test most likely to identify players that had not fully recovered from match play exertions. Range of motion tests did not discriminate fatigued and non-fatigued players, but did show a relationship to injury occurrence and should therefore be performed regularly.

A further aim of the injury mitigation process was to optimise team training. The literature review identified various forms of fatigue as risk factors for injury, and it was felt that improving the specificity of the training process would reduce player fatigue. Training optimisation involved using GPS monitoring devices to determine the actual in-match demands of players in various positions. Training sessions were then monitored using GPS to determine which training activities were the most specific to the match demands of players in different positions. Recommendations were made to improve the specificity of training for players in each positional group.

Further review of literature determined that in-match, activity-related fatigue is a likely risk factor for injury. Therefore, a GPS assessment of matches was conducted to determine how fatigue manifests during match play. The result of this analysis showed that fatigue profiles of backs and forwards are different. Forwards tend to fatigue more rapidly than backs during match play, and early substitution may further mitigate their injury risk.

9.2 Recommendations

The various processes carried out within the application of this injury risk management model and their associated recommendations for action are summarized in table 9.1. In brief, the risk reduction strategy recommended to the rugby team studied consisted of three major interventions –

1. Perform an effective pre-season screening protocol to determine the players at highest risk of injury.
2. Optimise training through improving the specificity of training activities for players in different positions.
3. Monitor training (volumes, intensity, loads, etc.) and player response to training (CMJ, ROM) to ensure that the desired responses are achieved, and that players don't become overly fatigued or develop injury risk factors as a result of training.

Unfortunately, assessment of the effectiveness of this process in ultimately reducing player injury risk was made difficult by a unique and unforeseeable set of circumstances. However, Fuller *et al.* (2012) notes that creating awareness of injury risk and thereafter providing support and guidance to the participants are the key components within the risk management process. A major outcome of this project was the increased awareness of both players and coaching staff regarding the injury problem. Coaching staff critically assessed their strategies and began looking for methods of mitigating risk in all areas of training.

Table 9.1 – Summary of research and associated recommendations for injury risk management

Summary of research	Injury outcome	Intervention/recommendation
Chapter 3 Injury risk assessment – team injury risk was estimated and then evaluated against current literature.	<p>↑ injury incidence.</p> <p>↑ training injury severity.</p> <p>↑ burden of non-contact injury (knee, hamstring, calf).</p> <p>↑ burden of shoulder contact injury.</p>	<p>Examination and evaluation of training methods.</p> <p>Medical staff beside field during training for immediate treatment + better management of training loads.</p> <p>Implementation of evidence prehabilitation programme including eccentric, stability, and agility and jump landing exercises.</p> <p>Increased focus on shoulder strength and stability within the training programme.</p>
Chapter 4 Assessment of FMS as a predictor of severe injury.	FMS ≤ 13 ↑ risk of contact and non-contact injury.	<p>Communicate “high-risk” players to coaches and medical staff to effect player management.</p> <p>+</p> <p>Implement player prehabilitation programme to improve movement patterns (effect on injury risk still to be assessed).</p>
Chapter 5 Assess relationship of training volume and intensity with injury incidence.	<p>High and low training volume ↑ injury incidence.</p> <p>↑ training intensity = ↑ non-contact injury incidence.</p>	<p>Maintain training volume between 8.3 and 9.0 h per week.</p> <p>Requires improved monitoring of training intensity though internal (RPE) our external (GPS) monitoring.</p>
Assessment of perceptual fatigue questions.	Sleep/wellness measures unrelated to training load/injury incidence.	Use a validated questionnaire and improve reporting compliance.
Assess application of readiness to train protocols.	↓ CMJ flight time following match participation for some players.	May be a good indicator of recovery status following match play. Monitor weekly and adjust player-training loads accordingly.

Table 9.1 continued – Summary of research and associated recommendations for injury risk management

Summary of research	Injury outcome	Intervention/recommendation
Chapter 5 cont. Assess application of readiness to train protocols.	↓ sit and reach = ↑ injuries.	Regularly monitor ROM and provide mobility training as necessary. Not related to fatigue following match play.
Chapter 6 Determine typical match exertions using GPS	Large differences in the movement requirements of players in different positions.	Design training programmes to adequately prepare players for actual match demands. + Use to determine if a player has significantly exceeded typical demands and requires additional recovery.
Chapter 7 Comparison of training activities to actual match demands using GPS	Generic rugby training is non-specific for players in different positions.	Design training programmes that are specific to positional demands. + Monitor training using GPS to insure adequate running distances and intensities for match preparation
Chapter 8 Determine fatigue profiles of rugby union players using GPS	Fatigue is demonstrated as a decrease in high-intensity running	Monitor players to determine when significant fatigue has occurred
	Fatigue profile of forwards ≠ backs	Replace forward players sooner due to steeper fatigue profile

9.3 Limitations

When performing research in an applied environment such as high-performance team sport, scientific research design principals are often incompatible with the practicalities of the environment (Bishop, 2008). However, there is value in testing sport science theory and approaches *in vivo* in genuine high-performance environments. In elite environments, the methodological designs may be more variable, and implementation may contain greater error variance or sources of bias, than under controlled conditions, but results obtained are likely to be more relevant and more likely to be adopted by sport-science practitioners (Bishop, 2008). Bishop (2008) notes that sport scientists should seek to embrace and study the complexity of the sporting world, rather than attempting to ignore or reduce it by studying only isolated situations.

With these considerations in mind, a pre-post study design to assess the effectiveness of the application of the injury risk management model, or any of its associated interventions, was not possible in this study. Changing circumstances between the two seasons that were the result of the highly dynamic nature of professional sport lead to a number of key problems in cross season comparisons. The main problems were -

- Different competitions in 2012 and 2013 (Super 15 vs. alternative) that were probably not of the same competitive standard.
- Change in both the head coach and strength and conditioning coach between seasons meant that there were changes in playing philosophy tactics and style, and differences in the approach to practice and to physical conditioning of players.
- Changes in playing staff (43%) across the two seasons resulted in significant differences in playing experience of the total player group across seasons.

An additional limitation of this study was that it only examined one team, with multiple measures performed on the same players. As a result, some of the results reflected here will be accounted for by individual player abilities, and others by team tactics, playing style and prevailing playing conditions. To make these results more generalisable, a larger sample consisting of players from multiple teams would be required.

A further limitation of this research design was the absence of an adequate control group. This is a common problem in research involving elite sports (Page, 2012). It would be unethical to provide injury management support to one group of participants within the team, and not to others (Page, 2012). Due to the applied nature of this research, a number of experimental factors could not be controlled leading to reduced internal validity of the research. However this reduced internal validity is counterbalanced by the improved external validity that is a product of real-world generalisability (Page, 2012).

9.4 Practical applications

Bishop (2008) notes that to have an influence on performance at the highest level, more sport science experiments need to take place in “real-world” rather than laboratory settings. Researchers need to take cognizance of issues that effect the implementation of research ideas into a team’s training programme. Research will improve sporting performance only if the findings of research are accepted, adopted and complied with by athletes, coaches and staff (Bishop, 2008).

To this end, this research project was largely successful! While the effect of the interventions was difficult to quantitatively and empirically assess, many interventions were adopted by the coaching and playing staff following their own subjective, qualitative assessment of the results. The most notable changes to team practices with regard to injury risk management are listed below.

1. The team has adopted a pre-season screening strategy to determine which players are at the greatest risk of injury. These players are now placed on supervised prehabilitative programmes to attempt to address the movement dysfunctions that may affect their injury risk. In certain circumstances this screen also affects player management strategies where “at-risk” players are more frequently rested, or provided additional recovery time between games.
2. Weekly training volume and training intensity were demonstrated to be risk factors for match injury. As a result, coaching staff now monitors weekly training volume and aim to maintain this within the recommended range of 8.3-9.0 h per week.
3. It was determined that the team’s previous method of monitoring response to training, through questions related to sleep quality and wellness, were ineffective and has been disregarded. This has created more time for medical and strength and conditioning staff to explore other avenues of athlete management.
4. Weekly Monday morning CMJ testing has been adopted to determine which players are not fully recovered from matches. These players are required to perform additional recovery actions and in consultation with the coaches and medical staff may be given additional rest time to facilitate recovery.
5. Transiently reduced ROM was identified as a risk factor for injury, and weekly ROM tests were implemented to determine players at risk. At risk players are supervised through mobility training exercises to restore ROM to baseline levels
6. GPS investigation determined that there were large differences in the match running requirements of players in different positions, and that these differences were not being adequately addressed by the training activities that are routinely used. This assessment provided advisement to

the strength and conditioning coach about how his training programme could be made more specific for players in different positions.

7. GPS investigation also demonstrated that the fatigue profile of backs and forwards is different with forwards fatiguing more rapidly during match play. Since activity-related fatigue during match play is a risk factor for injury this suggests that where possible forwards should be substituted sooner than backs and may affect how many forwards/backs substitutes coaches select on their bench.

9.4 Directions for future research

A major aim for future research following on from this research project will be to qualitatively assess the impact of various risk mitigation interventions. In particular, while the FMS test has been shown to be predictive of injury, research is required to determine whether a positive change in FMS score also results in a reduction in injury risk for the player concerned. A further aim for future research is to refine the collection of session-RPE data. A better quality session-RPE data set may allow for improved modelling to predict injury risk based on training loads. A longer period of GPS data collection with a greater number of GPS units available will allow for the assessment of movement patterns for all 15 individual positions, rather than for positional groups. This will give greater insight into the variability of performance for professional players and allow for even more specific recommendations in terms of training activities. A final direction for future research will be the improved assessment and quantification of contact loads for rugby union players. While it is accepted that the presence of physical contact rapidly increases the accumulation of player fatigue, advances in GPS system monitoring and the combination of GPS and video analysis will allow for improved understanding of this complex relationship.

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APPENDICES

1. INFORMATION SHEET

Dear Participant,

You have been invited to participate in a research project conducted by the University of Johannesburg's Department of Sport and Movement Studies. This research study will investigate methods of monitoring training loads and reducing injury in professional rugby union players. It is hoped that this study will assist your trainers and medical staff to improve your training and reduce the number of injuries sustained. This research will involve monitoring you over the course of the 2012 and 2013 rugby seasons, including your pre-season training.

All tests and procedures will be explained to you prior to the commencement of the tests. You are encouraged to ask any questions regarding the testing as well as to disclose any information that you feel the tester needs to know. Your participation in this research project is completely voluntary, and you may withdraw from the project at any time without any prejudice.

Conditions of participation

In order to participate in this research project will be required to do the following:

1. Wear a GPSports GPS monitor during all training sessions and matches.
2. Report your rating of perceived exertion (RPE) score to a member of the training staff 30 minutes after every training session or match.
3. Consent to having your injury data collected by Dr. Collins used for the purposes of this research.
4. Consent to having your physical data which has already been collected by the training staff used for the purposes of this research. The physical data

includes your age, playing position, height, weight, skinfolds, 1RM bench press, 1RM squat, Coopers run test scores and the results of your Functional Movement Skills (FMS) assessment.

Possible Risks – Your participation in rugby union carries with it an intrinsic risk of injury due to the physical contact that is a part of the game. This is an observational study, so you will not be asked to participate in any activities other than your normal rugby participation, and as such you will not be placed at any additional risk. The only change to your regular routine will be the requirement to wear a small (48mm x 20mm x 87mm) GPS monitor in the center of their back between their shoulder blades. You may experience mild discomfort due to the need to wear the garment and monitor. There is a risk that if you experience contact directly on the point of the GPS monitor, that it could result in injury, but since the vast majority of contact that occurs in rugby union is face to face or side on, this type of injury is unlikely.

Possible Benefits – The information provided by this research study will assist your coaches and trainers to by improve training practices, improving player management, and reduce your risk of injury.

Privacy, Confidentiality and Liability

All data generated for this study will be stored in a computer database in a secure facility, and in a manner that maintains your confidentiality. All results will be reported as group averages, no individual results will be revealed. All participants will remain anonymous in any ensuing publication.

Contact Information

Investigator Name	Telephone	Email
Jason Tee	082 300 9290	jasonctee@gmail.com
Supervisor Name	Telephone	Email
Yoga Coopoo	083 415 7466	yogac@uj.ac.za

Thank you for your participation in this research,

Regards,

Jason Tee

Project Co-coordinator

2. INFORMED CONSENT FORM

Dear Participant,

You have been invited to participate in a research project conducted by the University of Johannesburg's Department of Sport and Movement Studies. This research study will investigate methods of monitoring training loads and reducing injury in professional rugby union players. It is hoped that this study will assist your trainers and medical staff to improve your training and reduce the number of injuries sustained. This research will involve monitoring you over the course of the 2012 and 2013 Rugby seasons, including your pre-season training.

All tests and procedures will be explained to you prior to the commencement of the tests. You are encouraged to ask any questions regarding the testing as well as to disclose any information that you feel the tester needs to know.

Conditions of participation

In order to participate in this research project will be required to do the following:

1. Wear a GPSports GPS monitor during selected training sessions and matches.
2. Report your rating of perceived exertion (RPE) score to a member of the training staff 30 minutes after every training session or match.
3. Consent to having your injury data collected by Dr. Collins used for the purposes of this research.
4. Consent to having your physical data that has already been collected by the training staff used for the purposes of this research. The physical data includes your age, playing position, height, weight, skinfolds, 1RM bench press, 1RM squat, Coopers run test scores and the results of your Functional Movement Skills (FMS) assessment.

Freedom of consent:

"I have read and understood the above information. I understand the procedures and have had an opportunity to ask questions. I consent to participate in this test voluntarily and understand that I am free to withdraw from the research project at any point should I desire."

Name & Surname:

ID Number:

Signature:

Date:

3. ETHICAL APPROVAL FOR STUDY

FACULTY OF HEALTH SCIENCES

ACADEMIC ETHICS COMMITTEE

2 May 2012

TO WHOM IT MAY CONCERN:

STUDENT: TEE, JC
STUDENT NUMBER: 920204725

TITLE OF RESEARCH PROJECT: GPS Analysis of Elite Rugby Union Players – Implications for screening, modelling training and injury prevention

DEPARTMENT OR PROGRAMME: D.PHIL : Sport & Movement Studies

SUPERVISOR: Prof Y Coopoo CO-SUPERVISOR: Prof M Lambert

The Faculty Academic Ethics Committee has scrutinised your research proposal and confirm that it complies with the approved ethical standards of the Faculty of Health Sciences; University of Johannesburg.

The proposal has been awarded a Code 02 – Approved with suggestions without re-submission. The attached recommendations were made by the Committee which will add value to your proposal.

Please make these amendments to the satisfaction of your supervisor/s and submit a corrected copy of the proposal to the Faculty Research Administrator *after which your clearance number will be issued.*

The AEC would like to extend their best wishes to you with your postgraduate studies.

Yours sincerely,

Dr R Razlog (Acting)
Chair : Faculty of Health Sciences AEC

4. TURNITIN REPORT

8/30/2015

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5. EDITOR DECLARATION

DECLARATION OF EDITING AND PROOFREADING OF A DOCTORAL THESIS BY A THIRD PARTY

Name of candidate: Jason Cameron Tee
Student No.: 920204725

Degree: PhD (Sport Science)

Title of thesis: Injury risk management in professional rugby players: Applications of GPS technology. Functional movement screening and perceptual fatigue measures

Name of supervisor: Yoga Coopoo

Name of Co-supervisor: Mike Lambert

Name of editor/proof reader: Monique Clare Wessels

Qualification: Bachelor of Education, majoring in English FET Phase
(University of Johannesburg, 2011)

DECLARATION BY EDITOR/PROOF READER

I, Monique Clare Wessels, hereby certify that the thesis by the candidate, Jason Cameron Tee, has been thoroughly and meticulously edited and proofread to the best of my ability. These edits have been made in accordance to the guidelines as stipulated in the University of Johannesburg's **"Postgraduate Research Information Booklet 2015"**. The editorial intervention was restricted to language, grammar, syntax, completeness and consistency although the editions did not alter content, structure or contribute to the thesis.

Signature: Date: 31/Aug/2015