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PHD

Epidemiology and Risk Factors for Injury and Illness in Male Professional Rugby Union

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Award date:
2016

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Epidemiology and Risk Factors for Injury and Illness in Male Professional Rugby Union

Matthew Cross

A thesis submitted for the degree of Doctor of Philosophy

University of Bath

Department for Health

Submitted: January 2016

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ABSTRACT

This thesis investigates the epidemiology and risk factors for injury in professional Rugby Union with a view to informing injury reduction strategies. Over the last decade, concussion has rapidly become the principal player welfare issue faced by collision sports. Chapter 3 highlights the high and rising incidence of concussion in the professional game and suggests some possible reasons for the changing landscape regarding the reporting of concussion in professional Rugby Union. Given this high incidence, the findings from this study reinforce the importance of further understanding concerning the safe return to play following concussion. Therefore, chapter 4 explores the short and medium term clinical outcomes and return to play of players following a concussion. Players who reported a concussion had a 60% increase in injury risk following return to play when compared with players who did not sustain a concussion. Additionally, 38% of players reported a recurrence of symptoms or failed to match their baseline neurocognitive test score during the return to play protocol. Together, these findings highlight the need to explore an alternative (either a more conservative or different rehabilitation model) return to play pathway. Another prominent player welfare issue in elite Rugby Union is the management of match and training load. Chapter 5 of this thesis was the first study to investigate the training load-injury relationship in professional Rugby Union. Players had an increased risk of injury if they had high one-week cumulative or large week-to-week changes in load. Furthermore, a ‘U-shaped’ relationship was observed for four-week cumulative loads, with an apparent increase in risk associated with lower/higher loads and intermediate loads appeared beneficial in reducing injury risk in this setting. Finally, it has been suggested that the impact of illness on an athlete’s ability to participate can be as significant as that of injury. Chapter 6 provides the first study to investigate the epidemiology of time-loss illness in English professional Rugby Union. Although the burden of illness is significantly less than injury, the high severity and seasonal clustering of illness in this cohort clearly highlights the need for the continued surveillance of illness in this setting. Despite rugby being a collision sport with a primary focus on conditioning and performance, this research programme clearly highlights the potential for modifying existing practice in order to reduce injury risk. Conversely, injuries such as concussion are difficult to prevent without substantial law change, making the practical recommendations put forward in this thesis with reference to possible improvements in the management of players following concussion vital to consider.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks and gratitude to the following people who, without their support over the last three and a half years, the completion of this thesis would not have been possible.

Firstly I would like to thank my supervisors Dr. Keith Stokes and Dr. Grant Trewartha for their expert guidance, support and tuition throughout my time working on my PhD. Importantly, Keith allowed me to make my own successes and mistakes throughout this research journey whilst expertly steering me in the right direction when required.

I would like to thank Dr. Simon Kemp for his help and guidance as my external advisor. I would also like to thank those members of the RFU injury surveillance steering group for their valued comments.

I would like to thank all the medical and strength and conditioning staff from the following clubs for helping to facilitate the collection of injury and exposure data and also for their honest feedback throughout the various projects; Bath, Exeter, Leicester, Gloucester, Newcastle, Saracens, Harlequins, Worcester, Northampton, Sale, London Welsh, London Irish and London Wasps.

I would like to thank my colleagues in the Rugby Science research group and also many others based at the university that have helped and supported me in many facets of this work.

Finally, I would like to thank my family for giving me the ambition to pursue this body of work and for giving me the desire to always want to better myself. I would like to give special mention to my mum and dad for all their support and love during this time but also throughout my life. To my wife Catrin and my son Henry, you are everything, thank you for putting up with me during this time and for giving me the support to enable me to achieve my dreams.

I would like to dedicate this work to my Nan who sadly passed away before the completion of this thesis. I know that you would have been proud of me, rest in peace.

LIST OF PUBLICATIONS AND PRESENTATIONS

Published papers

- Cross M, Kemp S, Smith A, Trewartha G & Stokes K. **Professional Rugby Union players have a 60% greater risk of time-loss injury after concussion: A 2-season prospective study of clinical outcomes.** *British Journal of Sports Medicine*, 2015.
- Cross M, Williams S, Trewartha G, Kemp S & Stokes K. **The influence of in-season training loads on injury risk in professional Rugby Union.** *International Journal of Sports Physiology and Performance*, 2015.

Conference poster presentations

- Cross M, Trewartha G, Williams S, Kemp S & Stokes K. **The epidemiology of concussion in elite Rugby Union players.** Presented at: *The 18th congress of the European College of Sport Sciences (ECSS)*, Barcelona, 2013.
- Cross M, Kemp S, Smith A, Trewartha G & Stokes K. **Injury risk after returning from concussion in elite Rugby Union players.** Presented at: *The 8th World Congress on Science and Football*, Copenhagen, 2015.

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STATEMENT OF CONTRIBUTION

I confirm that this thesis presents my own original research, independent thinking and scientific reporting. I managed and co-ordinated the data collection process for all of the studies contained in this thesis and subsequently, I planned and conducted all of the analyses presented herein. In addition, I also carried out the drafting process for all of the work presented in this thesis upon which, my supervisors Dr. Keith Stokes and Dr. Grant Trewartha provided comment throughout. In addition, Dr Sean Williams (chapter 3 and 5), Dr Simon Kemp (chapters 4 & 5) and Dr Andy Smith (chapter 4) provided further comment on the manuscript versions of the studies that have been accepted or are currently in preparation for peer-reviewed journals.

Chapters 4 and 5 of this thesis have already been published by peer-reviewed journals. I can confirm that I was responsible for the conception of both of these studies and that I was responsible for the data analysis, interpretation and the preparation of each manuscript for submission. All other authors provided invaluable comment and important contributions towards the final presentation of both manuscripts.

CHAPTER 1: Introduction

1.1 Research Overview

Rugby Union was first played in 1823, and is now one of the most played and watched sports in the world. Global participation numbers across all forms of the game are currently thought to be in excess of 7.2 million (World Rugby, 2015b), with participation increasing annually at a rate of around 19% since 2007 (Williams et al., 2013). The hosting of the Rugby World Cup 2015 in England and the return of ‘Rugby Sevens’ (abbreviated form of 15-a-side rugby union) to the Olympic Games in 2016 is likely to further stimulate growth in participation and spectators at all levels of the game.

Participation in any sport always carries some level of inherent risk (Fuller and Drawer, 2004), and in the majority of sports the level of associated risk is usually high in comparison to everyday activity (Fuller, 2007). Rugby Union is a high-intensity collision sport that requires the development of a multitude of generic and position specific skills (e.g. running, passing, tackling, rucking, mauling, scrummaging and kicking) in order to fully participate in accordance with the laws of the game (Cahill et al., 2013). Rugby Union is physically demanding, with frequent bouts of high-intensity activity interspersed with contact events and short bouts of low intensity effort (Austin et al., 2011b, Duthie et al., 2003, Roberts et al., 2008). Therefore, perhaps unsurprisingly, the incidence of injury in the professional game is thought to be amongst the highest of any team sport (Williams et al., 2013). Current evidence suggests that the incidence of injury observed in other levels of play, for example; schoolboy (Palmer-Green et al., 2013), women’s (Schick et al., 2008) and men’s amateur (Roberts et al., 2013) are noticeably lower. However, in general, there is a shortage of high quality surveillance systems in place for amateur and community settings across a number of sports (Ekegren et al., 2015) and therefore any comparisons should, on the whole, be made cautiously. The professional and amateur settings provide different research challenges but the lack of financial resource and appropriately qualified medical personnel at the community level of play likely impact the quality and quantity of available data in this setting (Ekegren et al., 2015). At the elite end of the participation spectrum, there is some evidence (the limitations of both these studies with respect to sample size should be noted) to suggest that an increase in the risk of injury coincided with the advent of professionalism in 1995 (Bathgate et al., 2002, Garraway et al., 2000). This observed rise in the incidence of injury coincided with major changes to the governance of the game (such as law amendments introduced in 1997 regarding the increase in the number of replacements allowed to seven and the introduction of tactical replacements that could be used at coaches’ discretion; Quarrie and Hopkins, 2007) and also, the introduction

of full-time training practice. It is probable that changes to the governance of the game and the frequency of training resulted in marked changes to the nature and speed of the game (Quarrie and Hopkins, 2007) and players' physical characteristics (Sedeaud et al., 2012a). In addition, increases in the reliance and quality of sport science support since the start of the professional era is clear. Given the finding that the post-professionalism incidence of injury was significantly different to that in the pre-professional era (Bathgate et al., 2002), it would suggest either a) more focus was placed initially upon improving an individual's performance and physical characteristics rather than preventing injury, which ultimately had a deleterious effect on player welfare or, b) that players were not suitably conditioned to meet the demands of full time training and competition.

Rugby Union has come under increasing scrutiny from the media with regards to a number of player welfare issues (Peters, 2014) and moreover, whether the level of risk of partaking in Rugby Union has been fully disclosed and appropriately understood by those that regularly participate in the sport (Bull, 2013). This point is pertinent as, unlike high risk jobs in industry, there are no defined values for acceptable levels of risk in sport; what is deemed as acceptable often depends on the perceptions of the participants involved (Fuller and Drawer, 2004). Ultimately, in the professional game, each player is an employee of their club and thus, there is a clear importance for governing bodies and professional rugby organisations to be able to demonstrate that they have identified potential risk factors within the sport and have taken appropriate measures to try and mitigate exposure to these risks by introducing appropriate interventions (Fuller and Drawer, 2004).

One way in which governing bodies can begin to make evidence-based decisions about the level of injury risk in a particular sport is to commission a comprehensive injury surveillance system. (Finch, 2006, Fuller and Drawer, 2004, Fuller, 2007, van Mechelen et al., 1992). The Rugby Football Union (RFU) first commissioned the RFU English Professional Rugby Union Injury Surveillance Project in 2002 and it is the world's largest study of professional Rugby Union injuries and training practises. The Rugby surveillance project is also one of the most transparent globally, a publically released annual report highlights the incidence, severity and nature of injuries in the English Premiership (the highest level of club Rugby Union in England) and also the England senior and 7s teams. Whilst the aforementioned increase in injury incidence since the advent of professionalism in 1995 is on the whole, accepted, the annual injury report released by the RFU suggests that the overall risk of injury during match and training in the English Premiership have remained stable since 2002 (Rugby Football Union, 2015), suggesting no increase in injury risk over the last decade or more. Although the overall risk of match and training injuries

appears to be stable, the reported incidence of specific types of injury are likely to continue to change over time. It is probable that these changes are 'masked' when the overall mean injury rates are considered as a single entity, making investigations into specific types of injury important.

Undoubtedly the most topical player welfare issue of the modern era (from both a sports medicine and contact sport perspective) is concussion. The most high profile example of this concern was observed when the National Football League (NFL) were ordered to pay out £490 million (the sum has since been amended to an unlimited amount) in compensation after being found to have been negligent in providing full disclosure of the long-term health risks following concussive injury in American Football. Recently, the incidence and management of concussion in Rugby Union has received particular attention (Raftery, 2013) with previous studies showing that concussion is a common occurrence in professional Rugby Union (Fuller et al., 2015, Kemp et al., 2008). Each professional match gives rise to approximately 450 contact events (Fuller et al., 2007a) with each of these individual contact events theoretically having the potential to cause a concussive event. Therefore, research focusing on improving the understanding of concussion and associated risks is clearly of paramount importance in this setting.

Return-to-play decisions about concussion seemingly generate more debate than all other sports injuries combined (Kaye and McCrory, 2012), especially in collision sports. Arguably, the most widely adopted frame work for return to play after concussion has been provided within the international concussion consensus statement however, the limited evidence base for informing the content of these guidelines has been acknowledged (Broglia et al., 2015a). It has been recently suggested that premature return to play from concussion may increase the risk of long-term neurological consequences (Gardner et al., 2013, McKee et al., 2013) but it is also important to recognise that, in addition, little is known about the short and medium term clinical outcomes for a player following return to play from concussion. Further research in this area is clearly fundamental in order to be able to inform the decision making process regarding the return to play paradigm following concussion in professional sport.

In addition to investigating the level of risk and subsequent management of certain injuries, it is equally important to try and understand specific risk factors for injury in order to prevent them. Indeed, it has been suggested that the majority of sports injury research fails to move beyond collecting information regarding the aetiology and mechanisms of injury (Finch, 2006). The most important factor for practitioners once any relationship between an individual risk factor and injury risk has been established is being able to have the

knowledge and ability to modify that risk factor in order to reduce or even prevent injury. A player or team's training load has been previously suggested as one possible modifiable risk factor for injury within Rugby Union (Brooks et al., 2006), however, the training load-injury relationship in Rugby Union currently remains unknown. It is widely recognised that the planning and implementation of appropriate training load (intensity x duration) in order to balance the risk of injury (cost) with improvements in performance (benefit) is a difficult challenge for coaches. Anecdotally, it is believed that players are training for longer and are working harder throughout the season but despite this, only a small number of studies have looked at the relationship between training volume (duration) and injury incidence within Rugby Union (Brooks et al., 2006, Brooks et al., 2008, Viljoen et al., 2009) and no studies have looked at the association between training load and injury risk. Without this information it is not possible to say with any level of certainty how a player's weekly load, accumulation of load and changes in load across a competitive season modulates the risk of injury (Gabbett, 2010).

It is often overlooked that both injury and illness surveillance play an integral part in the protection of athlete health (Junge et al., 2008) and that the impact of illness on an athlete's ability to train and compete can be just as significant as that of an injury (Engebretsen et al., 2013). Therefore, data pertaining to the epidemiology of both injury and illness is fundamental in order to better our understanding regarding the short and long-term risks of participation in a particular sport (Steffen et al., 2011). Given the potential burden from illness, the last five years have seen a greater emphasis on the collection of illness data at major sporting events and tournaments (Dvorak et al., 2011, Engebretsen et al., 2013, Engebretsen et al., 2010). These data are an important first step towards understanding the burden of illness in a sporting context, although, one of the limitations of this approach is that tournaments and events only provide a 'snapshot' of information regarding illness burden. It is therefore important to extend illness epidemiology studies in order to collect data over a longer timescale. Rugby Union is a physiologically demanding sport (Roberts et al., 2008) and it has been suggested that training consistently under physiological stress in any sport may indirectly render players more susceptible to illness (Budgett, 1998). Despite this assertion, there is a paucity of research concerning the epidemiology of illness in professional Rugby Union with only three previous studies explicitly investigating the incidence of illness amongst professional players (Cunniffe et al., 2011, Schwellnus et al., 2012a, Schwellnus et al., 2012b). Thus far, no study has investigated the incidence of time-loss illness over multiple or longer seasons of competition or in a competition where the majority of matches are solely contested in one country. Consequently, the impact of illness upon player welfare remains unclear in this cohort. In addition, no studies have

reported the severity of time-loss illness in professional Rugby Union. Information of this type may help to improve team planning and resource management specifically related to the number of appropriate medical personnel that need to be employed based on the clinical requirements of the team. Moreover, research of this nature may provide new insight into the relative burden of player days lost as a consequence of illness compared with injury.

Overall, this thesis investigates the epidemiology and risk factors for injury in professional Rugby Union with a view to informing injury reduction strategies. In doing so, novel research questions are posed that will be of interest to clinicians, coaches, players and governing bodies. It is also important to recognise that the impact that an injury or illness has upon an individual or team can potentially be wide-ranging and enduring. For example, injuries sustained during a career can have a long-lasting effect upon a player from both a catastrophic and degenerative sense (Webborn, 2012). The potential risk of the latter has been highlighted recently in professional Rugby Union amongst front row forwards (Trewartha et al., 2015). In addition, there is also a financial consequence of injury in sport, such as the wages of the injured player, the cost of treatment to the player, and the cost of reduced performance in the player's absence (Drawer, 2001), all of which are applicable in a professional Rugby Union setting. Furthermore, player durability is an often under recognised facet of team success (Orchard, 2009) and recent work in professional Rugby Union has found an association between injury burden and team success (Williams, 2015b) thus, this research will also have the potential to impact upon team performance. Specifically, the findings of this research will give evidence based guidance to medical practitioners and coaches on concussion management and training periodisation, where the current evidence is limited in this setting.

1.2 Research Questions

- What is the current incidence and time to return to play following concussion in professional Rugby Union and has this changed during the period 2011-15 when compared with previously reported data from 2002-11?
- Are players who report a concussion at an increased risk of subsequent time-loss injury?
- What is the time course of symptom resolution, balance impairment and cognitive deficit after concussion and do specific clinical features predict a prolonged recovery time?

- Is there an association between specific training load measures and injury risk in professional Rugby Union?
- What are the prevalence, incidence, severity and overall burden of time-loss illness and what type of illnesses occur amongst professional Rugby Union players in England?

1.3 Chapter Organisation

Chapter 2: Literature Review

This chapter provides insight and context for the basis of this thesis using key extant literature in the area of injury epidemiology, particularly within Rugby Union. It aims to outline the key considerations related to the main methodological parameters in this field such as the apposite theoretical models and the common issues faced by researchers. Injury epidemiology data and risk factors for injury are then presented from a variety of contact and collision sports but specifically for Rugby Union. Latterly, an overview of the literature pertinent to the three key experimental areas across the four chapters is provided, namely, concussion injury, concussion management, training load as a modifiable risk factor for injury and illness epidemiology.

Chapter 3: The changing profile of match concussions in Professional Rugby Union

The aim of this chapter was to investigate and subsequently provide updated incidence and severity figures for reported match concussions that could be compared with previously reported values. The events associated with concussion and the time to return to play following concussion in professional Rugby Union players were also explored. Primarily, these longitudinal data provide the first description of how the reporting of concussive injury (with respect to all injuries) and player's adherence to best practice concussion return to play guidelines have changed over time.

Chapter 4: A prospective study of the short and medium term clinical outcomes and subsequent injury risk following concussive injuries in professional Rugby Union

The purpose of this chapter was to build upon the findings from chapter 3 in order to provide useful clinical information for improving player management in the acute phase following a concussion. The primary aim of this chapter was to ascertain if concussive injury was associated with an increased risk of subsequent time-loss injury (of any type) following return to play when compared with players who did not report a concussion during the season. In addition, this chapter also describes the pathway of clinical and cognitive recovery in professional Rugby Union players and establishes whether certain clinical features were associated with a protracted clinical recovery following concussion.

Chapter 5: The Influence of In Season Training Loads on Injury Risk in Professional Rugby Union Players.

The aim of this chapter was to determine the association between training load and injury risk in professional Rugby Union and how this relationship is moderated by load accumulation, weekly changes in load, training monotony and training strain. The chapter aims to move away from understanding the size of the injury problem to exploring a modifiable risk factor for injury in this setting.

Chapter 6: The Epidemiology of Illness in Professional Rugby Union

This chapter aimed to describe the prevalence, incidence, severity and overall burden of time-loss illness and to highlight the type of illnesses that occur amongst professional Rugby Union players. Currently, the impact of illness on player availability and clinical provision is unknown in this population. An understanding of the association between participation and the risk of both injury and illness in this specific setting is fundamental for evidence-based decision making following which, illness risk monitoring and subsequent management strategies explicitly targeted towards illness prevention can be established.

Chapter 7: General Discussion and Conclusions.

This chapter reinforces the key outcomes of the research thesis and synthesises the key findings from each chapter. This chapter also provides further discussion about the translation of this research into practice and the generalisability of this research into other settings. Importantly, an auxiliary discussion that outlines how the research in this thesis has already had an impact on player welfare, education and policy in Rugby Union is also included. Furthermore, the overall strengths and limitations of this methodological approach are discussed and the potential directions for future research based on this novel work are suggested.

CHAPTER 2: Literature Review

2.1 INJURY EPIDEMIOLOGY: THEORY AND CHALLENGES

'Injuries occur when energy is transferred to the body in amounts or rates that exceed the threshold for human tissue damage' (Baker et al., 1984).

In order to fully understand the risk of sustaining an injury in a specific context, epidemiological research should be conducted (van Mechelen et al., 1992). Research of this nature provides valuable evidence regarding the patterns and trends of injuries within a specific sporting context and also provides the reference point from which causation and effective injury interventions can be implemented (van Mechelen et al., 1992). In the most effective scenarios, injury surveillance data provides the framework from which an athlete's risk of injury can be derived and consequently reduced. In 1992, Van Mechelen published a seminal 4 stage sequence of prevention model that was the first to try and provide an applied framework that would provide a foundation from which the risk of injury could be studied and where possible, prevented (figure 2.1). Van Mechelen stated that the success of the sequence of prevention was dependent upon reliable, sport specific injury surveillance systems. In essence, injury surveillance data should provide the evidence and direction for all future injury prevention strategies (van Mechelen, 1997),

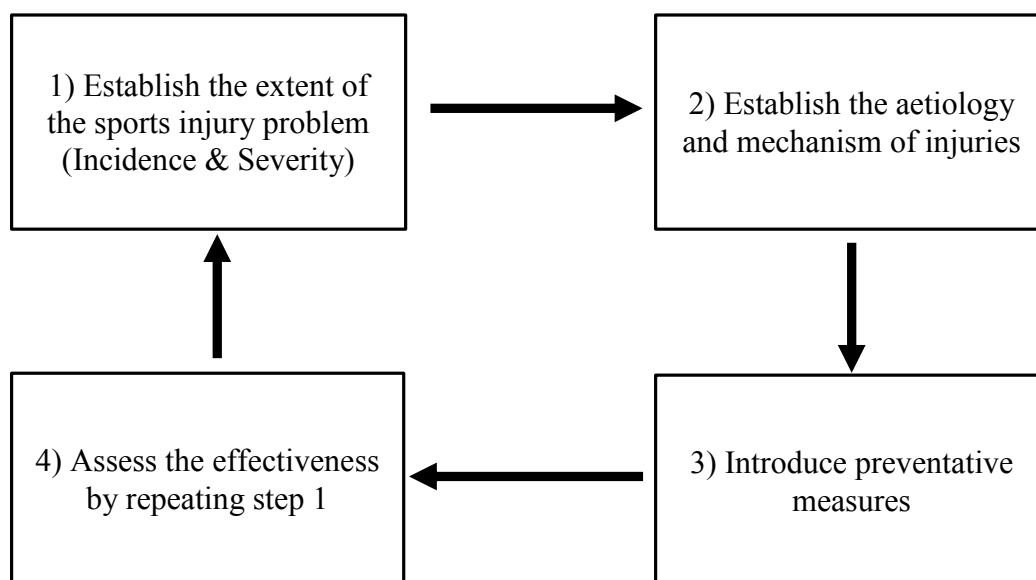


Figure 2.1: The 'sequence of prevention' of sports injuries (van Mechelen et al., 1992)

Whilst the original contribution of this injury prevention model in directing previous research in this field is noteworthy and well recognised, some limitations of its application into a modern sporting setting have also been suggested. Primarily, these are two-fold; a)

the model does not consider what happens once injury prevention strategies have been put in place and b) The model does not take into account the non-linear nature of sports injury. In addition to these applied limitations, it should also be noted that from a theoretical perspective the model does not consider the need to understand and identify risk factors for injury, a critical factor for planning effective and targeted injury prevention strategies (Donaldson et al., 2016). In an effort to address the aforementioned applied limitations, Finch and colleagues suggested a 6 stage, Translating Research into Injury Prevention Practice (TRIPP) model that includes modifications that allow for the assessment and application of applied interventions and the determination of the factors that influence safety behaviour in the sporting context (table 2.1).

Table 2.1: The 6 stages of the TRIPP model (Finch, 2006)

Stage	TRIPP
1	Injury surveillance
2	Establish aetiology and mechanisms of injury
3	Develop preventive measures
4	"Ideal conditions"/scientific evaluation
5	Describe intervention context to inform implementation strategies
6	Evaluate effectiveness of preventive measures in implementation context

The identification of specific and modifiable risk factors allows coaches and practitioners to make modifications to their practice in order to reduce the risk of injury (Kolt, 2013). Moreover, if an injury does occur, it allows practitioners to get players back to full fitness quicker by informing a decision based return to play model (e.g. Creighton et al., 2010; figure 2.2). In addition, complex multi-factorial injury prevention models have been developed to better understand the relationship between injury and risk factors for injury in a non-linear context (Gissane et al., 2001, Meeuwisse et al., 2007). The first cyclical model to question the original linear paradigm was the operational model suggested by Gissane et al. (2001) who suggested an interaction effect was present between intrinsic and extrinsic risk factors that determines the injury susceptibility of the athlete at a given time. In other words, the risk of injury is a consequence of how an athlete's intrinsic risk factor profile is modulated by exposure (or a lack of exposure) to extrinsic risk factors. Coaches and practitioners also have the opportunity to intervene before the injury event (e.g a warm up) to mitigate the risk of injury. Subsequently, a more complex dynamic and recursive model was suggested by Meeuwisse et al. (2007) that placed more emphasis on the adaptive response of the athlete before and after injury. In essence, an athlete's susceptibility for injury constantly evolves over time based upon fluctuations in both intrinsic and extrinsic

risk factors of injury following exposure (figure 2.3). This evolution is often highlighted in practice by athletes being exposed to similar sporting situations that result in vastly different injury outcomes (i.e one athlete may sustain an injury and another athlete does not). Equally, an athlete may experience the same exposure on multiple occasions during their career with each one resulting in a different injury outcome (Meeuwisse et al., 2007).

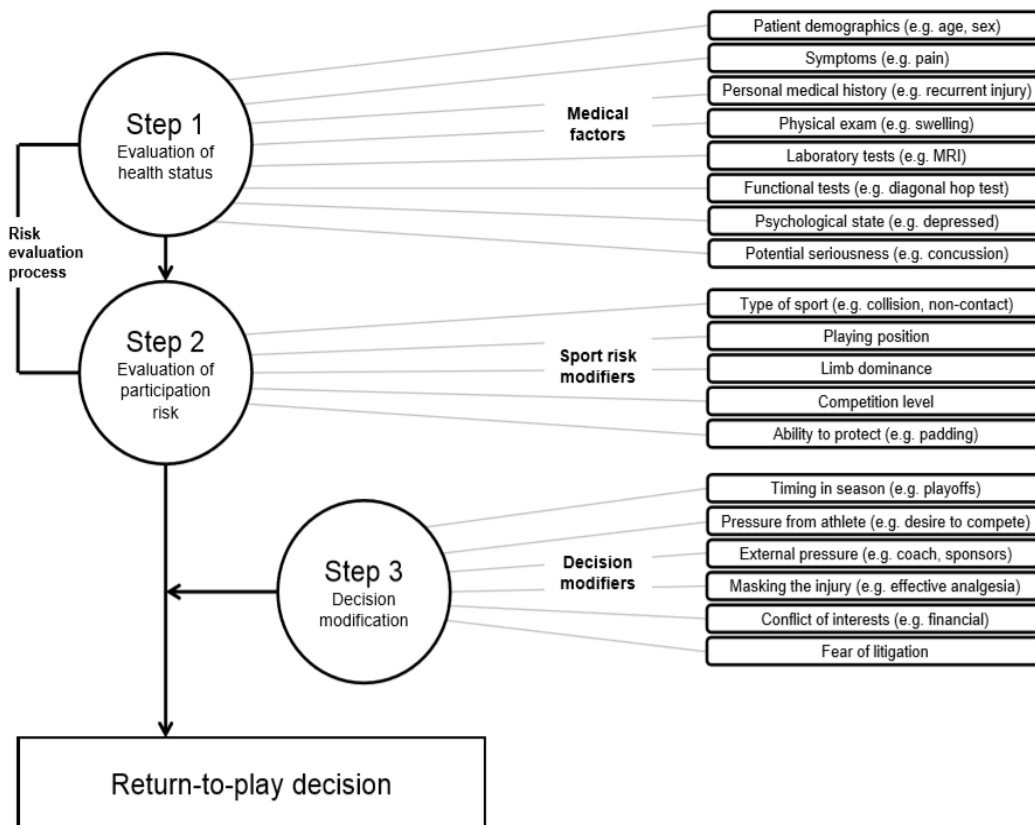


Figure 2.2: A decision based return to play model (Creighton et al., 2010) describing the conscious and sub-conscious decision making of medical practitioners.

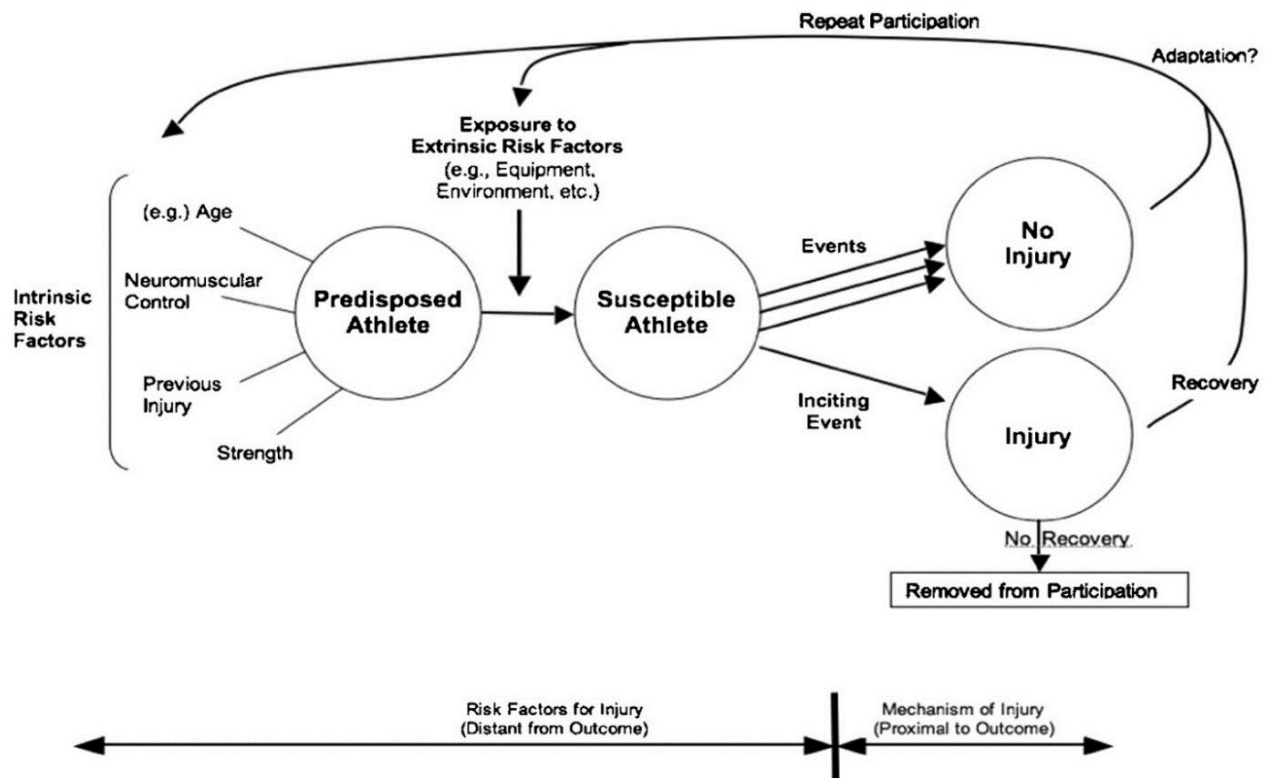


Figure 2.3: A dynamic and recursive sports injury model (Meeuwisse et al., 2007).

This literature review aims to identify the key methodological issues that need to be considered before undertaking epidemiological research in a sporting context. The identification of these pertinent challenges is essential for understanding the nuances of this research setting and for informing the planning phase of the experimental chapters of this thesis. Secondly, this literature review aims to summarise and critically evaluate the key topics for each of the experimental chapters, namely concussion, training load and illness in professional Rugby Union. In doing so, this literature review considers the current research landscape of the most important areas of sports medicine in professional Rugby Union.

2.1.1 Injury Definition

The area that is often most problematic for both researchers and practitioners, is the selection of the most suitable operational definition for reporting injury (Janda, 1997, Orchard and Hoskins, 2007, van Mechelen et al., 1992). The selection of an appropriate injury definition is essential in order to facilitate a balance between reporting reliability, an accurate representation of injury risk and an understanding of the clinical demand in a given context. It is important for researchers to understand that ‘one size does not fit all’ and choosing the correct injury threshold will largely depend upon a) the context and setting of the population and, b) the parameters within which the reporting is taking place (Clarsen and Bahr, 2014, van Mechelen, 1997). Arguments for both an inclusive (i.e. a

narrower definition of injury such as a > 24 hour time-loss definition) and a more exclusive (i.e. a broader definition of injury such as a > 7 day time-loss definition) definition of injury have been made previously. It has been stated that studies that adopt a more inclusive definition of injury should prove the reliability between the most motivated and least motivated teams. The reliability for the reporting of mild injuries (< 7 days; Orchard and Hoskins, 2007) has also been questioned due to the potential for large variability in the reporting of these injuries. It is important to remember however that the chosen definition of injury dictates how injury risk is presented in a particular context (Brooks and Fuller, 2006). Those injuries that are less severe may still represent a large proportion of the overall injury burden and thus the majority of clinical demand for practitioners. Therefore the collection of this data is important if you want to fully understand the full spectrum of injury in a particular setting.

The impact of using different injury definitions (both time-loss and those that do not use player time-loss as an inclusion criterion) has been studied in professional Rugby Union using the 2002-2004 injury surveillance data from the English Premiership. The injury definitions used and corresponding incidence rates (displayed as injuries/1000 hours) were; player missing >1 day 91 (95% CI 87-96), player missing \geq 1 match 40 (95% CI 37-43), player requiring diagnostic tests 25 (95% CI 22-27) and players requiring surgery 4.5 (95% CI 3.5-5.5). These significant differences highlight the importance of using a more inclusive definition of injury in professional Rugby Union and how the use of a range of definitions in sports injury research can lead to inconsistencies in reported data, making injury risk difficult to compare within and between sports (Fuller et al., 2007b). The identification of these inconsistencies led to reporting consensus statements being developed specifically in a number of sports (Fuller et al., 2006, Orchard et al., 2005), including Rugby Union (Fuller et al., 2007b). This consensus statement supports a more inclusive >24 hour time-loss injury definition and has vastly improved the consistency of reporting within epidemiological studies in Rugby Union (Williams et al., 2013) but it is important to note that some variation in adopted definitions and methodologies still exist in the research domain.

2.1.2 Injury Incidence and Exposure

The three most common methods for reporting injury data are; absolute numbers, proportions and incidence (Brooks and Fuller, 2006). Whilst absolute numbers and proportions have been used frequently to describe the magnitude of injury occurrence, these figures do not account for the diverse levels of exposure to match and training activities that are often experienced by teams or individuals. Therefore, it is not possible to

determine with any certainty, the relationship between injury and specific risk factors (van Mechelen, 1997). Conversely, the incidence of injury does however account for potential differences in exposure between teams or individuals. Accounting for exposure is the only way that the relative level of occurrence can be calculated, as proportions may remain similar across time whilst incidence may change significantly (Fuller et al., 2007b). The incidence of injury can also be expressed in various forms, with the denominator (exposure) being defined as either: athlete seasons, athlete games, athlete practice and the two most common expressions; athlete exposures (one athlete participating in one match or training session) and athlete hours (supported by the aforementioned Rugby Union consensus statement; Fuller et al 2007b). In order for the incidence of injury to be reported accurately, the selected measure of exposure should be collected as precisely as possible. Although more laborious, displaying incidence in relation to the number of athlete hours is usually favoured to athlete exposures (Knowles et al., 2006). In Rugby Union, it is widely accepted that the incidence of injury for match and training activity should be reported separately as a players training exposure is usually far greater than their match exposure (particularly at the elite level). As a consequence of this difference, a high volume of training exposure could mask a high incidence of injury sustained in competition (Brooks and Fuller, 2006, Fuller et al., 2007b).

2.1.3 Injury Severity

Reporting the magnitude of an injury is a critical factor across all stages of injury prevention (Bahr, 2009), as it allows researchers to understand the period of incapacity imposed upon a player following injury (Junge and Dvorak, 2000). The way that injury severity is measured and defined is often specific to the needs of each setting. For example, in acute emergency medicine it may be necessary to make a quick decision about the severity of an injury to ensure that the patient receives the appropriate medical intervention. A number of well-established injury severity scoring systems are often used in order to support such decision making (Baker et al., 1974). In addition, physiotherapists often use pre-defined grading systems in order to differentiate the severity of injury. In sports injury epidemiology literature, the severity of an injury is typically expressed as the number of days absent from training or match play and alongside injury incidence, can explain the overall burden (or overall risk) of an injury. One criticism of a severity based time-loss injury definition is that it does not capture those injuries whereby the player is able to continue to actively participate in training. It is likely that overuse injuries (those caused by chronic/cumulative damage rather than instantaneous energy transfer) account for a large proportion of these injuries. In some cases, athletes are able to continue to train and compete at high levels whilst experiencing pain and restriction without ever losing any

time through injury (Finch and Cook, 2013). Therefore, it can be reasonably argued that a time-loss definition of injury may underestimate the risk of injury in the sporting context (Clarsen et al., 2013). Recently, a new questionnaire based method for capturing data concerning overuse injuries has been proposed and has been validated in a number of sports (Clarsen et al., 2013). During the study, an average of 39% of athletes (from 313 athletes in total) reported having overuse problems suggesting that current time-loss definitions do not capture a large amount of injury information. However, it should be noted that the efficacy of this method in a multi-team surveillance system has not yet been established and the difficulties in maintaining reporting consistency in larger team-based sports has been accepted (Clarsen et al., 2014). Whilst the incidence of overuse injuries may be high in a number of sports, it has been suggested that the majority of injuries in Rugby Union are acute in nature (Bahr, 2009) although (perhaps in part due to the challenges around the definition of injury described above) the true burden of chronic injury in the sport is not well understood. The Rugby Union injury consensus statement recommends the use of days absence to report the magnitude of injury in the following categories; slight (0-1 days), minimal (2-3 days), mild (4-7 days), moderate (8-28 days), and severe (>28 days; Fuller et al., 2007b).

2.1.4 Overall Injury Risk

Whilst the incidence and severity of an injury are important to consider independently when trying to understand the dimensions of injury in a particular setting, they should be considered conjointly in order to fully understand the risk (or burden) of a particular injury or group. Risk can be defined as the product of probability of occurrence (incidence) and consequence (severity; Fuller and Drawer, 2004). Different injuries could have a similar probability of occurrence but may have completely different levels of risk and thus, simply considering incidence or severity independent of one another can often be misleading. It should also be noted that this model cannot be applied to establish all aspects of injury risk as the possible long-term sequelae of injury is not considered. For example, it is unclear whether single or repetitive concussive events have long-term implications upon cognitive function (Tator, 2014).

2.1.5 Injury Coding

The specificity of the injury diagnosis has improved rapidly over the last decade alongside vast improvements in the quality of diagnostic imaging techniques (Rae and Orchard, 2007). The accurate categorisation of this often detailed injury information is fundamental to a) facilitate the retrieval of records pertaining to a certain injury characteristic (e.g. body location) for future analysis (Orchard et al., 2010) and b) collate diagnoses to identify

potential trends in injury incidence and prevalence (Rae and Orchard, 2007). As such, a variety of injury coding systems have been proposed. Utilising the correct coding system is essential when balancing variations that exist between different sports, sporting codes, data sets and individual user background and expertise. Whilst there are several injury coding systems that are available to the user, the most commonly cited in sports injury epidemiology studies are the Sports Medicine Diagnostic Coding System (SMDCS; Meeuwisse and Wiley, 2007), Orchard Sports Injury Classification System (OSICS; Rae and Orchard, 2007) and the international classification of disease (ICD; World Health Organisation, 2012).

The ICD coding system was designed primarily for use in public health settings and following some trivial modifications to allow for the recording of morbidity, the latest version (subsequently named ICD-10-AM) was released in 2002. The use of ICD-10-AM in a sports medicine setting is sparse due to the absence of some diagnoses that are important to in the context of a sports medicine environment (Finch et al., 2014). Conversely, a number of standardised coding systems have been designed specifically for the sports medicine setting. SMDCS, was first developed in 1990 has been primarily used by the National Collegiate Athletics Association (NCAA), National Hockey League (NHL) and the Canadian Athlete Monitoring Program. Whilst the use of the system in injury surveillance has been reasonably extensive, to date, only one published paper could be found using SMDCS (Meeuwisse and Wiley, 2007). Equally, OSICS was first developed for use in elite Australian football and is now in its 10th version. The 10th version sees a 4 digit hierarchical system that allows for a greater and more detailed diagnostic classification than previous 3 digit versions of the system. The 4 digits pertain to anatomical location, injured tissue/pathology and specific diagnosis (digit 3 and/or 4 depending on the detail). The system has been recommended by various sport injury consensus statements and has been the most commonly utilised system amongst the extant sports medicine literature.

The reliability of ICD-10-AM and OSICS-8 has been compared previously (Rae et al., 2005). Ten sports physicians each coded one of 10 different lists of 30 diagnoses according to both ICD-10-AM and OSICS-8. The 300 diagnoses were then coded twice more by experts. It took on average 23.5 minutes less to complete the task with OSICS-8 than ICD-10-AM, this is particularly important when considering the use of each system within a busy and highly demanding professional sport setting. Furthermore, pairwise agreement between the groups was 57.2% for OSICS-8 and 35.3% for ICD-10-AM. Although the

overall agreement of OSICS-8 fared better than that of the ICD-10-AM system, both systems fell below the 70% level of agreement considered acceptable (Britt et al., 1998).

More recently, Finch and colleagues (2014) compared the coding assignment using the OSICS-10 between sports physicians and epidemiologists. Both coders agreed on the first character 95% of the time and on the first two characters 86% of the time, however of the 1082 injuries coded both coders assigned the same code for only 46% of cases. These findings were in agreement with an earlier study by Hammond and colleagues (2009) who reported an almost perfect agreement between coders of different backgrounds for the 1st digit but only a moderate agreement by the 4th digit. Both of these studies highlight the point that as the diagnostic specificity increases, the ability of a non-clinical coder to assign the correct code is reduced. It is important to mention that in most injury surveillance work and sports injury epidemiology the accuracy of the 3rd and 4th digit is less important when we consider that, for most reports, analyses and publications only the 1st and 2nd character is reported, for example 'Ankle' and 'Sprain'. In addition, the Premiership Rugby Injury Surveillance Project uses medical practitioners to code all injuries in order to improve coding accuracy. The Rugby Union injury consensus statement recommends the use of the OSICS in order to code and categorise injury diagnosis (Fuller et al., 2007b).

2.1.6 Recurrent Injury

To be able to correctly define and identify recurrent injuries within injury surveillance systems is important, as the incorrect identification of recurrent injuries may lead to the under or over reporting of injury incidence in both new and/or recurrent injury classifications (Hammond et al., 2011). It has also been shown that subsequent injury is strongly associated with previous injury (Häggglund et al., 2006, Ullah et al., 2012), clearly an important consideration for injury prevention. Therefore, a number of definitional taxonomies specifically related to improving the capture and objectivity of recurrent injury data have been proposed (Finch and Cook, 2013, Hamilton et al., 2011). Furthermore, sustaining certain types of recurrent injury may increase the chances of retirement in elite athletes (McCrory, 2001) and so understanding the overall risk of recurrent injuries in sport so that more effective injury rehabilitation and assessment protocols can be developed is clearly of significance. However, the accurate reporting of recurrent injuries is challenging as they often go underreported in injury surveillance studies due to recall bias. Indeed, from a methodological perspective, the correct identification, classification and monitoring of recurrent injuries over time is difficult (Finch and Cook, 2013).

It has been postulated that recurrent injuries are usually more severe than the index injury (Hägglund et al., 2009, Williams et al., 2013). Alternatively, it has also been proposed that there is no difference in the severity of recurrent injuries when each individual injury is compared to its original index injury rather than comparing the mean severity of new versus recurrent injuries (Hamilton et al., 2011, Waldén et al., 2005). A common limitation for the majority of studies is that most players will have sustained previous injuries before the beginning of the study and so reported severity values may already be influenced by these unaccounted injuries (Hägglund et al., 2013a).

The length of time between an index injury and a recurrence can convey important information about the current and future management of the injury to the practitioner. Three groupings have been defined to describe the time-frame in which a player sustains a recurrent injury. An 'early recurrence' describes a recurrent injury that occurs within 2 months of a player returning to full participation. A 'late recurrence' describes an injury recurrence within 2 to 12 months and a 'delayed recurrence' occurring after 12 months or more. In many cases recurrent injuries (especially early recurrence as it may suggest poor rehabilitation in some cases; Fuller et al., 2007b) are often used as a method of evaluating the performance of medical staff in professional teams and organisations. Alternatively, a late recurrence may indicate a predisposition to a certain type of injury (Meeuwisse et al., 2007). This emphasises the importance of the correct identification of multiple recurrences to enable practitioners to direct individualised injury prevention programs (which may require the need to prohibit or reduce participation in certain training modalities) in order to reduce injury recurrence.

2.1.7 Sample Size

As the size of a sample population increases, the size of the confidence interval decreases making it more likely that significant differences between groups will be identified (Brooks and Fuller, 2006). One problem vis-à-vis sports epidemiology research (particularly when considering studies that try to identify modifiable risk factors) is that the majority of studies are only able to include a relatively small number of subjects. In other words, these studies lack power. Power is the ability of a study to demonstrate an association between a risk factor and injury if such an association exists (Arnason et al., 2004). In general, the greater the frequency of injury the smaller the required sample size in order to see an association with the outcome variable (Bahr and Holme, 2003). In addition to the number of participants, the size of the sample can also be influenced by the duration of the study. Injury incidence in Rugby can vary greatly between seasons (Gabbett, 2003) and as a consequence findings from epidemiological studies that are of a

short duration should be interpreted with caution. The majority of studies in sports epidemiology do not follow a longitudinal study design (Finch and Cook, 2013) and thus, do not always account for natural seasonal variation.

The aim of this section was to summarise the research challenges faced when designing, implementing and disseminating epidemiological research. It is important that these aforementioned concerns are considered throughout the rest of this chapter and thesis in order to critically evaluate the scientific literature.

2.2 INJURY EPIDEMIOLOGY IN TEAM SPORTS

Before considering any potential associations between specific risk factors and injury it is important to understand the magnitude of the injury problem (van Mechelen et al., 1992). In order to fully assess this injury magnitude and to subsequently consider the possible efficacy of future research studies and injury prevention strategies, it is important to consider the risk of injury in contact sports and specifically in Rugby Union. This systematic and coherent approach will allow for further understanding of the high-level injury risk in professional Rugby Union and also for the comparison of injury risk with other sports (which is essential for understanding where Rugby Union falls on the spectrum of injury risk). Therefore, the aim of this section is to briefly summarise the high-level injury epidemiology in contact sports and in particular Rugby Union.

2.2.1 Australian rules football

The Australian Football League (AFL) started injury data collection in 1992 and is the longest running publically released injury surveillance system in professional sport. All teams and players at the elite level have reported injury data since 1996 (Orchard et al., 2013). It is important to note that the presentation of injury rates differ from those used by most other large injury epidemiological studies and those recommended by the consensus statement for reporting injuries in Rugby Union (Fuller et al., 2007b). From 1997 onwards the definition for an injury has been an “injury or medical condition which causes a player to miss a match” (Orchard and Seward, 2002). Injury incidence is reported as the number of injuries per club per season rather than the more common number of injuries/1000 player hours. Injury prevalence is also measured by number of matches missed through injury per club per season. The AFL suggest that while displaying injuries/1000 player hours is preferable from an academic perspective to allow comparisons within and between sports, these numbers are difficult to contextualise and apply for those working within the sport.

In a recent investigation of the results of 2 decades of injury surveillance data in the AFL (Orchard et al., 2013) the range of seasonal incidence was 30.3 – 40.3 new injuries per club and the range for injury prevalence was 116.3 to 157.1 matches missed per club. Recurrent injuries have steadily dropped over the study period ($P < 0.05$) and the most frequent and prevalent injury across the period was hamstring strain. In a study by Orchard and Steward (2002) the injury incidence/1000 hours was investigated in the AFL over 4 competitive seasons using a missed match definition of injury. Mean injury incidence for match injuries was 25.7/1000 player hours with 16% of players in the study cohort sustaining at least one injury during the study period.

2.2.2 Ice Hockey

In a systematic review of youth ice hockey by Emery and colleagues (2010), 22 studies were deemed to be of sufficient quality to be included. Injury rates ranged from 11.7/1000 player hours (upper extremities only) to 34.4/1000 player hours. Emery and colleagues noted that the studies in the review should be interpreted with caution due to the various injury definitions and study populations that were utilised. This is a general statement that can be applied to the majority of systematic reviews in sports epidemiology. In a recent six season study that included all professional national hockey league (NHL) teams, injury incidence was reported as 49.4/1000 player hours using a missed match definition of injury i.e. players had to miss at least one main season game (McKay et al., 2014). The study reported a reduction in injury rates in the final four seasons compared with the first two seasons (IDR 1.66, 95% CI: 0.56-1.76) but despite this reduction in overall incidence, there was a consistent increasing trend for the frequency of injury towards the end of each season. This finding is significant because it crudely highlights the potential impact of player fatigue and the important consideration of the cumulative effect of training load on injury risk. Furthermore, a recent study investigated the injury incidence in international World championship and Olympic competitions and found the incidence of injury to be 52.1/1000 hours and 59.3/1000 hours, respectively (using a time-loss definition that also included medical attention injuries for lacerations, concussions and dental injuries regardless of whether they led to time-loss). It is important to note that there is currently no large scale public injury epidemiological study or consensus statement for reporting injury surveillance figures within Ice Hockey which might explain the large variation in figures and incidence rates presented in the contemporary literature.

2.2.3 American Football (NFL)

The NFL maintains an injury surveillance system that has been in existence since 1980. However, unlike most other injury surveillance data, the results are not widely available in

the public domain (Hershman et al., 2012). In a study by Feeley and colleagues (2008) injuries were reported for one squad's NFL training camps between 1998 - 2007, during the study period a total of 696 different players were included. An injury was defined as 'an event that occurred as a result of participation in an organized practice or game, required medical attention by an athletic trainer or physician and resulted in restriction of the athlete's participation for at least 1 day beyond the day of injury (i.e., broadly consistent with the recommended definition from the Rugby Union injury consensus statement employed in this thesis). However, injury rates were measured as number of injuries/1000 athlete exposures (AE) where an athlete exposure is defined as one athlete participating in one practice or game therefore, making any direct comparisons of injury rates between sports is difficult. The injury rate was higher during games 64.7/1000AE than training 12.7/1000AE ($P < 0.01$), this figure for training injuries is reported to be approximately twice the rate for collegiate American football players (Shankar et al., 2007). Knee sprains were reported as the most common injury overall across match and training scenarios.

2.2.4 Football (Soccer)

The consensus statement for reporting injury data in football (Fuller et al., 2006) has improved the consistency of recent injury epidemiology studies conducted within the sport. It has been shown that in a squad of 25 players, around 50 injuries are likely to be sustained during a season (Ekstrand et al., 2009) and around 15 players will likely sustain a muscle injury during the season. Muscle injuries account for ~40% of injuries in professional football and represent around a quarter of time lost from match or training practice (Ekstrand et al., 2011). Junge & Dvorak (2013) reported injuries that occurred in all FIFA tournaments and the Olympic Games between 1998-2012 for men and women. An injury was defined as 'any physical complaint (including concussion) incurred during a match that received medical attention from the team physician regardless of the consequences with respect to absence from the match or training'. Injury incidence was expressed as number of injuries/1000 player hours. The overall male match injury incidence was 77.3/1000 player hours (95% CI: 74.9 - 79.7) using the above definition. In the case of time-loss match injuries, the incidence rate was 32.8/1000 player hours (95% CI: 31.1 - 34.5) with no difference seen in the injury incidence between male and female players. Of these time-loss injuries 37% were expected to prevent players participating in full match/training for up to 7 days 5% for 8 - 28 days and 2% for 29 days or more. Interestingly, in a study of a number of European championships by Häggglund et al. (2009), the importance of training injuries were highlighted as they accounted for 20% of all injuries and 26% of player unavailability during the study even though the incidence of injury was low (range: 1.3-3.9/1000 player hours).

2.2.5 Rugby League

The methodological approach to studies that report the profile of injuries in rugby league has been generally inconsistent and thus, variations previously reported in injury incidence are often the result of relatively small numbers of teams and players (King et al., 2009). In 2002, (Gissane et al., 2002) performed a pooled data analysis of injury incidence in Rugby League. In total six studies met the inclusion criteria and were included in the analysis. All six studies used an injury definition that required the injured player to miss a subsequent game. A total of 517 injuries were reported across 753 games where the overall match incidence rate was 40.8/1000 hours (95% CI: 36.9 – 43.8). More recently, King and colleagues (2014c) undertook a further pooled data analysis in which 5785 match injuries were recorded from 34 studies that met the inclusion criteria. Injuries were then split into either time-loss injuries (injuries that resulted in the player missing the subsequent match or training session) or non-time loss injuries (injuries that did not result in any missed sessions). The match and training incidence for time-loss injuries was 57 (95% CI: 55 – 60) and 2.7 (95% CI: 2.5 – 2.9), respectively. Interestingly, the non-time loss injury incidence was \approx 5 times greater for matches and \approx 3 times greater for training than the time-loss incidence which may suggest that non-time loss injuries take up the largest proportion of clinical time in this setting (they may still require treatment and ongoing management [if the injury is chronic in nature]). However, as discussed previously, the reliability of reporting such injuries is unclear and thus, the inclusion of non-time loss injuries in epidemiological studies remains contentious (Orchard and Hoskins, 2007)

2.2.6 Rugby Union

A number of studies have described the epidemiology of injuries in professional Rugby Union (Brooks et al., 2005a, Brooks et al., 2005b, Brooks et al., 2005c, Brooks and Kemp, 2008, Fuller et al., 2008, Fuller et al., 2007a, Fuller et al., 2015, Kemp et al., 2008). A recent meta-analysis (Williams et al., 2013) aimed to summarise a number of these studies (and others not mentioned above) to determine the incidence, severity and causes of injury in professional Rugby Union. Fifteen studies (between 1995 and 2012) were included of which, 10 provided incidence data and 9 provided severity data. The overall incidence was 81/1000 hours and 3/1000 hours in match and training respectively. Furthermore, the mean severity was reported as 20 days for matches and 22 days for training. Lower limb injuries were the most common but upper limb injuries were the most severe. Overall, the burden of injury was highest in the lower limb. Muscle and tendon and joint (non-bone) and ligament injuries were the most common injury groups whilst fractures had the highest average severity. Interestingly, this study reported a lower incidence in the first quarter of

matches, highlighting the importance of the effective management of a player's recovery in reducing the risk of injury in this setting.

It should be noted that a number of the studies included in this meta-analysis (particularly those that were conducted before the introduction of the consensus statement for reporting injuries in Rugby Union) were not without limitation. Specifically, different study definitions, methodological approaches and small sample sizes all make meaningful comparisons between studies challenging. This assertion was highlighted by the of the reported incidence in the meta-analysis (32/1000 player hours to 218/1000 player hours) The introduction of the consensus statement in 2007 has gone some way to improving the consistency and overall quality of the research more recently although, some inconsistencies still exist (Williams et al., 2013).

2.2.7 Summary

This section has highlighted that Rugby Union has some of the highest reported rates of injury in any sport. This suggests that either a) the risk of injury is greater in professional Rugby Union than in a number of other sports or b) that the reliability and validity of the reported injury data is better in Rugby Union than in other sports or c) that the inconsistent methodologies and definitions utilised in different sports and individual studies do not allow for adequate comparison. It is most likely that a combination of these factors should be considered when interpreting these epidemiological data. Ultimately, further understanding of the risk and clinical outcome of high-impact (i.e. the most common and/or highest risk injuries) alongside sport specific risk factors for injury will likely attenuate the risk of injury in this cohort.

2.3 COMMON RISK FACTORS FOR INJURY IN RUGBY UNION

In Rugby Union, epidemiological studies that report injury incidence, type and causation are well documented (Bathgate et al., 2002, Bird et al., 1998, Brooks et al., 2005a, Brooks et al., 2005b) and, although not demonstrable with scientific evidence, have likely been successful in improving the understanding of risk exposure and management, particularly at the elite level. Whilst this information is vital to understand the extent of the injury problem (in accordance with the sequence of injury prevention model outlined previously), the implementation of injury prevention strategies are dependent on the identification of individual risk factors for injury (van Mechelen et al., 1992). Currently, the understanding of modifiable (e.g. training load) and non-modifiable (e.g. age) risk factors for injury in Rugby Union is limited. This issue is not specific to Rugby Union and is generalisable to sport as a whole, whereby the majority of research output is descriptive and does not allow

for effective transition across the 'research to practice' gap (Hanson et al., 2014). It is important to note however that there has been some recent success in Rugby Union that has highlighted an effective transition from research into practice. In brief, the scrum was identified as having a high propensity for injury (Taylor et al., 2014) and subsequent research investigating different engagement strategies was able to reduce the biomechanical loading on front row players by ~20% (Cazzola et al., 2014). This research ultimately led to a worldwide law amendment across all levels of the game and continued surveillance will determine how successful this law change has been in mitigating injury risk at the scrummage.

2.3.1 Playing Level

It has been postulated that incidence of injury is positively correlated to playing level (Bathgate et al., 2002, Bird et al., 1998, Brooks et al., 2005a, Garraway et al., 2000, Quarrie et al., 2001, Targett, 1998) although, there is a disproportionate amount of research pertaining to the professional game rather than at amateur levels (Brooks and Kemp, 2008). This is likely due to the enhanced medical support and human resource available at professional clubs that consequently makes conducting studies of this type easier and more reliable at this level (Ekegren et al., 2015). The differences in injury risk between amateur and professional levels were highlighted by Garraway et al. (2000) whereby, injuries were recorded over 2 seasons; 1993-1994 (pre professionalism) and 1997-1998 (post professionalism). Whilst the number of playing hours decreased, the proportion of players suffering an injury almost doubled from 27% to 47%. Match injury incidence increased from 29.5/1000 hours for amateur players to 60.9/1000 hours for professional players. In a study of elite Australian rugby union players, match injury incidence also increased from the pre professional (47/1000 hours) to post professional era (74/1000 hours; Bathgate et al., 2002). Differences in injury incidence have also been identified between individual strata in both the amateur and professional games. In a study of approximately 90 English community level rugby union clubs, players at semi-professional clubs had a higher injury incidence (21.7/1000 hours; 95% CI: 19.8-23.6) than those playing at amateur (16.6/1000 hours; 95% CI: 15.2-17.9) and recreational (14.2/1000 hours; 95% CI: 13.0-15.5) levels (Roberts et al., 2013). In a 2 season study of youth rugby players playing at either elite academy or school level, the match injury incidence for academy players was greater than for school players (47/1000 hours and 35/1000 hours, respectively; Palmer-Green et al., 2013). A recent meta-analysis of professional rugby players by Williams et al (2013) suggested a clear difference between playing level and injury incidence with 123/1000 hours (95% CI: 85-177) for international; 89/1000 hours (95% CI: 75-104) for level 1 clubs (played in the highest league of a tier one nation) and 35 (95% CI: 27-45) for level 2

clubs (played below the highest league in a tier one nation or in the highest league of a tier two nation). These differences may reflect the true difference between injury risks at different levels of play likely due to increased playing and training demands apparent between playing levels (Quarrie and Hopkins, 2007) or, it may reflect the quality of injury reporting and the overall level of clinical support given to players at each standard of play (Williams et al., 2013).

2.3.2 Playing Position

Playing position is an easily identifiable, non-modifiable risk factor for injury in Rugby Union (Brooks and Kemp, 2011). Playing demands have been shown to be specific to a player's position during match play, with one study highlighting differences in the demands of forwards (more high-intensity activity and more time spent in static exertion) and backs (more distance covered and more high-intensity running) in elite matches (Roberts et al., 2008). In a more recent study in which player actions and movements were coded using video analysis for 90 matches involving New Zealand, forwards were also found to sustain much greater contact loads than backs (Quarrie et al., 2013). Despite these distinct positional differences between forwards and backs, the majority of previous studies have found a negligible difference in injury risk between these positional groups in professional Rugby Union (Brooks et al., 2005a, Quarrie et al., 2001). This statement is supported by a recent meta-analysis of injuries in elite Rugby Union (Williams et al., 2013) whereby, there was a 76% and 80% likelihood that the differences in incidence and severity between forwards and backs was trivial. One possible explanation for similar risk profiles is that as players continue to become better conditioned, the difference in the workload profile between forwards and backs has become narrower (Quarrie and Hopkins, 2007). Furthermore, positions are often grouped for analysis to increase statistical power which may mask any individual differences between specific positions (Cahill et al., 2013). On balance, the risk of injury between positional groups (i.e. forwards and backs) appears to be similar although, it should be noted that the type of injuries sustained are likely to be significantly different (Brooks and Kemp, 2011). Therefore, specific injury prevention strategies should be designed to offset the risk of injury in each position in this setting (Brooks and Kemp, 2011, Williams et al., 2013)

2.3.3 Injury Event

It is well known that the tackle is associated with the largest number of match injuries and the greatest time lost in Rugby Union at the elite level (Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013). Specifically, it is thought that the ball carrier has the highest risk of injury within the tackle (Williams et al., 2013). However, perhaps the high

incidence of injury associated with the tackle is not surprising considering that tackles account for the largest proportion (almost 50%) of contact events during matches (221 of 457 events per game) in Rugby Union (Fuller et al., 2007a). Therefore, it is also important to consider the probability that a particular type of event will cause injury. In a two-season prospective cohort study in the English Premiership (Fuller et al., 2007a), collisions (defined as the tackler attempting to stop the ball carrier without the use of his arms) were 70% more likely and scrums were 60% more likely to cause injury than a tackle when considering the injury risk per event (Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)(Brooks et al., 2005a, Fuller et al., 2007a, Williams et al., 2013)

2.3.4 Physical & Physiological Profile

Since the advent of professionalism in 1995 and the subsequent emphasis on sport science support, many teams have sought to gain competitive advantage by improving the physical characteristics of players through different physical conditioning practices (Fuller et al., 2013). In general, it has been suggested that better conditioned players are less likely to be susceptible to fatigue, therefore reducing their risk of injury during match and training (Brooks et al., 2005a). However, it also means that well-conditioned players have the potential to be exposed to more events during a match (due to their increased work capacity) and, as a consequence, that may increase their risk of injury. The physical profile of a player usually differs in accordance with level of play, with players at the elite level of the game usually stronger, faster and more powerful than their amateur counterparts (Brooks et al., 2005c). It is this difference in a player's physical attributes that provides the most common explanation for the majority of research highlighting a linear increase in injury incidence in accordance with playing level (as discussed earlier). The perception of the media is that the size and power of professional Rugby Union players is increasing exponentially which has led to an increase in the overall risk of injury in professional players (Peters, 2014). However, although the physical stature of professional Rugby players in the English Premiership (the highest tier of club Rugby in England) has

gradually increased since 2002 (Fuller et al., 2013), the incidence of match and training injury has remained stable over the same period (Rugby Football Union, 2015).

Body mass index (BMI) has been shown previously to be a risk factor for injury incidence in Rugby Union. In one study, Quarrie et al. (2001) used univariate analysis on a cohort of 258 players to show that players who had a BMI of >26.5 had a greater incidence of injury than those with a BMI of <23 . The same study also used multivariate analysis to show that those players who were considered more frail (those with a BMI of <23) were at increased risk of losing time during the season when controlling for other known risk factors. Fuller et al. (2008) proposed that the increase in match injury incidence of international players (218/1000 player hours) compared with club level players (91/1000 player hours) was primarily due to the superior anthropometric characteristics and greater power of international players. Conversely, in a more recent study of 704 amateur players by Chalmers et al. (2011) no evidence of association was found between injury incidence and height, weight, BMI or pre-season conditioning. It should be noted that the match and training demands placed upon amateur players is vastly different to that of professional players and may explain the lack of association in this setting.

Furthermore, in a three season study of 66 professional Rugby League players, the authors aimed to identify the risk factors for contact injury. A frailty model (an extension of the Cox proportional hazards model) was used to assess the association between physical fitness components and the risk of injury with effect sizes expressed as Hazard Ratios (HR). In this study, heavier (body mass; HR= 2.6), and faster players (40m sprint; HR = 2.1), and those with poorly developed intermittent running (HR = 2.9) and upper-body strength (chin-up; HR 2.2) had a higher incidence of contact injury in Rugby League (Gabbett et al., 2012). It should be noted that these findings were based upon one professional team and are likely to reflect the training practices and match tactics in this particular environment and thus, the generalisability of these results remains unknown. The finding in this study that faster players are at a greater risk of injury is also supported by previous studies in Rugby Union (Garraway et al., 1999, Quarrie et al., 2001) but a larger multi-team study is required to be able to make some more meaningful assertions in this setting. Overall, studies that focus on the body composition, power and rate of force development of players rather than measures of height, mass or BMI are likely to provide more valuable insight as to whether changes to the physical characteristics (rather than stature alone) of players has impacted upon the risk of injury in Rugby Union.

2.3.5 Training Volume

A small number of studies have investigated the relationship between training volume (duration of training) and injury risk in Rugby Union (Kemp et al., 2008, Viljoen et al., 2009). Brooks and colleagues (Kemp et al., 2008) found that the mean training volumes for pre-season and in-season were 9.2 and 6.3 hours respectively with more time spent on conditioning in pre-season and skills training in season (Brooks et al., 2005b). The lowest number of days lost due to injuries occurred during weeks of intermediate training volume (6.2 - 9.1 hours per week). A higher training volume (> 9.1 hours per week) did not increase injury incidence rates but did increase the severity of match injuries. It was concluded that modifying the volume or content of training has the potential to alter injury incidence rates and/or injury severity. The authors also noted that a potential limitation of the study was that training intensity was not captured and that this should form the basis for future research. In addition, Viljoen and colleagues (Viljoen et al., 2009) recorded training volumes within a professional team over a three year period and concluded that a reduction in training volume over three seasons was associated with slight reduction to in-season injury rates. It was also noted that the team's league position also changed from 3rd to 7th (2002-2004) and thus, did not recommend reducing training volumes too much as the players may no longer be exposed to the required training stimulus in order to be able to compete effectively during matches.

Both of these studies suggest that training volume can be modified in order to reduce injury rates although the impact upon performance needs to be considered. Training intensity was not recorded in either study and as a result, training load could not be derived. Currently, the association between training load and injury risk remains unknown in professional Rugby Union.

2.3.6 Surface Type

Commercial interest in the use of artificial turf as a viable alternative for match play in rugby union has increased in recent years (Williams et al., 2015) with currently, 2 English Premiership teams playing their home matches on artificial turf and many more using artificial surfaces for training purposes. The use of artificial turf is thought to have many advantages from a participation (increasing participation due to pitch availability; Williams et al., 2015), commercial (increased longevity of an artificial surface compared to natural grass, making it cheaper to maintain) and spectator (makes matches quicker with players able to change direction at quicker speeds; Gains et al., 2010) perspective. It has been postulated that playing and/or training on artificial turf may have an impact on a player's injury risk (Drakos et al., 2013, Gains et al., 2010) however, the risk of injury in football

would appear similar for both artificial turf and natural grass (Bjørneboe et al., 2010, Ekstrand et al., 2006).

There have been two studies that have investigated the association between artificial turf and injury risk in professional Rugby Union. Fuller et al. (2010) conducted a two-season study and found no significant differences in match (based on six teams competing in Hong Kong division 1; RR: 1.42, $p = 0.134$) or training (based on 2 teams competing in the English premiership; RR: 1.36, $p = 0.204$) but there was concern that whilst not statistically significant anterior cruciate ligament injuries were nearly 4-times higher on artificial turf than natural grass (RR: 3.82, $p = 0.222$) and warranted further study. Recently, Williams et al. (2015) investigated time-loss injury risk (in 39.5 matches), abrasions (in 27 matches) and perceived muscle soreness on both surfaces. In agreement with the earlier study by Fuller et al. (2010) this study found no significant difference in the risk of injury between artificial and natural surfaces. The risk of sustaining an abrasion was considerably higher on artificial turf than natural grass (RR: 7.92, 90% CI: 4.39-14.28) but these injuries did not usually lead to absence from match or training. Perceived muscle soreness was higher following exposure to artificial turf although the magnitude of effect was small (0.26-0.40).

2.3.7 Previous Injury

Understanding a player's previous injury history is important for the modification of rehabilitation programmes and the selection of appropriate training modalities in order to reduce injury risk (Brooks and Kemp, 2011). Meeuwisse et al. (2007) expanded their original framework to consider how a player's risk factors for injury evolve over time as a result, in some part, to the previous injury profile of the player (Shrier et al., 2015). Previous injury has been shown to be a risk factor for injury in other contact (Watson, 2001) and non-contact (Chalmers, 2002) sports, but a paucity of consistent data exists within Rugby Union (Chalmers et al., 2011). In a study of 356 male and female club and school Rugby Union players, Quarrie et al. (2001) found that players with a higher pre-season injury rate were more likely to sustain further injury within the same season, but there was no increase in the risk of injury if the player entered the season free from injury. Similarly, Lee et al. (2001) reported a substantial increase in the risk of injury during the following season for players that were injured at the end of the previous season. More recently, Chalmers et al. (2011) found no association between the number of previous injuries in the last 12 months and incidence of injury in the current season in Rugby Union players. The authors did however find that players who had a history of playing whilst injured had a 46% higher risk of injury that season. This finding highlights the importance

of full rehabilitation from the previous injury before returning to play. Overall, whether or not a player's previous injury profile is a risk factor for injury in Rugby Union remains unclear and future studies in this area should focus on a) methodology that allows the direct measurement of individual previous injury risk from injury surveillance systems (rather than self-reported history which is susceptible to recall bias; Williams, 2015a) and b) statistical modelling that does not assume that each injury is an independent event (subsequent injuries are often influenced by previous occurrences) and that accounts for clustering effects within teams (Ullah et al., 2012). This will likely give a clearer, more robust indication of the nature of this association in future investigations within Rugby Union.

2.3.8 Summary

This section of the literature review aimed to summarise both the intrinsic and extrinsic risk factors for injury in Rugby Union. The multitude of risk factors that have been considered above is not intended to be exhaustive but, instead, this section has aimed to provide key findings pertaining to a well-considered range of risk factors that are considered to be the most significant (in a player welfare sense) in professional Rugby Union. For example, whilst there is anecdotal evidence to suggest that high training and match loads are associated with an increase in injury risk in professional Rugby Union (Woodward, 2015), there has been no quantitative research to date that either supports or refutes this assertion. Without this information, practitioners cannot make evidence-based decisions about the optimal prescription of the training 'dose' to reduce the risk of injury in this cohort. Furthermore, the influence of previous injury upon high-level injury risk in professional Rugby Union remains unclear. However, it is also likely that this association varies according to the type of injury that has been sustained. Indeed, Orchard (2001) found that previous exposure to one type of muscle strain increased the risk of sustaining other types of muscle strains. Establishing the level of association of specific injury types and subsequent injury risk is important in order to be able to make practical and evidence-based recommendations for the evolution of existing rehabilitation and treatment programmes in order to subsequently attenuate the risk of injury in this setting.

2.4 SPORTS RELATED CONCUSSION

2.4.1 The Spectrum of Brain Injury

Sport related traumatic brain injury (TBI) has been highlighted as an important public health concern (Jordan, 2013); with nearly 4 million sports related concussions reported to occur in America alone each year (Langlois et al., 2006). For decades, the majority of research concerning traumatic brain injury has focused on more acutely severe forms of

brain injury (Meaney and Smith, 2011) such as focal injuries to the brain; however, more recently, a lack of understanding regarding the short, medium and long-term implications of athlete health following concussion has been identified which in turn compelled research to aggregate in this area.

The term concussion is often used interchangeably with mild traumatic brain injury but it has been suggested that this is potentially misleading given the growing evidence for chronic neurocognitive degeneration following concussion. Consequently, in the research domain, it remains unclear whether concussion is in fact a separate pathology. For example, it has been suggested that the sequelae of concussion is vastly different to other mild traumatic brain injuries (McCrory et al., 2013b) whilst another set of expert guidelines propose that concussion is a subset of mild traumatic brain injury (Harmon et al., 2013). If concussion is indeed a separate injury, further obscurity exists regarding where concussion fits on the spectrum of brain injury. This contention is primarily due to the fact that the outcomes of concussive injury are poorly understood. In keeping with the common methodological challenges outlined earlier in this chapter, it is important that consistency in injury terminology exists in order to compare correct outcome data and to identify the true incidence of mild traumatic brain injury or concussion (Cassidy et al., 2004).

2.4.2 A Brief History of Concussion

The word concussion originates from the Latin stem *concutere* meaning to dash together or shake violently. In the 10th century the Persian physician Rhazes defined concussion as an abnormal physiological state (McCrory and Berkovic, 2001) thus, making the initial distinction between concussion and severe brain injury. It was then almost 400 years until the European physician Lanfrancus added to this definition suggesting the first possible mechanism of concussion; that this abnormal physiological state is caused by the shaking of the brain (Johnston et al., 2001). This proposed mechanism of concussion was the first pathophysiologic description of the injury.

It was in the 16th century that accelerated progress started to be made in the understanding of the pathophysiology of concussion as a consequence of improvements in the understanding of the composition and basic mechanisms of the brain. Explicitly, Berengario da Carpi was the first to specify a mechanism for concussion by stating that it was as a result of the thrust of the “soft structure of the brain against the solid part of the skull” (McCrory and Berkovic, 2001). With the discovery of the cell in the 17th century, many proposed hypotheses that have attempted to provide further reasoning for the injury mechanism have been based on injury at the cellular level. One hypothesis, the collision of

the brain against the skull, has been studied using biomechanics and is still in use today. Others, such as that concussion is a result of cerebral congestion due to circulatory failure, have been disproved (McCrory and Berkovic, 2001).

In 2001, the first consensus statement on concussion in sport was held by the concussion in sport group (Aubry et al., 2002). The group subsequently met in 2004 (McCrory et al., 2005), 2008 (McCrory et al., 2009) and 2012 (McCrory et al., 2013b). Whilst other consensus statements now exist (Giza et al., 2013, Harmon et al., 2013), the concussion in sport group consensus statement is considered the cornerstone regarding the definition, diagnosis and management of concussion (Craton and Leslie, 2014). The overarching definition of concussion that was agreed during the consensus meeting was

“Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces...”

However, the consensus statement has recently come under increasing pressure for its lack of evidence base and definitional specificity from both a theoretical and operational perspective (Craton and Leslie, 2014, Leslie and Craton, 2013).

2.4.3 The Biomechanics and Pathophysiology of Concussion

The biomechanics of head impacts have been investigated in a variety of settings over the past 60 years but the potential for the practical application of the findings from this research field still remain unclear (Guskiewicz and Mihalik, 2011). Currently, there is no known biomechanical force threshold for a clinical concussion but both translational (linear), rotational (angular) forces or impact deceleration are likely to contribute to sustaining a concussion (figure 2.4). During complex sporting movements, it is likely that these forces will be experienced simultaneously by the athlete (Rowson et al., 2009) and the relative contribution of these two injury modes is likely to vary with each individual contact dependent on the location and direction of the force being applied.

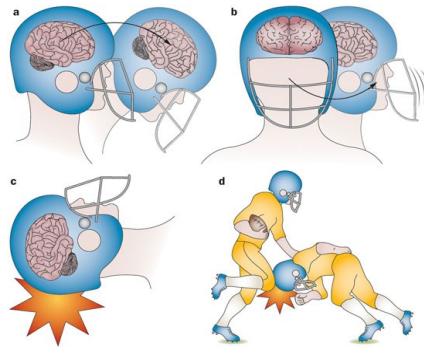


Figure 2.4: Mechanisms of concussion. a. Linear (translational) acceleration. b. Rotational (angular) acceleration. c. Impact deceleration. d. Impact deceleration secondary to the head striking an opposing player's body (Jordan, 2013).

Perhaps the most impactful work to date in the area of sport concussion biomechanics has been the work of Pellman et al. (2003) whereby crash test dummies were used to simulate video footage of concussive events in the NFL. Risk curves were developed for both linear and angular acceleration and the threshold for concussion was deemed to be around 70 to 75g. Whilst applauded for its rigour, this study likely overestimates the threshold of concussion as head impacts that did not cause concussion were not incorporated into the analyses (Funk et al., 2012). This study formed the foundations for instrumentation of headgear to allow all head impacts to be captured and risk curves to be established (Rowson and Duma, 2011). As such, subsequent work by Duma et al. (2005) and Mihalik et al. (2008) in American football and ice hockey, respectively, found that the threshold for concussion is likely to be substantially lower than the 70-75g first proposed by Pellman.

Many intrinsic and extrinsic factors impact upon the body's ability to dispel impact forces to the head. These may include individual differences in cerebrospinal fluid levels, susceptibility to brain trauma, specific strengths and weaknesses in the musculoskeletal system and the ability to anticipate imminent collisions (Clark and Guskiewicz, 2016). The influence of these individual differences are clearly highlighted in competition by the ability of some players to be able to withstand accelerations of 80-90g repeatedly throughout a season and not sustain a concussion (Guskiewicz and Mihalik, 2011) while some players cannot tolerate single head impacts of much lower force. Thus, the relative contributions of angular and linear accelerations and the varied ability for players to dissipate impact forces are still not clearly understood with respect to concussion.

Whilst theoretical suggestions have been put forward to describe the complex concussion pathway (e.g. the neurometabolic cascade; Giza and Hovda, 2001), a detailed discussion of these conceptual proposals falls outside the scope of this literature review. However, in a broad sense, two overarching hypotheses regarding the pathophysiologic mechanisms of

concussion remain prominent in the current literature; 1) the mechanism of concussion causes structural damage to the brain and 2) the mechanism of concussion causes temporary disruption of function of the brain. The most recent concussion consensus statement from the concussion in sport group refers to concussion as a ‘functional’ rather than a ‘structural’ injury (McCrorry et al., 2013b). There is, however, growing evidence to suggest that concussion may lead to ‘structural’ change. Indeed, Ling et al. (2013) investigated 50 patients and 50 matched controls via a clinical battery of tests that assessed symptoms, attention, memory, processing speed and imagery. The authors concluded that patients showed significant grey matter abnormality (structural change) following an mTBI that was still present at a 4 month follow up. Overall, the underlying debate between these hypotheses is whether or not concussions cause permanent pathophysiological damage. This issue is clouded not only by the lack of pertinent data, but also by the aforementioned confusion in concussion terminology (McCrorry et al., 2001).

2.4.4 The Diagnosis of Concussion

In the last two decades, sports governing bodies have moved from employing anecdotal strategies for the management of concussion to following international consensus based guidelines (King et al., 2014a). There has been a proliferation of recently published guidelines that have made recommendations for providing best practice care in the areas of diagnosis, assessment and management of sports concussion (Giza et al., 2013, Harmon et al., 2013, McCrorry et al., 2013b) and recently, standardised all sport national guidelines were released in Scotland, specifically aimed at the grassroots level (Sport Scotland, 2015). While these guidelines go some way to aiding the decision making of the clinician, concussion is still considered to be one of the most complex injuries to diagnose, assess and manage (McCrorry et al., 2013a). The heterogeneous nature of the presentation of concussion makes the correct identification and subsequent diagnosis of concussion challenging. In addition, there is no recognised minimum threshold or single diagnostic test that allows for its accurate detection (McCrorry et al., 2013a), therefore, the diagnosis of concussion remains subjective. It is however important to note that investigations regarding diagnostic biomarkers for concussion (namely SNTF) are currently underway in the research domain (Shahim et al., 2014). The early findings from these studies are encouraging (Johnson et al., 2015b, Shahim et al., 2015, Shahim et al., 2014), however this research topic remains in its infancy and it is unclear if these biomarkers are sensitive enough to be applied in a practical setting. Therefore, current practice dictates that clinicians often have to make a rapid on-field assessment to determine a players’ ability to continue to play safely (McCrorry et al., 2013b).

In Rugby Union, World Rugby guidelines state that when a concussion is either confirmed or suspected on the field of play by the team doctor, the player must be immediately removed from play. Some sports (including Rugby Union) have introduced new measures to allow the clinician time away from the field in order to triage the player when a head injury event is witnessed but a diagnosis of concussion is not immediately apparent (Appendix C1). For example, in American football, independent trained concussion “spotters” have been employed with the remit to stop the game and remove players who have sustained a head injury for assessment. Similarly, in Rugby Union, a temporary substitution is available with the intention of aiding the team doctor in making a decision on whether the player can return to participate in the match. Even though these measures have come under recent scrutiny (Patricios and Makdissi, 2014), evidence suggests that this off-field assessment has greatly reduced (56% to 13%) the number of players that are subsequently diagnosed with concussion having not left the field of play (Fuller et al., 2014). It has been stated that there is probably still some way to go with the propagation of these relatively new guidelines as implementation and dissemination often takes time to catch up in the sporting environment (Patricios et al., 2013). Nevertheless, in practice the on-field identification of concussion still remains problematic. In a Rugby Union scenario, medical staff need to track 15 players at any given time and may not always be pitch-side if they are required to provide in-game treatment for another player. The majority of concussions occur also in contact events which often involve multiple players, making it difficult to identify the acute reaction of the player. Ultimately, the timely identification and correct diagnosis of concussion is a difficult undertaking for sports medicine practitioners working in professional sports settings.

2.4.5 The Reporting of Concussion

Concussion is unlike the majority of other injuries as there is often no visible indicator for the symptoms of the primary injury (e.g., loss of consciousness occurs in as little as 10% of concussions; McCrory et al., 2013b) and confusion and dizziness are often difficult to observe during match play (Moreau et al., 2014). For that reason, the diagnosis of concussion is often contingent on the athlete self-reporting symptoms in order for trained medical personnel to be able to assess and subsequently manage the injury appropriately. However, it has been suggested that athletes are not likely to report symptoms in order for them to keep playing (Murray et al., 2015). This may be particularly true of athletes participating at the elite level when professional contracts are dependent upon consistent performance in competition. Indeed, in a recent study of professional Rugby Union players, only 46.6% of players who retrospectively reported having sustained a concussion also reported it to medical staff (Fraas et al., 2014). In addition to wanting to play on, the

players stated that they didn't feel that the injury was serious enough to be removed. These findings clearly highlight two things; a) the need for the team doctor to be the principal decision maker (McCrory et al., 2013b) and b) the need for further concussion education (Fraas et al., 2014) in order to provide a stimulus to initiate a change in reporting culture. It is likely that future education initiatives are fundamental for improving the knowledge and attitudes of players, coaches, match officials and medical staff regarding concussion at the elite level. This was highlighted in the findings from a recent study of 370 players, 44 coaches, 40 medical staff and 33 referees that identified several misconceptions and deficiencies in knowledge and attitudes towards concussion management (Mathema et al., 2015). For example, the majority of stakeholders incorrectly believed that protective equipment prevented concussion and that concussion did not impair performance. A resounding 80% of medical staff stated that they had felt pressure to clear players with concussion. It is then likely that changes to the knowledge and attitudes towards concussion through education will provide the catalyst for a "culture change" towards this injury. It is important to note that the underreporting of concussion is not exclusive to Rugby Union and has been highlighted as an important issue in a number of other team-orientated sports such as Soccer (Broglia et al., 2010), American Football (Delaney et al., 2002) and Ice Hockey (Benson et al., 2011). In fact, the potential impact of such a change in players culture was highlighted in a study of elite ice hockey players whereby, athletes who perceived that the majority of other athletes would report a concussion had an increased likelihood of reporting a concussion themselves. In other words, if it was felt that reporting a concussion would be accepted by their teammates, athletes were more likely to report their injury to medical staff (Kroshus et al., 2014).

At the time of writing, the most recent epidemiological data for the incidence of concussion in professional Rugby Union is from the 2010-11 season in this cohort (Fuller et al., 2015). Since this date the professional game has seen the introduction of a number of education initiatives, changes to the on-field (introduction of the temporary substitution) and off-field (graduated return to play guidelines) management and an increase in media attention. It is not known whether these changes have gone some way to improving the level of reporting, the recognition and the management of concussion in this cohort. This thesis (specifically chapters 3 and 4) will aim to address this research gap.

2.4.6 The Epidemiology of Concussion in Contact and Collision Sport

It is perhaps not surprising that combat (rather than contact or collision) sports such as boxing, mixed martial arts (MMA) and taekwondo appear to have the highest incidence of concussion of all sports (Koh et al., 2003, Noble and Hesdorffer, 2013). One such study

concluded that the rate may be 3 times higher (8 times higher when considering time as an exposure) in mixed martial arts than American Football (Zemper and Pieter, 1994). In a recent study by Hutchison et al. (2014), head trauma (defined as knock-outs and technical knock-outs) occurred in approximately one third of mixed martial arts bouts (31.6%). In addition to combat sports, equestrian sports have also shown a high prevalence of concussion. In a recent 7-season study of amateur and professional jump and flat jockeys, 15% were considered concussed with the highest incidence seen in amateur jump jockeys (Rueda et al., 2010). Other sports in which high incidence of concussion have been identified include cheerleading (20% of all injuries; Marar et al., 2012) and winter sports. In a study of injuries sustained at the 2010 winter Olympics, 7% of all injuries were concussion with snowboarding and bobsleigh having the highest incidence rates (Engebretsen et al., 2010). The following paragraphs highlight the epidemiology of concussion in professional team sports in more detail.

2.4.6.1 Soccer

Soccer is often associated with a lower risk of concussion than other contact sports (Marar et al., 2012) but concussion rates are still moderate with a number of high profile cases being publicised during the 2014 World Cup (Junge and Dvořák, 2015). Head injuries (including concussion have been shown previously to account from 4-22% of all injuries in soccer (Al-Kashmiri and Delaney, 2006). Recently, the incidence rate of match concussions in soccer has been reported to be 0.06/1000 hours or, 0.4 concussions per team per season (Giza et al., 2005, Nilsson et al., 2013) for both men and women, although in international competition this has been shown to be much higher at 1.1/1000 player hours (Dvorak et al., 2007, Fuller et al., 2005). In a recent study by Nilsson et al. (2013), concussions were 78 times more likely to occur in match play than in training (RR 78.5 95%CI: 24.4-252.5) with defenders highlighted as being the only position with an increased risk of sustaining a concussion when compared with all other positions (RR 1.8 95%CI: 1.0-3.1).

2.4.6.2 Ice Hockey

It has been suggested that Ice Hockey has the highest incidence of concussion of any contact or collision sport (Koh et al., 2003). However, a recent systematic review of concussions in Ice Hockey once again highlighted the variable nature of injury reporting in this sport, due to the use of multiple definitions of time-loss injury and specifically, time-loss concussion. This coupled with the potential for underreporting outlined above make the formulation of meaningful conclusions difficult to reach (Ruhe et al., 2013). This assertion led to the review recommending that a standardised definition of concussion be

used in all future studies. In the review, seventeen studies met the inclusion criteria and the incidence of concussion ranged from 0.2 to 6.5 /1000 game hours or 2-22% of all reported injuries during the study periods. In a more recent study of injury incidence during men's international competition during 2006-2013, around 10% of all match injuries were concussions with 11.5% of players who had been diagnosed with a concussion returning in the same game. The majority of players returned within one week (53.8%) but 7.7% of players were absent from training or matches for more than 3 weeks. It is unclear how these proportions changed over time during the study as data were presented as overall means rather than on a seasonal basis. In the only study where team clinicians agreed on an operational definition of concussion before the start of data collection the incidence was far higher than in any other published results (6.5/1000 match hours; Tregner & Lorentzon., 1996).

2.4.6.3 American Football

In 1995, the national football league (NFL) started a data collection of clinical concussion parameters focusing on the incidence, severity and circumstances at the time of injury (Pellman et al., 2004). A series of studies were then published based on these data during the period 1996-2001. The number of concussions per team-game during was reported as 0.21, with around two thirds of concussions (67.7%) being caused by contact with the opposition's helmet. More recently, data collected on the same cohort during 2002-2007 was compared to the original data from 1996-2001 (Casson et al., 2010). The findings were remarkably similar to the period 1996-2001 with 0.19 concussions per team-game or, or approximately 1 concussion every 2.5 matches. However, the severity (number of days lost from training or match play) did change significantly (1.92 versus 4.73 days) indicating that clinicians were becoming more conservative regarding the timing of the return to play decision. Moreover, significantly fewer players returned to play during the same game in the period 2002-2007. Overall, the incidence of concussion was higher in both studies for players in high speed positions (e.g. wide receiver and quarterback). It should be noted that thus far, concussion rates during practice have not yet been reported in this sport.

2.4.6.4 Australian rules football

In a recent paper by Orchard et al. (2013) investigating 2 decades of injury surveillance data in the Australian Football League (AFL), the incidence of concussion was approximately 0.5/1000 player hours. However, the true incidence of concussion in the AFL is likely to be much higher as the injury surveillance data only includes injuries that cause a player to miss a match (Hrysomallis, 2013). The actual value is thought to be nearer 5-6 concussions/1000 player hours or 6-7 concussions per team per season

(Australian Football League, 2012). If these estimates were to be accurate, this would bring the incidence rates of concussion in Australian football in line with the incidence rates previously reported in professional Rugby Union (Fuller et al., 2015, Kemp et al., 2008).

2.4.6.5 Rugby League

In comparison to other collision sports, there are a limited number of studies available in Rugby League that report the incidence of concussion (Gardner et al., 2015a). In a recent review by Gardner et al. (2015a) that investigated all studies between 1900 and 2013 that focused on Rugby League, only 39 studies (from a total of 199) specifically reported concussion incidence, with only 6 studies presenting the epidemiology of concussion as the primary aim of the publication. In summary, the incidence of concussion varied between 0.0 (King et al., 2006) and 40.0 (Gabbett, 2003) per 1000 match hours with differences in sampling, level of play and injury definitions cited as the most likely cause of the large variation in incidence. Gardner and colleagues also suggested that the most reliable studies (those that included a strict criterion for injury and concussion) estimate that concussion incidence is between 8.0 and 17.5 injuries per 1000 hours. Specifically, concussion rates in professional Rugby League have been shown to be between 9.8 and 28.3 concussions per 1000 player hours (Hinton-Bayre et al., 2004, Savage et al., 2013). Only a small number of concussions occur in training, with one study reporting an incidence of 0.3/1000 hours (Gabbett, 2004a). Like the majority of collisions sports, most concussions in Rugby League are reported to occur in the tackle (Gabbett, 2003, Gabbett, 2004a, Gissane et al., 2002, Norton and Wilson, 1995), with the ball carrier most at risk. In one study, as much as 29% of concussions were due to illegal play (Norton and Wilson, 1995), highlighting the importance of the strict implementation of the rules and regulations of the sport in the prevention of this injury.

2.4.6.6 Rugby Union

Rugby Union has a high incidence of reported concussion but there have been a limited number of studies undertaken that focus on the epidemiology of concussion in Rugby Union at the elite level. In one study, head injuries in elite Rugby Union were investigated in 757 professional players during three seasons (2002-03, 2003-04 and 2005-06). Nine percent of players sustained at least 1 concussion during the study period and the incidence of reported match concussions was 4.1/1000 hours (Kemp et al., 2008). The average severity (days absence) of concussion was 13 days. In common with Rugby League, the tackle was the most common injury event but unlike Rugby League, most risk was observed in the tackler rather than the ball carrier with 28% of concussions attributed to head on tackles. In a more recent study on the same cohort (Fuller et al., 2015), the

epidemiology of concussion was investigated for the period 2007-11. The match incidence of concussion remained consistent with the previous study at 4.5/1000 hours. The mean severity (days absence) of concussion during this period was lower (10.1 days) than reported in the previous study. The authors noted that 48% of players returned in less time than the minimum of 6 days currently recommended in the World Rugby guidelines and that this warranted further investigation. Fuller and colleagues also commented that more recently, there appeared to have been an increased awareness and behavioural change amongst players, medical staff, coaches and referees with regards to concussion, likely as a result of ongoing national and international governing body education initiatives and a significant increase in media exposure (Fuller et al., 2015). This assertion highlights the need for further investigations that could yield comparable incidence data for the most recent seasons (2012-15) that coincided with the introduction of the initiatives and increased awareness mentioned above. Indeed, in one study, the incidence of concussion was described during three seasons (2011-14) in one international team. The incidence of reported match concussion in this study was 13.5/1000 player hours (Moore et al., 2015). Thus, chapter 3 of this thesis will aim to describe the profile of time-loss match concussions in professional Rugby Union during this period.

2.4.6.7 Summary

In general, the correct identification and diagnosis of concussion in professional sport is challenging. It would appear that, specifically, difficulties in immediately recognising a concussive event and the potential for players to underreport concussion are the key barriers to effective concussion management. The incidence values presented in the extant literature once again highlights the difficulties in comparing epidemiological data between sports, particularly when there is no widely recognised operational definition of concussion (Quarrie and Murphy, 2014). Therefore, the reported incidence rates in the literature to date are likely to be a minimum estimate of the actual incidence of concussion and therefore should be interpreted with caution. Overall, it is clear that a better understanding of the current levels of concussion risk and a clearer picture of timing of return to play within each sport will help to direct future research efforts, education strategies and medical management practices designed to improve player welfare.

2.4.7 Return to Play Following Concussion

Once the potential for concussive injury has been identified, the player removed, and concussion has been confirmed, the timing of a player's return to play is the most important decision for the clinician (Aubry et al., 2013). This decision is especially important as recent literature has highlighted the potential long-term neurocognitive

consequences (see the section below) associated with premature return to play (Gardner et al., 2013, McKee et al., 2013). In addition to providing specific and clear guidance on acute concussion management, guidance on return to play following concussion in Rugby Union is provided by World Rugby; table 2.2). These guidelines were extensively updated in late 2011 and are consistent with the 2012 Consensus statement on concussion in sport (McCrory et al., 2013b).

Table 2.2: World Rugby Graduated return to play guidelines (adapted from the 4th international concussion consensus statement)

Stage	Recommended Activity
1	Rest: Complete physical and cognitive rest until asymptomatic
2	Light aerobic exercise: Walking,swimming,stationary cycling
3	Sport Specific Exercise: Running Drills,
4	Non-contact training drills and progressive resistance training
5	Full contact practice
6	Return to play

Following physical and cognitive rest, protocol-guided return to play such as the example outlined above is believed to be essential in acute concussion care (Echlin et al., 2010). Although standardised guidelines are important for providing best practice care advice for clinicians and consequently best practice care for players, there is currently a limited evidence base for the current return to play guidelines (Broglia, 2015). So whilst it is agreed that a standardised graduated return to play process is fundamental for safe return to play, further research is needed to establish whether the content and/or the length of the current best practice guidelines are optimal. In common with the challenges faced when making a diagnosis of concussion, the timing of a safe return to play is also challenging for clinicians as there is also a distinct absence of an unequivocal threshold and diagnostic procedure to assess recovery (McCrory et al., 2013a). The management of players that have sustained a sports related concussion is complicated further by the possible individual variation of the neurological changes that occur in the first few days post concussion (Putukian et al., 2013). As a result of this heterogeneous presentation, each concussion should be managed on a case by case basis whilst still considering best practice guidelines.

Although best-practice guidelines are provided in Rugby Union, adherence to these guidelines at the elite level remains unclear. At the schoolboy and community levels in Australia, Hollis et al. (2012) found that the majority of players who sustained a

concussion returned in 3 days or less and that 78% did not receive any return to play advice at all. All 187 players who reported a concussion failed to adhere to the minimum three week stand-down (the best practice guidelines for this level of play at the time of the study). It should also be highlighted that issues with adherence to return to play guidelines is not unique to Rugby Union with 56% of 92 English professional football league teams not following best practice concussion guidelines (Price et al., 2012). Furthermore, approximately one third of clubs were using outdated stand-down periods to manage a player's return to play pathway.

2.4.8 The Risk Factors for Concussion

The identification of factors that may make a player more susceptible to sustaining a concussion is clearly of importance. Firstly, it enables clinicians to direct appropriate treatment modalities and return to play management towards specific cohorts of players. Secondly, it helps to structure and direct future injury prevention strategies and thirdly, risk factor identification can help to further the current understanding of the underlying mechanisms of concussive injury (Abrahams et al., 2014). Although the exact aetiology of concussion still needs to be established, previous research in other contact sports suggests that the risk of concussion may be modulated by several factors such as age, gender and history of previous concussions (Echlin et al., 2010, Guskiewicz et al., 2005, Makdissi et al., 2013b, Schick and Meeuwisse, 2003) with further research into at risk groups (younger athletes and females) being recommended as a priority (Clay et al., 2013). However, in a recent systematic review of sports concussions by Abrahams et al. (2014), 86 articles with a level of evidence between I (randomised controlled trials and high-quality prospective cohort) and III (case-control) were studied. The results suggested that history of concussion and match play were the only two risk factors for concussion that had a high level of certainty (consistent results from level I studies).

Another commonly cited modifier for an individual's concussion risk during participation in contact sport is the use of protective equipment. In Rugby Union, wearing protective equipment is an optional consideration (unlike in other sports such as Ice Hockey and American football) and ultimately, remains the decision of the player (with the exception of mouth guards which are mandated as part of the professional medical minimum standards in this cohort). Ongoing research in this area is important because in the absence of an objective diagnosis of concussion, the best method of treatment is considered to be prevention (Benson et al., 2013). In a recent study conducted in professional Rugby Union, 82% of players, 66% of coaches and 64% of referees thought that headgear reduced the risk of concussion (Mathema et al., 2015), however, it is thought that as little as 7% of

players wear headgear in the professional game (Kemp et al., 2008). Despite the beliefs of the majority of players, coaches and referees outlined above, there is no clear evidence to suggest that headgear reduces the risk of sustaining a concussion in contact sport (McCrory et al., 2013b) or specifically in Rugby Union (Kemp et al., 2008, McIntosh et al., 2009). It should be noted that headgear may however be effective in reducing the incidence of superficial scalp and facial injuries (Jones et al., 2004). Similarly, the majority of research that has studied the effect of mouth guards on concussion risk has also shown no clear protective effect (McCrory et al., 2013b). However, mouth guards have often been shown to reduce the risk of orofacial injuries (Abrahams et al., 2014). This assertion has already been highlighted in Rugby Union when a 47% reduction in dental injuries coincided with the introduction of a mandatory law for wearing mouth guards in the professional game in New Zealand (Quarrie et al., 2005).

It is also plausible that players may in fact increase their risk of injury as a result of risk compensation whilst wearing protective equipment. In a study of male youth Rugby Union players, those that wore headgear believed that they could tackle harder (Finch et al., 2001) and the incidence of concussion was higher in university Canadian football players that wore a mouth guard when compared to those that did not (Delaney et al., 2002). Overall, the ability for protective equipment to mitigate the risk of concussion in professional Rugby Union is most likely trivial but suitably powered prospective cohort studies are necessary in order to confirm this assertion.

Currently, there are few studies that focus on the risk factors of concussion specifically within Rugby Union and furthermore, the variable definitions of concussion utilised within different studies has so far made it difficult for risk factors to be identified (Gardner et al., 2014). There is some evidence to suggest that a player's concussion history is associated with decreases in cognitive functionality in Rugby Union players. In a study by Gardner et al. (2010), investigating processing speeds in Rugby Union, 34 players with a history of 3 or more concussions (but none in the last three months) had significantly lower processing speeds than 39 players who had not had a reported concussion. These findings support those from an earlier study in Rugby Union that highlighted reduced processing speeds in a group of elite players that had sustained more than 2 concussions (Shuttleworth-Edwards et al., 2008) but are not supported by a large scale multi-sport study of college athletes where no correlation between processing speed and the number of reported concussions was found (Bruce and Echemendia, 2009). These studies are not without limitation; the number of concussions was based on self-reported information and was therefore susceptible to recall bias. In addition, no information regarding the severity of the previous concussions

were provided even though it has been shown to influence long-term consequences following concussion in a previous study (Bruce and Echemendia, 2009). Overall, there is a paucity of available evidence that investigates the association between concussion and intrinsic and extrinsic risk factors in professional sport. Without this information, establishing the fundamental components for concussion prevention in contact sport (without dramatically changing the laws of the game) is problematic.

2.4.9 Concussion as a Risk Factor for Subsequent Injury

Evaluating the association between a primary and subsequent injury may provide important information that is necessary for the overall protection of athlete health in the short, medium and long term. In addition, further understanding of any link between concussion and other injuries specifically is likely to provide insight into the pathophysiology of concussion and, in turn, aid the formation of novel diagnostic and rehabilitation paradigms. In the first study to show concussive injury as a risk factor for subsequent injury, Nordström et al. (2014) showed that the risk of sustaining an injury in concussed professional European soccer players was approximately 50% greater in the following 12 months than their non-concussed counterparts. It is important to note that 46 teams took part in the study and that the diagnostic criteria of concussion was not standardised for all teams. In another study, 3647 retired National Football League (NFL) players were asked to take part in a concussion history survey. Of the 2429 respondents, 61% reported sustaining at least one concussion during their career and players sustaining 1, 2 or 3+ concussions were 18-63%, 15-126% and 73-165% more likely to report a musculoskeletal injury during their career than those that did not report a concussion on the survey respectively (Pietrosimone et al., 2015). However, the survey did not allow the authors to comment on whether the reported musculoskeletal injuries came before or after the concussion event. Concussion as a risk factor for musculoskeletal injury has also been investigated in a 2 year multi-sport (including both contact and non-contact sports) study by Lynall et al. (2015). Within 1 year post-concussion, the concussed group (n=44) were almost twice as likely to have suffered a lower extremity muscle injury when compared to those players that had not reported a concussion (n=58). In the 180 days post-concussion, the concussed group was also more than twice as likely to have sustained a lower extremity muscle injury when compared with the same time period before they sustained a concussion. At the time of writing, no study investigating concussive injury as a risk factor for subsequent injury exists in Rugby Union therefore chapter four of this thesis will aim to investigate this important association.

2.4.10 Potential Long-term Implications – Chronic Traumatic Encephalopathy

Chronic Traumatic Encephalopathy (CTE) has received remarkable media attention in recent years, primarily fuelled by the publication of autopsy case studies, retrospective surveys and the conclusion of a high profile legal case against the NFL in America. Broadly speaking, CTE is defined as a progressive neurodegenerative disease (usually occurring 10-20 years after an athlete retires) marked by a distinctive accumulation of tau positive neurofibrillary tangles (Johnson et al., 2015a) separating the diagnoses from Alzheimer's disease. There have been a number of reported case studies that have indicated posthumously the presence of CTE pathology in retired athletes and military personnel (McKee et al., 2013, Omalu et al., 2006, Omalu et al., 2005, Omalu et al., 2010) with an exposure to head trauma the primary commonality between subjects. It has also been suggested that even repetitive low-level head trauma that does not lead to a diagnosed concussion (such as heading a football) may also significantly increase the risk of neurological disorder (Chiò et al., 2005). However, not all individuals that participate in contact sports seem to be affected, suggesting that other non-modifiable and modifiable factors (e.g., genetics and substance abuse) may also be important to consider. Previously, it has been proposed the prevalence of ApoE4, a genetic marker for neurodegenerative disease, was not different in those athletes diagnosed with CTE compared with the general population (Bertram et al., 2007, Kutner et al., 2000), although it is accepted that both studies were underpowered. Furthermore, there is currently a scarcity of evidence to support the notion that the diagnosis of CTE is more common in athletes with a history of concussion than those without (Gilbert, 2015, Hazrati et al., 2013) or even that neurocognitive decline and symptoms of depression are greater in contact sport athletes compared with the general population (McCrory et al., 2013c).

Research investigating the incidence and prevalence of CTE in non-helmeted contact sports remains in its infancy and, as a consequence, there is a paucity of research concerning CTE in Rugby Union (Patricios and Kemp, 2014). Neurologists have long suspected that the long-term implications of repetitive head impacts could pose a significant problem in Rugby Union because of the emphasis on high-speed "hits" (Lawton, 2014) and even though tackling above the shoulders is illegal in the laws of the game, such tackles do occur; furthermore, the head and the brain can still receive trauma during 'normal' tackling and in other contact-orientated facets of the game (Fuller et al., 2007a). Despite these observations, only 2 cases of CTE have been reported in Rugby Players (Patricios and Kemp, 2014), though it should be noted that the majority of the research so far has been carried out in amateur populations. In a recent (*unpublished*) study of 131 retired elite Rugby Union players, the majority of players displayed no reduction in

cognitive function when compared with age-matched controls on an individual basis (Hume et al., 2015). However, on average, the retired player cohort exhibited greater variability in their test results and performed slightly worse than a group of non-contact sport controls in the four cognitive domains that were tested (complex attention, cognitive flexibility, processing speed and executive function).

At the time of writing, no published prospective or cross-sectional studies relating to CTE could be found and, thus, it is not possible to determine causality or risk factors for this pathology with any level of certainty at this time (Gardner et al., 2013, McCrory et al., 2013c). In addition, it should also be recognised that case reports are also inherently susceptible to selection bias (Maroon et al., 2015). Even though the extent of the long-term risk of CTE to contact sport athletes is still to be established, policy makers in contact sports should remain cautious in their approach to providing concussion management guidelines to their athletes and clinicians until high quality longitudinal prospective studies are available in the research domain (Gilbert, 2015). One problem with trying to establish the risk of any long-term injury or condition is that the majority of research paradigms adopt a traditional approach to risk-management in sport (Fuller and Drawer, 2004) that often do not consider the long-term implications of injury. Moreover, conventional epidemiological measures of risk such as injury burden are not appropriate for ascertaining long-term risk as they only consider the risk of injury in the acute sense (i.e. during participation). Ultimately, assessing the association between a particular exposure and long-term health is, in general, challenging and thus, there is a paucity of unequivocal data in the sporting setting.

2.4.11 Summary

Overall, whether there is an increased risk of long-term neurocognitive decline in professional contact sport athletes remains unclear. Although this thesis will not be focused directly on the long-term clinical outcomes of concussion, it has been suggested that the way in which a player is managed following a concussion can influence a player's long-term risk (Gardner et al., 2013, McKee et al., 2013). Therefore, it would seem logical that if the management of players following a concussion could be improved, the possibility of any long-term risk to neurocognitive function could be abated. For that reason, chapters 3 and 4 of this thesis may both directly influence short and medium term clinical practice as well as having the potential to indirectly improve long-term player health.

2.5 TRAINING LOAD

2.5.1 Measuring Training Load in Contact Sports

To maximise physical capacity, training should be accurately planned, monitored and implemented (Lambert and Borresen, 2010). The stochastic nature of training activities in collision based sports provide a unique challenge for coaches, as training load quantification needs to account for the impacts that the player sustains (Clarke et al., 2013) and coaches must find a balance between prescribing loads that will improve performance (Foster et al., 1996) but that don't significantly increase the risk of overtraining and injury (Gabbett and Jenkins, 2011). Training can be described in terms of its process (external load) and outcome (internal load; figure 2.5). The external training load constitutes the training stimulus planned by the coaches (i.e. distance run or weight lifted) whereas, the internal training load can be simplistically described as the players overall response to the external load (i.e., heart rate or rating of perceived exertion; Impellizzeri et al., 2005) and reflects the difference between a negative function (fatigue) and a positive function (performance). Internal load is likely to be influenced by both the external load and other modifiable and non-modifiable factors such as genetics and the athlete's fitness level at the start of the session (Bouchard and Rankinen, 2001). It is important for coaches to be able to quantify both the internal and external load as external training loads confirm if planned training outcomes are achieved, whereas internal training load measures can be used to determine how players are responding or coping with the prescribed training stimulus (Scott et al., 2013). Whilst there is still no 'gold standard' to measure training load (Veugelers et al., 2015), in recent years, the use of Global Positioning Systems (GPS) and accelerometer technology in measuring external training load has increased in team sports (Colby et al., 2014) and is particularly prominent at the elite level football (Akenhead and Nassis, 2015) and Rugby Union (Bradley et al., 2015). However, even though this technology continues to evolve, the validity of these measures in intermittent team sports is yet to be fully established (Chambers et al., 2015, Jennings et al., 2010). Similarly for internal load, currently, the only widely accepted measure (beyond simple heart rate monitoring) used in professional team sports the session rate of perceived exertion (sRPE) method proposed by Foster (Foster et al., 1995). In fact, a recent review highlighted the lack of correlation between subjective and objective measures of training load with subjective measures showing superior sensitivity and consistency when compared with their objective counter-parts (Saw et al., 2015).

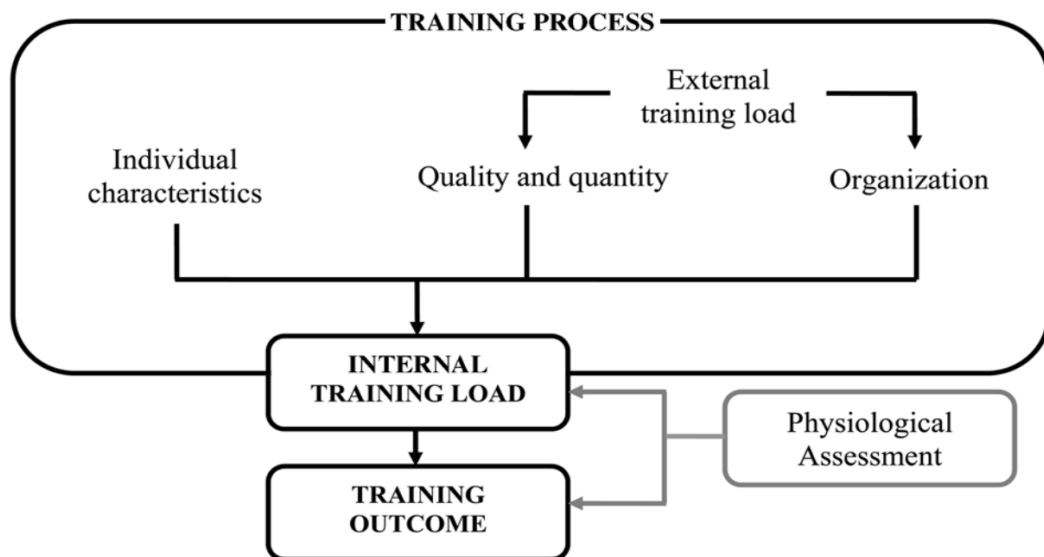


Figure 2.5: The training load model: external and internal training load (Impellizzeri et al., 2005)

2.5.1.1 Session-RPE

This method requires athletes to subjectively rate the intensity of the training session using a rating of perceived exertion (RPE) according to the category ratio scale proposed by Borg (1998). This intensity value is then multiplied by the training duration (minutes) to create a single measure of internal training load in arbitrary units (AU). Whilst there are other methods for the overall monitoring of internal training load many of these are invasive and difficult to apply in a field based setting (Borresen and Lambert, 2009). A clear advantage of utilising session RPE as a method of quantifying training load is that it is inexpensive, simple to administer and practical to apply in an elite population (Clarke et al., 2013). In addition, while training load assessment using heart rate measures is well regarded and utilised in endurance sports, this method has been questioned in team sports since the overall training load within a training block often comprises workouts of varying modalities such as resistance training (Borresen and Lambert, 2009). These modalities often do not induce large changes in cardio-respiratory load and thus, this type of loading upon a player cannot be captured by heart rate data alone.

Importantly, the session RPE method has previously been shown to be a valid method for estimating exercise intensity (Dunbar et al., 1992, Impellizzeri et al., 2004a) and positive correlations of 0.89 and 0.86 have been reported with training heart rate and training blood lactate concentrations, respectively, during typical rugby league training activities (Gabbett and Domrow, 2007). Conversely, it has been suggested that session RPE may not be suitable to reflect the changes in underlying physiology that result from frequent collisions

and intermittent high speed running in contact team sports (Lambert and Borresen, 2010). However, more recent studies have negated this argument by showing moderate to strong correlations between session RPE and various internal and external load measures in collision sports such as professional Rugby League (Lovell et al., 2013) and Canadian football (Clarke et al., 2013). Lovell and colleagues (2013) specifically identified large correlations ($r = 0.55$) between session RPE and the intensity of impacts. These more recent findings confirm session RPE as an inexpensive, non-invasive and valid global measure that can be used to estimate training load in team collision sports.

2.5.2 Training Load Measures as Risk Factors for Injury in Collision Sport

Training load has been previously highlighted as a modifiable risk factor for injury within collision sport. Along with daily training load as a risk factor (Gabbett, 2010), previous literature has suggested that a multitude of additional training load indices may have the potential to cause injury. The aim of this section of the literature review is to describe the key findings from extant literature concerning collision sports that involve these indices (table 2.3).

Table 2.3: Training load measures, definitions and supporting literature.

Training indices	Definition and supporting literature
1,2,3 and 4 weekly cumulative load	The sum of the previous 7, 14, 21 and 28 days load (Rogalski et al., 2013)
Week to week change in load	The absolute difference in training load from week to week (Rogalski et al., 2013)
Training Monotony	The day to day variability of training load within a given week [daily mean/standard deviation] (Foster, 1998a)
Training Strain	Weekly training load x training monotony (Foster, 1998a)
Training Stress Balance (acute to chronic workload ratio)	The ratio of a players acute (1 week) and chronic (4 week) workload [acute workload/chronic workload] (Hulin et al., 2013)

The first training load studies in collision sports were conducted in Rugby League. Gabbett (2004b) reported a significant positive correlation ($r = 0.86$) between training load and injury incidence for 79 sub elite rugby league players during one competitive season. This study also found significant positive correlation with match load ($r = 0.86$) and injury

occurrence (figure 2.6). In a further study exploring training load and injury incidence in professional Rugby League the findings were similar, with training load significantly ($r = 0.82$) related to overall injury rates (Gabbett and Jenkins, 2011). Gabbett and colleagues also Gabbett (2010) provided the first study in collision sport to investigate the feasibility of predictive modelling (via logistic regression) using training load as a risk factor to predict non-contact soft tissue injuries in 91 elite rugby league players over 2 seasons (Gabbett, 2010). Injury prevalence in the model was calculated as the proportion of players injured when actual training loads exceeded planned training loads by a moderate amount (effect size = 0.5). In this cohort, the model was shown to be both sensitive (87%) and specific (99%) for the prediction of non-contact, soft-tissue injuries. In addition, players were 50-80% likely to sustain an injury within the training load range 3000 – 5000 AU. Lower training loads could not be tolerated towards the end of the season with players 50-80% likely to sustain an injury within the range 1700 - 3000 AU.

A recent study of 46 elite AFL players was the first to explore the association between injury and a) weekly cumulative loads for 1, 2, 3 and 4 week periods and b) absolute week to week changes in load (Rogalski et al., 2013). The study concluded that as the sum of 1 and 2 weekly load or change from previous to current week loads increased, so does risk of injury. It is important to note however that for future studies that explore training load variables such as 1, 2, 3 and 4 weekly loads, the researchers should consider the likelihood that these measures are highly correlated. Players who experienced a previous to current week change in load of >1250 AU in this study were found to be 2.58 times more likely to be injured in comparison to the reference group of <250 AU absolute change (+/-) in load. From a practical perspective, week to week changes in load may be especially important to consider when a player returns following injury and may not have time to gradually increase their training load thus potentially increasing their risk of re-injury. Interestingly, in the same population that used an external measure of training load (GPS), three-weekly cumulative loads were also associated with an increased risk of injury (Colby et al., 2014).

Conversely, in a study of 16 Australian Football League (AFL) players no significant relationship between weekly training load and injury and illness risk across 15 weeks of pre-season was found (Piggott, 2008). In addition, Killen et al. (2010) also failed to identify any association between training load and injury incidence in a 14 week pre-season study involving 36 elite rugby league players. It is important to note however that it is likely that both of these studies lacked the statistical power to elucidate any true associations between training load and injury risk (Colby et al., 2014).

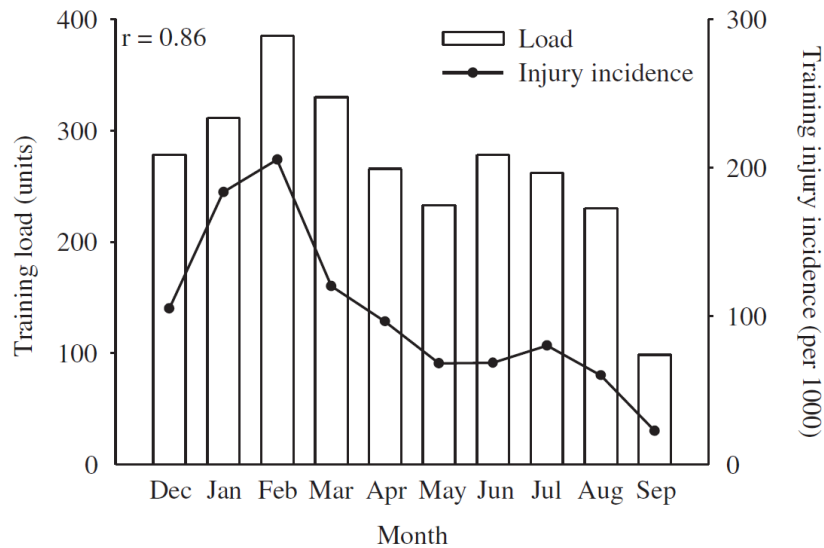


Figure 2.6: The influence of training load (AU) on training injury incidence in semi-professional Rugby League (Gabbett, 2004b)

In addition to the aforementioned daily loads, weekly cumulative loads and week to week changes in load, there are other training indices within the literature that have also been alluded to as potential risk factors for injury. It has been postulated that the variation and pattern in how training load is prescribed may also play a key role in contributing to the risk of injury. The concept of quantifying 'training monotony' was first introduced by Foster (Foster, 1998a). 'Training monotony' is a measure of the regularity of training within a week therefore; a high monotony score indicates a large load combined with little variability in load across a week (small standard deviation). A low monotony score would indicate lower training load and high variation in training during the week (large standard deviation). Foster suggested that lighter training days need to be periodised each week to allow a given overall training load to be accomplished with comparatively fewer negative outcomes (Foster et al., 2001). Since it is plausible that high monotony and high training load may individually not have an impact on injury incidence/severity, but that the two factors combined could result in a significant change in injury risk, Foster also suggested that the product of training load and training monotony, "training strain," may also be related to injury risk (Foster, 1998a).

Despite these original conclusions, hitherto, only one study has explored the association training monotony and training strain with injury risk in collision sport. Piggott (2008) found no relationship between training monotony and training strain on injury and illness rates in professional AFL players. The lack of statistical power in this study has been

highlighted previously in this section. Particularly, the reported injury incidence was much lower than expected during the 15 week study duration. In other team sports however, Training monotony and strain was shown to have a significant association with traumatic injury with odds ratios (OR) of 2.59 and 1.01, respectively in 53 elite male adolescent soccer players over two competitive seasons. Both of these studies suggested that further research into the impact of these training indices in injury risk warrants further investigation in order to comprehensively assess training load as a risk factor for injury and illness.

Training stress balance (or acute to chronic workload) is a more recently proposed training load measure calculated by dividing the acute workload (1 week) by the chronic workload (4 week) and the output is either a positive (i.e chronic workload is higher than acute workload) or negative (i.e acute workload is higher than chronic workload) training stress balance (Hulin et al., 2013). Training stress balance is modelled on the relationship between fitness and fatigue whereby, the chronic workload is likely to best represent the fitness component of an athlete and the acute workload represents the fatigue component. In a recent study investigating the association of this measure on 28 fast bowlers over 5 seasons, a negative training stress balance was associated with injury in the following week $RR = 2.2$. Fast bowlers that had a training stress balance of greater than 200% were 4.5 times more likely to get injured than the reference group of 50-99% (figure 2.7). Despite these promising original assertions the validity of this measure to monitor injury risk in collision sports remained unclear until a recent study in elite Rugby League players, found that players with a high chronic workload were more resistant to injury when subjected to spikes in acute workload (Hulin et al., 2015) suggesting that players are able to tolerate high acute workloads as long as they have the required level of fitness (an outcome of the high chronic workload) to tolerate these acute spikes in load.

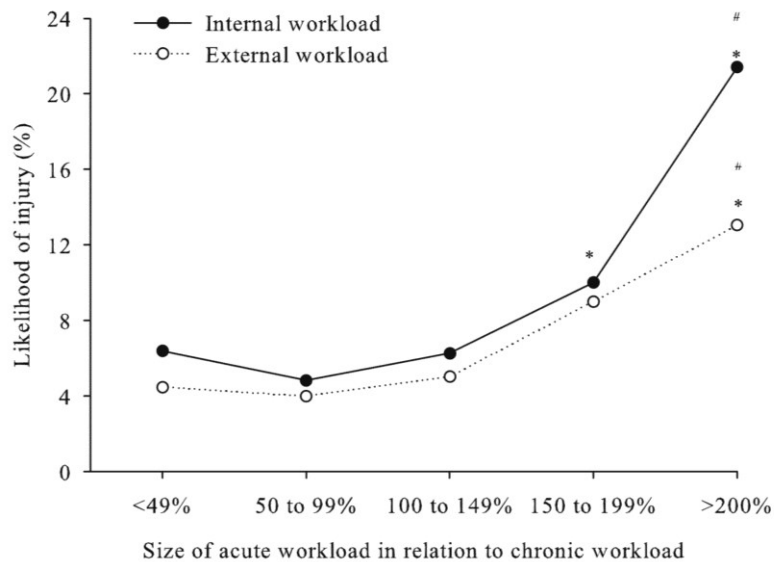


Figure 2.7: Training stress balance and the likelihood of injury in professional cricket fast bowlers (Hulin et al., 2013).

2.5.3 Training Volume in Rugby Union

To date, a small number of studies have investigated the relationship between training volume (duration of training only) and injury risk in Rugby Union. Brookes and colleagues investigated the impact of training volume on the incidence and severity of injuries in 502 professional Rugby Union players. Higher training volumes (>9.1 hours per week) did not increase the risk of injury but did increase the severity of match injuries. The smallest number of days lost due to injury was seen during intermediate training volumes (6.2-9.1 hours per week) suggesting that this volume of training might be protective. One limitation highlighted by the authors was that intensity was not reported and that the use of RPE in the future may provide further insight into the training-injury relationship in Rugby Union. In addition, Viljoen et al. (2009) recorded training volumes within a professional team over a three year period and concluded that a reduction in training volume over three seasons was associated with slight reduction to in-season injury rates. However, it was noted that the team's league position also changed from 3rd to 7th (2002-2004) and thus, did not recommend reducing training volumes too much as the players may no longer be exposed to the required training stimulus in order to be able to compete effectively during matches. To date, training load has not been investigated as a modifiable risk factor for injury in Rugby Union and many of the training load variables have not investigated in any collision sport despite promise in other settings. Chapter 6 of this thesis will aim to investigate the relationship between training load and injury risk in professional Rugby Union.

2.6 ILLNESS IN SPORT

It has previously been suggested that illness appears to be related to an athlete's stress and recovery (Brink et al., 2012). It is thought from previous research that an athlete's immune system becomes compromised when stress reaches demanding levels at which point an athlete's performance tends to suffer (Foster, 1998a). However there is still much debate around whether the changes in immune function that are synonymous with regular exercise produce an increased incidence of infections and illnesses in highly trained athletes (Fricker et al., 2005).

It has been suggested that an elite setting, medical staff may spend as much as 50% of their time treating illness (Derman, 2009) and that the impact of illness upon the ability to train and compete can be just as significant as that of an injury (Engebretsen et al., 2013) however, the reporting of illness data remains in its infancy, with the majority of injury surveillance systems focusing primarily on the collection of injury data alone (Clarsen and Bahr, 2014). The majority of available illness surveillance data is provided from studies conducted during major international competitions (Dvorak et al., 2011, Engebretsen et al., 2013, Engebretsen et al., 2010). Whilst this data provides a good platform for understanding the risk of illness in each particular sport, the nature of these competitions is not likely to reflect the risk to the athlete during normal training and competition within a season. Without this information, the short and long-term risks of participation in a particular sport cannot be fully established (Steffen et al., 2011).

2.6.1 Illness Epidemiology in Rugby Union

During this literature review, only four epidemiological studies that have described the incidence of illness in Rugby Union could be found (Cunniffe et al., 2011, Schwellnus et al., 2012a, Schwellnus et al., 2012b, White and Grant-Kels, 1984). In the first study to explore illness or infection of any type in Rugby Union, White and Grant-Kels (1984) investigated the prevalence of herpes simplex virus in one Rugby Union team. The authors noted that players were susceptible to contracting the infection due to the close contact between players on a regular basis and that all players (n=3) that contracted the virus were forwards. In a broader more recent study, Cunniffe et al. (2011) investigated the illness incidence in 31 elite Rugby Union players from one team during a season. Illnesses were either self-reported using an online diary or reported by medical staff. All complaints were reported regardless of whether a player missed time from training or match play. Ninety-two percent of players sustained at least one upper respiratory tract infection (URTI) during the season (mean number=4) with a mean severity of 4.7 days. In around 25% of cases, the illness reduced the activity of the player, clearly highlighting the clinical and

practical importance of capturing this information as this meant that these players were probably unavailable to train or for team selection. In addition to URTI complaints, 25 gastrointestinal complaints were also reported (40% of players during the season).

In the first multi-team study Schwellnus et al. (2012a) investigated the incidence and severity of illnesses in the Super 14 (now 15) Rugby Union tournament during competition (16 weeks). Two hundred and fifty nine elite players were recruited and all complaints (regardless of time lost) were reported. Illness incidence was reported as the number of illnesses/1000 player days. Over 70% of players reported an illness during the 16 week period and the incidence of all illness was 20.7/1000 player days, with only 16% of these illnesses resulting in time lost from training or match play. In agreement with the previous study by Cunniffe et al. (2011) the most commonly affected systems were the respiratory system (30.9%) and the digestive system (27.5%). In addition, in agreement with White and Grant-Kels (1984) skin infections were common and the authors commented that it was likely due to personal hygiene and the number of contact situations during match and training. In a further study of the same cohort, Schwellnus et al. (2012b) explored the effect of travel on the risk of illness during 16 weeks of competition. The super rugby tournament is unique because it involves clubs from South Africa, New Zealand and Australia and thus involves significant travel and changes in time zones (up to 11 hours). It is a particularly physically demanding competition (Austin et al., 2011a) lasting 16 weeks (as opposed to the English Premiership competition phase of around 40 weeks long). The main finding of the study was that the risk of illness increased 2-3 times (15.4/100 player days versus 32.6/1000 player days for all illnesses) for teams that travelled to a location with more than 5 hours' time zone difference in either direction.

In both studies by Schwellnus and Colleagues, the author notes that due to the unique aspect of the super rugby tournament (short duration and travel), results from these studies are not generalisable to other competitions, no data is currently available for illness in elite European competition. In addition, no study has yet combined multiple seasons of data collection from multiple teams and furthermore, given that the illnesses that lead to players missing time from match-play or training are of importance from both a clinical and performance perspective (squad availability is associated with team success in Rugby Union; Williams et al., 2015) it would seem sensible that future studies in this area should focus on time-loss illness. Thus, chapter 6 of this thesis will aim to address this.

2.7 RESEARCH RATIONALE

This chapter summarises the overarching literature with respect to the field of injury epidemiology in professional sport. In addition, this chapter presents the current evidence in order to highlight some of the significant challenges faced by researchers and practitioners alike in this area of research. Time-loss injuries in professional sport can place huge practical and financial burden on clubs at the elite level. Team success has recently been shown to be associated with squad availability in professional Rugby Union (Williams, 2015b) and, given that the reputation of both player and coach is often measured by performance outcome, the importance of minimising injuries for both competitive advantage and player welfare in this setting is clear. Overall, the incidence of time-loss injury in professional Rugby Union is one of the highest amongst all professional team sports (Williams et al., 2013) but comparison of epidemiological data between sports and between studies often proves difficult due to the lack of consistent definitions and methodology. Therefore, the use of consensus statements to support study definitions and processes should be adopted where possible.

This chapter then provided more detail and highlighted some of the key findings from team sports as a whole but also specifically in the context of professional Rugby Union in three salient areas of player welfare; concussion, training load and time-loss illness. In doing so, this chapter identified some considerable gaps in the current knowledge and, consequently, some novel opportunities for the following chapters within this thesis. Concussion has been described as the number one player welfare issue in Rugby Union (Murray et al., 2015) and on a wider scale, a public health burden (Jordan, 2013). The reported incidence of match concussion in professional Rugby Union is high and remains similar to what has been reported in other contact sports. As a consequence of this rise in incidence, the overall burden (a product of incidence and severity) of concussion continues to rise (Rugby Football Union, 2015). The absence of recent epidemiological data alongside the introduction of a number of player welfare initiatives in the professional game and an increasing public profile of concussion mean that the current ‘size of the problem’ (step one of the injury prevention model; van Mechelen et al., 1992) remains unknown. Furthermore, no information exists regarding the management of players during or the short and medium term clinical outcomes after return to play in professional Rugby Union. It is likely that a better understanding of the current levels of concussion risk and return to play paradigm and outcomes will likely help to direct future research efforts, player education strategies and medical practice within Rugby Union, but will also help to inform future international consensus guidelines.

This literature review has presented associations between training load measures and injury risk in contact sports such as Rugby League (Gabbett, 2010, Gabbett and Jenkins, 2011) and Australian Rules football (Colby et al., 2014, Rogalski et al., 2013) but this potential association has not been studied in Rugby Union. Given the different periodisation patterns and physical demands of training and match-play imposed upon players, it is likely that the training load-injury relationship for each sport (and furthermore each individual athlete) is unique. The players in this cohort are currently limited as to the amount of matches that they are allowed to play during a season as part of the competition agreement, however, there are currently no guidelines or restrictions regarding the amount of training (in general or for particular activities such as tackles) that can be performed during the competitive season. Advances in the understanding of the training load-injury relationship should enable coaching staff to have more confidence that the training loads that they prescribe do not significantly increase a player's risk of injury.

Whilst the integration of time-loss illness into surveillance systems at major sporting tournaments has become commonplace (Dvorak et al., 2011, Engebretsen et al., 2013, Engebretsen et al., 2010), little is known about the burden of time-loss illness in contact sports. Specifically, only a small number of studies were identified concerning the incidence and severity of time-loss illness in professional Rugby Union (Cunniffe et al., 2011, Schwellnus et al., 2012a, Schwellnus et al., 2012b, White and Grant-Kels, 1984) and, as of yet, no study has investigated illness incidence over multiple seasons of competition, or in a competition where the majority of matches are solely contested in one country (the competition structure of most professional leagues). The following experimental chapters are included in this thesis:

- CHAPTER 3: The Changing Profile of Match Concussions and Time to Return to Play in Professional Rugby Union
- CHAPTER 4: A prospective study of the short and medium term clinical outcomes and subsequent injury risk following concussive injuries in professional Rugby Union
- CHAPTER 5: The Influence of In-Season Training Loads on Injury Risk in Professional Rugby Union
- CHAPTER 6: The Epidemiology of Time-loss Illness in Professional Rugby Union

CHAPTER 3: Investigating Temporal Change in Match Concussions and Return to Play in Male Professional Rugby Union Players

3.1 ABSTRACT

Aim: The aim of this study was to describe the reported incidence of match concussions and the time to return to play during 2011-15 and to investigate if the reported incidence and return to play times had changed when compared with previously reported data from 2002-11

Methods: 2248 male professional Rugby Union players competing in 12 seasons of the English Premiership between 2002 and 2015 were included in this prospective cohort study. Match injury incidence was recorded as the number of injuries per 1000 hours. Severities were reported as mean and median days absence. Descriptive statistics were used to show the time to return to play and the associated match event. Differences in the incidence of injury between groups and time periods (2002-11 and 2011-15) were considered significant if the 95% confidence intervals did not overlap.

Results: The reported incidence of match concussion in this study during 2011-15 was 8.9/1000 hours (95% CI: 7.9 – 10.0). Between seasons 2009-10 and 2014-15, the incidence of match concussion increased year-on-year with significant differences in match concussion incidence during 2013-14 and 2014-15 versus 2002-13. Concurrently, there was no significant change in the incidence of all injuries. The mean severity of concussions was 12 days (95% CI: 11-13); there was no significant difference in the mean severity between 2002-11 (11 days 95% CI: 9-13 days) and 2011-15 (13 days 95% CI: 12-15). When compared with 2002-11, the number of players returning to play sooner than the recommended minimum guideline of 6 days in 2011-15 was reduced by more than half from 40% to 19%.

Conclusions: Concussion incidence for 2011-15 was higher than reported previously in this cohort and in other sports. The reported incidence of concussion continues to increase, therefore, future research with a focus on concussion prevention and management should be prioritised. Although it is not possible to separate improvement in reporting practice from any inherent increase in concussion risk, it seems likely that the biggest change is in reporting behaviour and increased awareness rather than in concussion risk *per se*. The reduction in the number of players returning to play before recommended guidelines is encouraging; however, a small number of players still return earlier than recommended.

3.2 INTRODUCTION

The incidence and management of concussion in both competitive and recreational sports has received growing attention in recent years. The initial diagnosis of concussion is notoriously difficult as there is no recognised minimum threshold or single diagnostic test, and clinicians often have to make a rapid on-field assessments to determine players' ability to continue to play safely (McCrory et al., 2013a). Likewise, the timing of a safe return to play is also challenged by the lack of an unequivocal threshold and diagnostic procedure to assess sufficient recovery (McCrory et al., 2013a). Historically, sports-related concussions have been considered to result in transient symptoms and temporary neurocognitive impairment (Rowson et al., 2012) but recent research has suggested possible association between repetitive concussive and subconcussive events and long-term neurological degeneration (Gavett et al., 2011, Lehman et al., 2012).

Over the last two decades, an overall rise in sports-related concussion has been identified (Selassie et al., 2013), although it has been suggested that this increase is likely due to increased awareness and improved identification of symptoms rather than an increase in risk per se (Hootman et al., 2007, Lincoln et al., 2007). Rugby Union is a contact sport with players regularly exposed to collisions and contact events involving the upper body in both match and training environments, with around 450 contact events (approximately 200 tackles) in total per professional match (Fuller et al., 2007a). As a consequence of the significant potential for head impact events in Rugby Union, there is growing awareness of and focus on concussion (Raftery, 2013). Kemp and colleagues investigated head injuries in 757 professional Rugby Union players during three seasons (2002-03, 2003-04 and 2005-06), reporting that 9% of players sustained at least one concussion during the study period and an incidence of reported match concussions of 4.1/1000 player hours. Between 2007-11, incidence of reported match concussions in the same cohort was 4.6/1000 player hours, with 72% of players who had sustained a concussion returning to play within 10 days (Fuller et al., 2015).

Subsequent to both of these studies, as part of an overall concussion management strategy a number of player welfare initiatives have been introduced in top-level rugby. In May 2011, graduated return to play guidelines aligned with the 4th international consensus statement of concussion (McCrory et al., 2013b) were introduced, replacing the previous 3 week minimum stand down (players who were cleared by a neurological specialist could return sooner). In 2012, a standardised off-field multimodal triage protocol in the format of a temporary substitution was introduced with a previous iteration shown to significantly reduce the number of players that continued to play that were subsequently diagnosed as

concussed post-match (Fuller et al., 2014). In 2014-15, mandatory on-line education modules were introduced for players, coaches, medical staff and game officials engaged in professional rugby in England (Rugby Football Union, 2014). In addition to these initiatives, it has been suggested that a substantial increase in media attention has been observed during this period, particularly around the potential long-term effects of concussion on neurological function (Gardner et al., 2014). However, the incidence, severity and timing of return to play for concussion injuries in professional rugby have not been described for the period since 2011, prior to when these changes have taken place. It is hypothesised that the combined effect of these player welfare initiatives will have increased the incidence of reported concussions in recent seasons. Given the reduction in the minimum time to return to play, it is anticipated that the reported average return to play time following a concussive injury will be lower from the 2011-12 season onwards.

A better understanding of both the current levels of concussion risk and how this may have changed since the introduction of the aforementioned player welfare initiatives in the period 2011-15 and a clearer picture of timing of return to play will likely help to direct future research efforts, education strategies and medical management practices designed to improve player welfare in this setting. Thus, the aims of this study were to 1) investigate the reported incidence of match concussion and the time to return to play following concussion and describe any changes in the reported incidence and time to return to play between 2002-15 compared with previously reported data during the period 2002-11.

3.3 METHODS

3.3.1 Participants

Data for 2248 male professional Rugby Union players competing in 12 seasons of the English Premiership between 2002 and 2015 are included in this prospective cohort study. Mean data for the periods 2002-06 (Kemp et al., 2008) and 2007-2011 (Fuller et al., 2015) have been published previously but have been included in this study to allow for a year-on-year comparison with the 2011-15 data. In addition, 2011-15 was also the period that saw the introduction of a number of concussion-focused player welfare initiatives and thus these data were considered separately for analysis, Data were not collected for the 2004-05 season. All 12 clubs participating in the Premiership each season were required to record injury data as part of the competition agreement, and players were included if they were a member of the first team squad and had provided written informed consent (Appendix A1). The study was approved by the research ethics committee of the academic host institution where the project was based for each season (University of Leicester, University of

Nottingham and the University of Bath) and player consent was obtained every season regardless of whether the player had consented to the project previously.

3.3.2 Procedures

All match injuries were reported by club medical personnel on a weekly basis. Staff either completed a standard medical report form by hand (2002-13) or electronically via a medical records system (2013-15) that detailed the injury diagnosis using the Orchard Sports Injury Classification System (OSICS; Orchard, 1993). The form also included other injury specific information reported by the player and medical personnel (e.g. playing position, match event and the time of injury). Strength and conditioning staff at each club reported individual player match exposure so that injury incidence could be calculated. The time-loss injury definition was consistent with that recommended by the Rugby Union consensus statement for reporting injuries (Fuller et al., 2007b). Throughout this study, match-related concussion was suspected on the basis of the on-field presentation of one or more of the typical symptoms, physical signs, or cognitive features described in the 2001 (Aubry et al., 2002), 2004 (McCrory et al., 2005), 2008 (McCrory et al., 2009) and 2012 (McCrory et al., 2013b) concussion consensus statements after a blow to the head or body during a match. All confirmed cases of concussion would have led to time lost from playing and training, resulting in inclusion in this study (Fuller et al., 2007b). For seasons 2002-2011 the return to play guidelines recommended that all players had a 3 week minimum stand down period following a concussion unless cleared by a neurological specialist. From 2011-12 onwards, clubs were advised to manage players according to the graduated return to play protocol set out by World Rugby (World Rugby, 2014) . The protocol comprises 6 stages, with players completing each stage in sequence, and only progressing to the next stage if they remain asymptomatic for an unbroken period of 24 hours. If the player becomes symptomatic they should return to the last step at which they were asymptomatic. If using the protocol correctly, the minimum time to return to play is 6 days from the day of injury (an additional weeks rest at the beginning of the protocol is required for players under 19 years old, making their minimum return time 12 days; Rugby Football Union, 2013).

Injury severity was defined as the number of days absence from full training and/or match play. Ninety-five percent of reported concussions during the study period occurring during match play, so training-related concussions were not included in the analysis. Match concussions were included in the study if they occurred in 1st team Premiership, National and European Cup Competitions. Match concussions that occurred in pre-season non-league matches and those matches classified by club staff as 2nd team were not included

due to the difficulty in capturing player exposure for these matches for the period 2002-2012.

3.3.3 Data Analysis

Match injury incidence (for concussion and all injuries) was recorded as the number of injuries per 1000 hours with 95% Poisson confidence intervals (CI) and were reported by season. Injury Severity was reported as both mean and median days absence from training or match play. Descriptive statistics (proportions) were used to show the time to return to play and the associated match event. Differences in the incidence of injury between groups and time periods (2002-12 and 2012-15) were considered significant if the 95% confidence intervals (95% CI) did not overlap.

3.4 RESULTS

Between 2002 and 2015, 96,260 hours of match exposure were recorded (44,922 hours for backs and 51,338 hours for forwards) giving rise to a total of 8,076 time-loss injuries, of which 559 were reported match concussions (2002-2011: 268; 2011-15: 291). Throughout 2002-2015, 273 concussions were sustained by backs and 286 to forwards. Out of 2248 players that were included in this study (a total of 6243 player seasons), 1956 (87%) did not report a concussion. The overall cumulative prevalence of concussion for the period 2002-15 was, therefore, 13%. In addition, the seasonal prevalence is reported below in figure 3.1. Of the 291 players that reported a concussion during the period 2011-15, 76 reported 2 concussions and 23 reported three or more concussions. The highest number of concussive events reported for one player across the study period was seven. Forty-six players sustained more than one concussion during the same competitive season, with only one player sustaining more than three concussions in the same season.

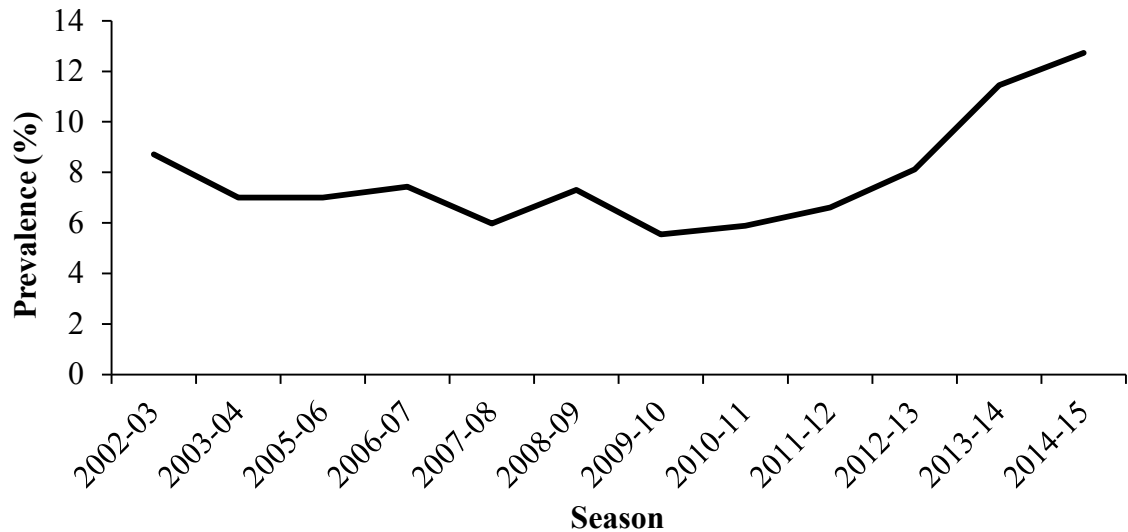


Figure 3.1: The prevalence of concussion by season during 2002-15

3.4.1 Incidence of Concussion & Season Variability

The mean incidence of all match injuries across the study period (2002-15) was 86.2/1000 hours (95% CI: 84.3-88.1) and ranged between 73.0/1000 hours (95% CI: 67.0-79.0) and 100.0/1000 hours (95% CI: 93.0-107.0). There was no significant change in the incidence of all injuries throughout the duration of the study (figure 3.2). The mean incidence of reported concussions across the study period was 5.9/1000 hours (95% CI: 5.4–6.4) and for 2011-15 specifically was 8.9 (95% CI: 7.9-10.0). There was no difference in the incidence between backs (2002-11: 4.6/1000 hours 95% CI: 3.9-5.4; 2011-15: 9.1/1000 hours 95% CI: 7.7-10.7) and forwards (2002-11: 4.2/1000 hours 95% CI: 3.6-5.0; 2011-15: 8.7/1000 hours 95% CI: 7.4-10.2). Between the 2009-10 season and the 2014-15 season, the reported incidence of concussion increased every year, and there were significant differences in the incidence of concussion in seasons 2013-14 and 2014-15 when compared to all other seasons (figure 3.2). For the period 2002-2011, concussion was the 4th most commonly reported match injury. However, from 2011-12 to 2014-15, concussion was the most commonly reported match injury in the English premiership (table 3.1; Rugby Football Union, 2015).

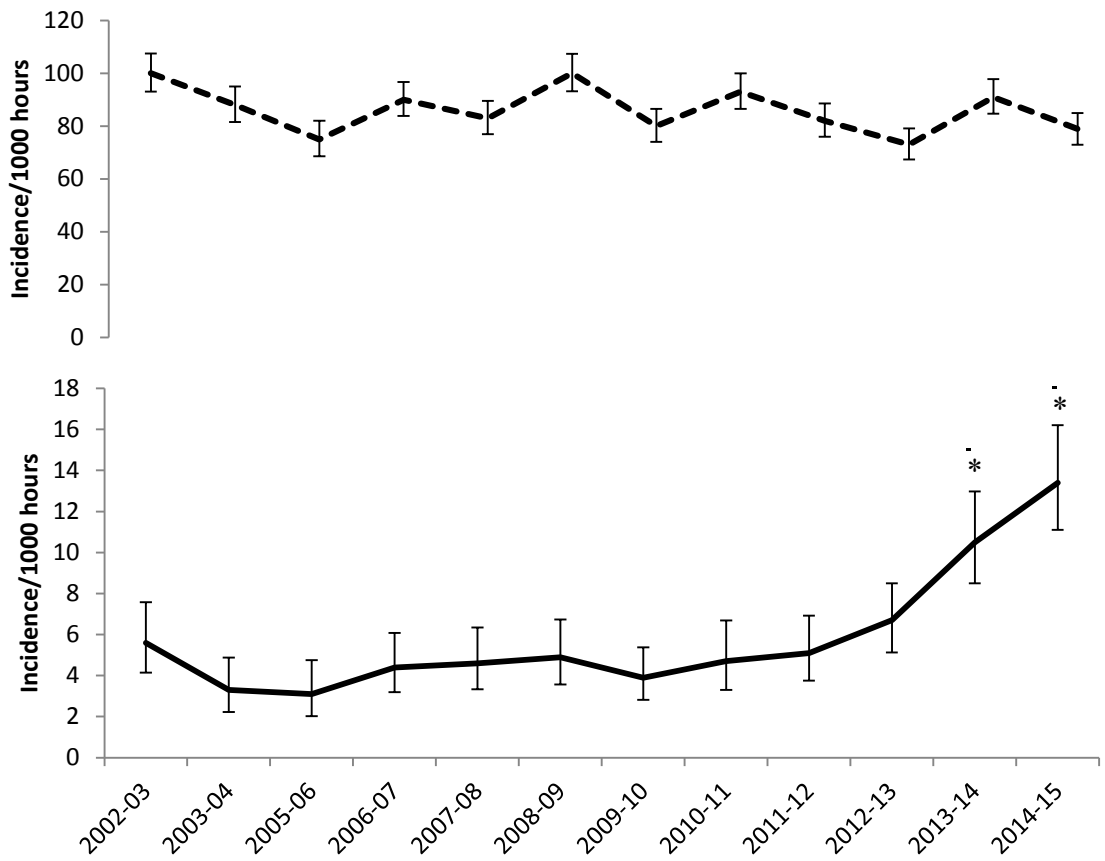


Figure 3.2: The incidence (per 1000 hours) of all match injuries (dotted line) and match concussions (solid line) during 2002-15. Error bars show 95% Poisson CI for each season. *indicates a significant difference with all years 2002-03 to 2012-13.

Table 3.1: The 5 most common match injuries with incidence (injuries/1000 hours) for the period 2002-11 and for the last 4 seasons. Data for the period 2002-14 obtained from the Rugby Football Union (Rugby Football Union, 2015).

Rank	2002-2011	2011-2012	2012-2013	2013-2014	2014-15
1	Thigh Haematoma: 6.6	Concussion: 5.1	Concussion: 6.7	Concussion: 10.5	Concussion: 13.4
2	Hamstring Muscle: 5.2	Hamstring Muscle: 5.0	Hamstring Muscle: 4.9	Thigh Haematoma: 4.2	Hamstring Muscle: 4.4
3	Calf Muscle: 4.4	Thigh Haematoma: 4.9	Syndesmosis: 3.8	MCL Injury: 3.7	Thigh Haematoma: 3.4
4	Concussion: 4.3	Calf Muscle : 4.8	MCL Injury: 3.6	Ankle Lat. Ligament: 2.9	MCL Injury: 3.3
5	MCL Injury: 3.9	MCL Injury: 4.0	Thigh Haematoma: 3.8	Hamstring Muscle: 2.5	AC Joint Sprain: 2.9

3.4.2 Severity and Return to Play

The mean severity of the concussive injuries reported over the whole study period (2002-15) was 12 days (95% CI: 11-13) and the median 9 days. There was no significant difference in the mean severity between 2002-11 (11 days 95% CI: 9-13 days) and 2011-15 (13 days 95% CI: 12-15) or between backs (2002-11: 10 days 95% CI: 9-12; 2011-15: 14 days 95% CI: 12-17) and forwards (2002-11: 12 days 95% CI: 10-14; 2011-15: 11 days 95% CI: 9-13). During 2002-11, 56% of players returned to play within 7 days, 23% in 7-14 days and 21% missed more than 14 days of full training/match play. In 2011-15, 44% of players returned in 7 days, 35% in 7-14 days and 21% missed more than 14 days (figure 3.3). Between 2002 and 2011, 89% of players returned to play within 21 days (the recommended return to play guideline during that period). Between 2011 and 2015, the proportion of players returning in 21 days was 88%. Between 2002 and 2011, 40% returned in less than 6 days (the current minimum number of days for return to play according to best-practice guidelines), whereas during the period 2011-2015, 19% returned in less than 6 days. With only 6% (6 players) returning in less than 6 days following a reported concussion during the 2014-15 season (Figure 3.4).

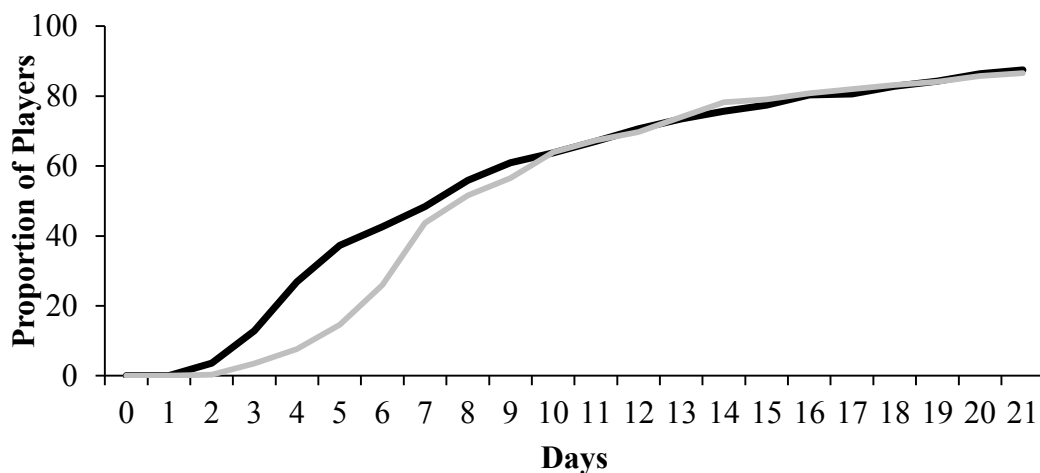


Figure 3.3: Time to return to training/match play (days) after sustaining a concussion during the period 2002-11 (black line) and 2011-15 (grey line).

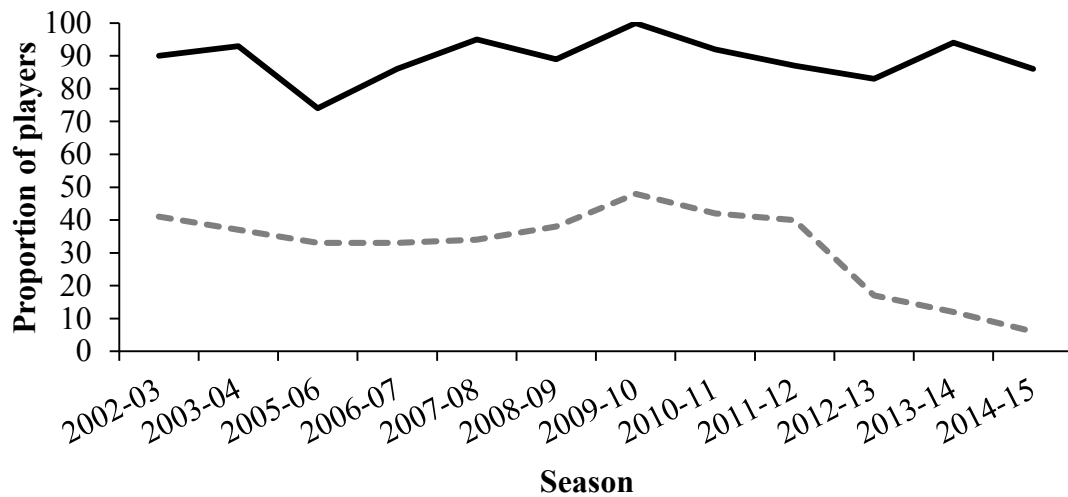


Figure 3.4: The proportion of players with reported match concussions returning to full training/match play <21 days (solid line) and < 6 days (dotted line) 2002-15.

3.4.3 Match Event

In line with the increase in the overall reported incidence of concussion, significantly more concussions were associated with collisions and tackles between 2011 and 2015 than between 2002 and 2011 (figure 3.5). However, the proportion of concussions attributed to each match event was similar throughout the study. The tackle was the main match event associated with concussions during the study period and accounted for more than 50% of all concussions (tackling 32% and being tackled 22%). Data on the number of concussion injuries attributed to illegal collisions was only available from the 2009-10 season onwards, with 12% of match concussions deemed to be associated with an act of foul play.

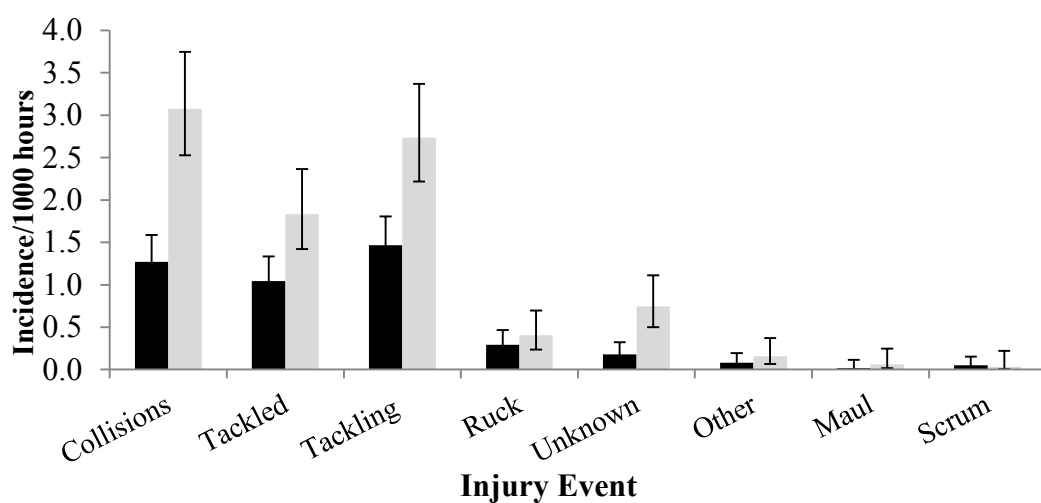


Figure 3.5: A comparison of the incidence of match concussions attributed to each match injury event for 2002-11 (black bars) and 2011-15 (grey bars). Legal and illegal collisions (2009-10 onwards) are combined in this figure to form the collisions group.

3.5 DISCUSSION

The aims of this study were to a) describe the reported incidence of match concussions and the time to return to play during 2011-15 and b) investigate if the reported incidence and return to play times had changed since 2002-11. In agreement with the hypothesis, the reported incidence of match concussion in this study during 2011-15 was 8.9/1000 hours, almost double the incidence previously reported in this cohort (Fuller et al., 2015, Kemp et al., 2008). In addition, concussion increased from being the 4th most common injury between 2002 and 2011 to the most common match injury for the period 2011-15. When compared with 2002-11, the number of players returning to play sooner than the recommended minimum guideline of 6 days in 2011-15 was reduced by more than half from 40% to 19%, respectively. Since 2009-10, this number has reduced year-on-year, with only 6 players (6%) returning in less than 6 days in 2014-15.

Based on the results presented in this study, the reported incidence of concussion is higher than previously reported in other professional collision sports such as Rugby League (King et al., 2014b) and Australian Rules Football (Hrysomallis, 2013). The reported incidence of 13.4/1000 hours during 2014-15 was the highest observed in this cohort, accounting for 17.5% of all match injuries that season. This is similar to the incidence of 13.8/1000 hours reported in a recent study that investigated injury incidence in one international Rugby Union team (Moore et al., 2015). The observation of such a rise in the incidence of concussion is not unique to Rugby Union and has been observed previously in American Football (Lawrence et al., 2015) and in other sports at both collegiate (7% annual increase from 1998 to 2004; Hootman et al., 2007) and high school (16% annual increase from 1997-2008; Lincoln et al., 2011) levels of participation. A change in incidence of this magnitude provides further evidence to support the assertion that concussions have previously been largely under-reported in professional Rugby Union (Fraas et al., 2014). In retrospect, the fact that the incidence of concussion has continued to rise since 2009-10, coupled with the currently unknown levels of under-reporting in this population mean that even the most recent incidence values reported in this study should serve as a minimum estimate.

Identifying the reasons for the sudden increase in the reported incidence of concussion was beyond the scope of this study. However, it has been postulated that the risk of concussion has increased in professional Rugby Union as a result of the magnitude of the forces produced by heavier, faster more powerful players (Murray et al., 2014). Furthermore, it

has been suggested that having taller and heavier players is a prerequisite of team success and that consequently, a culture of “super-sized” players has ensued (Sedeaud et al., 2012b). However, changes in the anthropometric data in this cohort have been described previously (Fuller et al., 2013) and whilst the height and weight of players increased during the study, these increases represented a small, gradual change over a 10 year period. In addition, Usman et al (2011) failed to find any association between a player’s stature and the magnitude of shoulder forces produced in a tackle, suggesting that in a tackle situation (where the vast majority of concussions are sustained), technical coaching rather than a player’s size determines force production. The physical demand placed upon players in order to compete in this competition (the English premiership) are high (Roberts et al., 2008). It has been proposed that increases in match characteristics such as ball in play time, speed of play and the number of contact events have augmented the potential for injury in professional Rugby Union (Austin et al., 2011a, Quarrie et al., 2013). Although no comparative data exists apropos of the English premiership, previous data provides a comparison of the changes in match characteristics between 1972 and 2007 in international Rugby Union (Quarrie and Hopkins, 2007). The advent of professionalism was associated with an increase in the number of passes, tackles, rucks, tries, and ball-in-play time but in a similar fashion, since professionalism, the rate of increase in these characteristics appears to have been gradual. Furthermore, the observed increase in concussion incidence during 2011-15 occurred in the absence of any change in the overall match injury incidence, suggesting that whilst the reported incidence of concussion has increased, the overall risk of injury has remained stable for the past 12 seasons; in fact the incidence of the remaining injuries has slightly reduced. Since a decrease in non-contact injuries and an increase in contact injuries could be masked by the stability of the overall incidence rate, it is important to note that the incidence of other common contact injuries such as shoulder dislocations and acromioclavicular joint sprains have also remained stable during this period (data not shown). If as suggested, changes to player stature and match characteristics had contributed to the rapid rise in concussion incidence, it would seem logical that a similar rise in the incidence of all injuries (particularly other contact injuries) would have also been observed.

It is perhaps more plausible that in agreement with conclusions from previous studies (Hootman et al., 2007, Lincoln et al., 2007), the rapid increase in reported concussion incidence is likely to reflect increased awareness, understanding and improvements in reporting behaviour amongst players, medical staff, coaches and referees as a result of

successful education initiatives and the cascade of noteworthy media exposure. In order to try and contextualise this statement, a rudimentary bibliometric analysis was undertaken (Corlan, 2004) whereby, the total number of publications per year on MEDLINE between 2002 and 2013 had approximately doubled (562171 to 1136936 publications) but during the same period, the number of publications concerning concussion had increased by approximately 4.5 times (119 to 551 publications). It should be noted that whilst the total number of publications increased steadily between 2002 and 2013, the majority of the increase regarding concussion publications (247 to 551 publications) occurred during the period 2009-13. Likewise, the popularity of searches for “ankle sprain”, “anterior cruciate ligament” and “dislocated shoulder” on the internet search engine Google remained consistent relative to the total number of searches during the period 2004-2015. In contrast, the search popularity of “concussion” remained consistent until 2010 after which there was a rapid increase that has persisted over the last five years (Google, 2015).

In accordance with the possible change in reporting behaviour, it has also been stated that the diagnostic approach to reporting has also changed, specifically, that the subjective threshold used by clinicians in order to diagnose a concussion has been lowered, leading to more cases being reported over time (Quarrie and Murphy, 2014). In fact, the significant difference in the reported incidence of concussion during seasons 2013-14 and 2014-15 against other years observed in this study coincided with the lowering of the threshold for immediate removal as part of the ‘World Rugby’ concussion assessment process (lowered at the beginning of the 2013-14 season, and lowered again at the beginning of the 2014-15 season; World Rugby, 2015). Specifically, during 2012-13, the threshold for immediate removal from play comprised of 3 criteria; confirmed loss of consciousness, tonic posturing and concussive convulsions. In 2013-14 the criteria was expanded to include, in addition; suspected loss of consciousness, ataxia and observable disorientation. Before the start of the 2014-15 season, being clearly ‘dazed’ or ‘dinged’, definite confusion and definite behavioural change were also added. It is therefore likely that a change in the diagnostic criteria for concussion over time has changed what is actually being counted as a concussion in recent surveillance studies (Quarrie and Murphy, 2014).

Players who return to play prematurely may further exacerbate concussive symptoms and may have an increased risk of subsequent concussion (Helmy et al., 2013). Although controversial, premature return to play may also be associated with catastrophic diffuse cerebral swelling following further impact (McCroory et al., 2012) and adverse long-term

neurological outcomes (McKee et al., 2013). In addition, recent studies in other sports (also investigated in this cohort in chapter 4 of this thesis) have highlighted a 50-65% increase in the risk of further injury following return to play from concussion (Lynall et al., 2015, Nordström et al., 2014) when compared with non-concussed players. Contrary to the hypothesis, this study found no difference in the time to return to play following concussion during 2002-15 even though the minimum stand down period reduced from 21 days to 6 days at the beginning of the 2011-12 season. The findings highlight that during the period 2002-11, 89% of players returned quicker than the minimum IRB recommended stand down period of 3 weeks, suggesting that all were cleared to return by a neurological specialist. This findings may suggest that players were already being managed using a graduated return to play protocol by medical staff before being formally adopted by the governing body in 2011-12 (Fraas et al., 2014). In 2011-12, 40% of players returned to play earlier (<6 days) than the then newly adopted Rugby Football Union recommended guidelines (Rugby Football Union, 2013). However, the mean number of players returning earlier than the recommended guidelines between 2012 and 2015 reduced to 12%, with only 6 (6%) players returning in <6 days during 2014-15. These findings are encouraging and highlight the success of on-going player safety and stakeholder education initiatives in reducing the number of players returning to play in advance of the recommended minimum stand down. It is recommended that these initiatives continue in order to sustain this improvement. However, the reasons as to why a small number of players return to play before the recommended minimum return time remains unclear. Future research directed towards the current return to play paradigm will likely provide a clearer picture of the overall risk and recovery pathways of concussion in this cohort (See chapter 4).

This study found no differences in the proportion of concussions attributed to certain match events during 2011-15 when compared with 2002-11. Twelve percent of reported concussions were deemed to have been as a result of foul play (from 2009-10 onwards when this reporting differentiation was introduced) highlighting the importance of the application of the law and referee behaviour in reducing the number of concussions in the professional game. However, it remains unknown as to whether the law was applied correctly in each case by the referee and further research in this area is likely to be useful in suggesting law and referee initiatives that may reduce head injury. In agreement with previous studies (Fuller et al., 2015, Kemp et al., 2008) during 2011-15, the majority of concussions occurred in the tackle. Whilst the importance of technical coaching and player safety in this area is vital at all levels, spending more time in this domain with already

proficient elite players who will consistently prioritise stopping the opposition player over a good tackling profile (in a player welfare sense) is likely to have a limited impact on the rate of concussion injuries. However, two potential areas that may be efficacious for informing future concussion prevention strategies at this level are proposed. The first is to conduct future research studies that explore the biomechanics during the concussion-collision mechanism to inform future mitigation strategies such as law changes in the professional game (Fuller et al., 2015). The potential of such an analysis has already been explored in a preliminary study in professional Rugby League (Gardner et al., 2015b) finding that the majority of concussions occurred as a result of a high tackle and that all injured ball carriers were hit high. Secondly, in a recent study of 10 professional Rugby Union payers, higher neck strength was shown to be associated with a reduction in head accelerations during the tackle (Dempsey et al., 2015). In addition, greater neck strength has also been associated with a reduction in the number of concussions in high school athletes (Collins et al., 2014). Further studies with a larger sample size that incorporate other factors such as tackle force and tackle direction would likely inform the potential for neck strengthening exercises to reduce the risk of concussion in this setting (Dempsey et al., 2015). Furthermore, consideration should also be given to the respective adaptive and non-adaptive ability of both physical tissues (skeletal muscle and bone mass) and the brain with specific reference to physical match events such as peak impact velocity in the tackle. The adaptive nature of muscle tissue versus the non-adaptive nature of the brain may increase the absolute and relative risk of injury to a specific organ (i.e the brain). Further research in this area is needed in order to fully understand physical adaptation in this setting from a longitudinal perspective.

3.5.1 Conclusion

The incidence of concussion in this study was higher than reported previously in this cohort and in other collision sports. This study found that the reported incidence of concussion in this cohort continues to rise and therefore future research with a focus on concussion prevention should be prioritised. Although it is not possible to separate improvement in reporting practice from the possibility of an inherent increase in the risk of concussion in recent years, it seems likely that the biggest change is in reporting behaviour and increased awareness rather than in the risk of sustaining a concussion. The reduction in the number of players returning to play before the recommended minimum time is encouraging; however, a small number of players still return to play quicker than the recommended time-frame highlighting the potential for further improvement in this setting.

CHAPTER 4: A prospective study of the short and medium term clinical outcomes and subsequent injury risk following concussive injuries in professional Rugby Union

4.1 ABSTRACT

Aim To investigate incidence of concussion, clinical outcome and subsequent injury risk of professional Rugby Union players following concussion.

Methods In a two-season (2012-13, 2013-14) prospective cohort study, incidence of diagnosed match concussions (injuries/1000 hours), median time interval to subsequent injury of any type (survival time), association of specific concussion signs, symptoms and modifiers with protracted recovery and time spent at each stage of the graduated return to play pathway were determined in 810 male professional Rugby Union players (1176 player seasons).

Results Match concussion incidence was 8.9/1000 hours with over 50% occurring in the tackle. Subsequent incidence of any injury for players who returned to play in the same season following a diagnosed concussion (122/1000 hours, 95% CI 106-141) was significantly higher (IRR 1.6, 95% CI 1.4-1.8) than for those that did not sustain a concussion (76/1000 hours, 95% CI 72-80). Median time to next injury following return to play was shorter following concussion (53 days, 95% CI 41-64) than following non-concussive injuries (114 days, 95% CI 85-143). Thirty-Eight % of players reported recurrence of symptoms or failed to match their baseline neurocognitive test during the graduated return to play protocol.

Conclusions Substantially greater risk of all time-loss injury for players who returned to play in the same season after a diagnosed concussion and the substantial proportion of players who reported recurrence of symptoms or failed to match baseline neurocognitive test scores during graduated return to play suggests that more conservative and comprehensive graduated return to play protocols, with a greater focus on active rehabilitation, should be investigated.

4.2 INTRODUCTION

Rugby Union has a high reported incidence of concussion, which is a trait shared with other contact and collision sports (Fuller et al., 2015). There is potential for very rare but catastrophic short-term consequences if a player is not removed from play appropriately or returns to play prematurely after concussive injury (Cantu and Voy, 1995). There is also increased risk of protracted recovery in the medium term following subsequent concussions (McCrory and Johnston, 2002a). Consequently, ensuring consistent recognition, delivery of optimal acute management and safe return to play of athletes in relation to concussion is of paramount importance.

Specific and clear guidance on acute management and return to play following concussion in rugby, consistent with the 2012 Consensus statement on concussion in sport (McCrory et al., 2013b), are provided by the International Federation ('World Rugby'). However, the evidence base for current return to play guidelines is limited (Broglia et al., 2015a), and guidelines are often implemented inconsistently (Fuller et al., 2015). Furthermore, very little is known about the consequences following return to play (Nordström et al., 2014). In professional soccer, concussion is associated with a 50% increase in risk of subsequent injury within the following year (Nordström et al., 2014), and college athletes are more likely to suffer acute musculoskeletal lower extremity injuries in the months after recovery from concussion (Lynall et al., 2015).

It has also been postulated that the presence of specific clinical signs and symptoms post-concussion may be associated with a more protracted recovery period. These include; postconcussive headaches (Collins et al., 2003), balance disturbance (Lau et al., 2011b) and previous concussions (Guskiewicz et al., 2003). In addition, symptom burden, defined as the product of the number of symptoms and the severity of these symptoms (Erlanger et al., 2003) has also been associated with a prolonged recovery period. A better understanding of the predictive value of these factors is important for both clinicians and researchers as it will provide both focus for individual treatment decisions and for the further development of treatment modalities (Makdissi et al., 2013b).

The aims of this study were to: 1) establish whether concussion is associated with an increased risk of subsequent time-loss injury (of all types) and 2) describe the time course of symptom resolution, balance impairment and cognitive deficit after concussion and determine whether specific clinical features are associated with prolonged recovery time.

4.3 METHODS

4.3.1 Participants

This was a prospective cohort study of all first team players in the 12 clubs at the highest level of club rugby in England (English Premiership). Data were collected for 810 male professional players over two seasons (2012-13 and 2013-14), with 366 players participating in both seasons. The study was approved by the Research Ethics Approval Committee for Health at the University of Bath. Written informed consent (Appendix A2) was obtained each season from each participant.

4.3.2 Procedures

All >24-hour time-loss injuries (Fuller et al., 2007b) were recorded by team medical personnel as part of the Premiership rugby injury surveillance project (Rugby Football Union, 2015). Concussion injuries were included in the study if they occurred in 1st or 2nd team competitive matches. The diagnosis of concussion was made by team doctors based on their clinical judgement supported by the Sport Concussion Assessment Tool (SCAT) version 2 (2012-13) or SCAT version 3 (2013-14; Appendix B1). Clear guidelines were given to club medical staff at the beginning of both seasons in relation to on-field recognition of suspected concussion and the need for permanent removal if concussion was suspected.

At the beginning of the pre-season period, all players undertook baseline computerised neurocognitive testing (CogState Sport, Cogstate, Australia) and completed SCAT versions 2 or 3 (Guskiewicz et al., 2013). If a player was diagnosed with concussion during a match, the player (under supervision of the team doctor) was asked to complete a post-match full SCAT2/3 within an hour of the end of the game. Players were then assessed using the SCAT2/3 (omitting the Glasgow coma scale and physical signs sections) each day until asymptomatic. Symptom severity scores (number of symptoms x self-reported severity [7-point Likert scale 0-6 for each symptom]) were calculated from the SCAT2/3. Players who presented with symptoms or signs of concussion after, rather than during, a match also completed the assessments stated above but from the time point at which the signs and/or symptoms presented.

Clubs were advised to manage players according to the graduated return to play protocol set out by World Rugby (World Rugby, 2014). The protocol comprises 6 stages: 1) physical and cognitive rest until asymptomatic; 2) light aerobic exercise; 3) sport specific

exercise; 4) non-contact training drills; 5) full contact practice; 6) return to play. Players should have completed each stage in sequence, and only progressed to the next stage if they remained asymptomatic for an unbroken period of 24 hours. If any player became symptomatic they should have returned to the last step at which they were asymptomatic. If using the protocol correctly, the minimum time to return to play was 6 days from the day of injury. In addition to the graduated return to play protocol, at stage 4 players completed post-injury neurocognitive testing (CogState Sport, Cogstate, Australia) as a mandatory RFU/Premiership Rugby requirement before being permitted to return to contact practice. The post-injury test was compared with each player's pre-season baseline test and in order to be deemed valid, a player must have declared themselves symptom-free and should have scored within 1.65 age based normative standard deviations of his baseline test score (Louey et al., 2014).

Full clinical recovery was defined as complete symptom, cognitive and balance recovery and return to full training or match play. Symptom recovery was defined as the point at which no reported symptoms were present on the SCAT2/3 Graded Symptom Checklist and in addition no other post-concussive symptoms were raised by the player. Acknowledging that symptoms may result from non-concussive pathologies, a small number of players were deemed to have achieved symptom recovery if they were not symptom free but their symptoms matched their baseline SCAT2/3 symptom scores. In these cases, the day of clearance was recorded as the day of symptom recovery. Cognitive recovery was defined as the point at which all SCAT2/3 standardised assessment of concussion components (orientation, immediate memory, concentration and delayed recall) returned to baseline. Balance recovery was determined by the return to baseline of the total number of errors seen in the SCAT2/3 balance error scoring system.

4.3.3 Data Analysis

Descriptive statistics were used to summarise player symptoms, recovery, time to return to play and the clinical pathway through the graduated return to play protocol, with any significant difference in the time spent (days) at each stage of the graduated return to play protocol identified if the 95% confidence intervals did not overlap. In addition, the proportion (%) of injury events that lead to a diagnosed concussion during this study is also described.

Total number of reported concussions and overall match exposure (calculated from match report cards) for all players were used to calculate the match concussion incidence rate for

the study (expressed per 1000 hours of exposure). Incidence rates for any injury were then calculated for players that were diagnosed with a concussion before they were concussed (pre-injury) and following return to play from concussion (post-injury). Match incidence rates for any injury were also calculated for players who did not report a concussion. These calculations were based on individually recorded match exposure for the players in each group during the study. Ninety-five percent confidence intervals were calculated using the Poisson distribution and incidence was compared using incidence rate ratios (IRR). A result was considered significant if the 95% confidence intervals for the rate ratios were either both less or greater than 1.0. Median time to subsequent injury (number of days) was estimated using survival analysis via the Kaplan-Meier method (Kaplan and Meier, 1958) for reported match concussions and an equal number (n=135) of randomly selected non-concussive match injuries from the consented professional players who did not have a reported concussion during the study period but that had reported another injury. Each injury was assigned a unique reference number and the injuries were selected at random from the group of players that did not report a concussion. To ensure that the results were reliable, this analysis was conducted with three unique sets of random injuries. For this part of the analysis, each season was treated independently and the next injury was only included if it occurred in the same season as the concussion or randomly selected non-concussive injury. Significant differences between time to next injury estimates were accepted if the Mantel-Cox log rank test was $p < 0.05$.

The relationship between initial clinical signs & symptoms and protracted clinical recovery were analysed using binary logistic regression via the entry method, with influence of independent factors determined via odds ratios. A result was considered significant if the 95% confidence intervals for the rate ratios were either both less or greater than 1.0. Protracted clinical recovery was defined as >14 days absence from full training or match play, as 80-90% of concussions resolve within 7-10 days (McCrorry et al., 2013b). This timeframe has been used previously in a similar analysis (Lau et al., 2011a) and in a practical sense, this duration of absence would typically require a player to miss two games. The 22 symptoms on the post-concussion symptom scale have been shown to cluster into 4 major groups with adequate internal consistency (Cronbach's alpha); head (headache, pressure in head, neck pain, nausea, dizziness, blurred vision, balance problems, sensitivity to light and sensitivity to noise; $\alpha=0.87$), cognitive (feeling slowed down, feeling in a fog, don't feel right, difficulty concentrating, difficulty remembering, fatigue or low energy and confusion ; $\alpha=0.89$), sleep (trouble falling asleep and

drowsiness; $\alpha=0.79$) and neuropsychological (more emotional, irritability, sadness, more nervous or anxious; $\alpha=0.78$; Pardini et al., 2004), and these clusters were used in the logistic model for ascertaining associations with protracted recovery in the analyses.

4.4 RESULTS

Of the 810 players in the study, 150 players (19%) reported a total of 181 (2012-13, 66; 2013-14, 115) match concussions in 20 275 (2012-13, 9655; 2013-14, 10 620) hours of match play. The overall incidence rate of reported match concussions was 8.9/1000 hours (95% CI 7.7-10.3), (2012-13, 6.8/1000 hours; 2013-14, 11.0/1000 hours). Six hundred and sixty players (81%) did not report a concussion, 121 players (15%) reported one concussion and 28 players (3%) reported two concussions (19 players sustained two concussions in the same season) with two players reporting a second concussion in the first game back following a previous concussion. One player (<1%) reported three concussions. The mean time lost due to concussion was 11 days (95% CI 9 – 12). Fifteen players (8% of concussions) returned to play sooner than the 6-day minimum (11 players in 2012-13 and 4 players in 2013-14). Thirty-Seven percent of players returned within 7 days. The most common match events associated with concussion were tackling (30%) and being tackled (23%; figure 4.1).

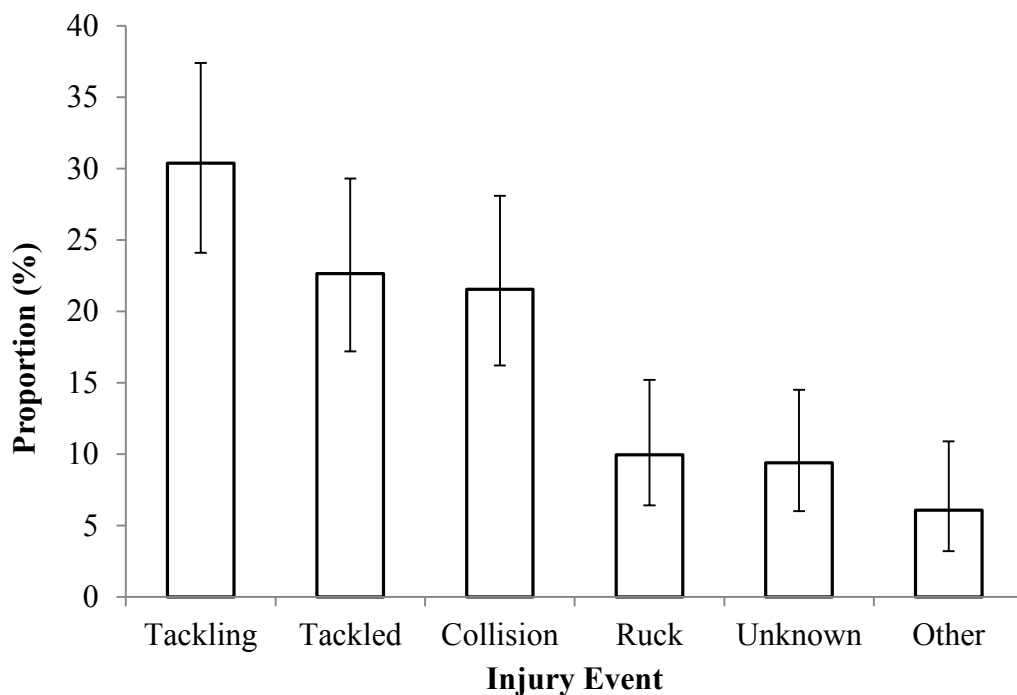


Figure 4.1: Match event responsible for concussions (n=181). Error bars show 95% CI.

4.4.1 Incidence of injury post-concussion

Fifteen players were excluded from this analysis due to insufficient follow up (14 players did not play again during the season after sustaining a concussion and 1 player retired due to another injury) leaving 135 players for this analysis. Following a concussion, players were 1.6 (95% CI 1.4-1.9) times more likely to suffer a match injury of any type than players who had not sustained a concussion (table 4.1). The difference in pre-concussion incidence for players who sustained a concussion and the injury incidence of players who did not sustain a concussion was not significant (IRR 1.1 95% CI 0.8-1.5). Subsequent injury incidence was not significantly different in players that returned from concussion in 14 days or less (116.1/1000 hours; 95% CI 94.5-144.6) compared with those with a prolonged (>14 days) recovery (152.5/1000 hours; 95% CI 108.9-213.4; IRR 1.3 95% CI 0.9-2.0). The risk of subsequent injury following a diagnosed concussion was not different between forwards (122.9/1000 hours; 95% CI 95.6-158.0) and backs (121.3/1000 hours; 95% CI 96.6-152.3; IRR 1.0 95% CI 0.7-1.4).

The median time interval to subsequent injury following return to play from concussion was shorter ($p=0.007$) following a concussion (53 days, 95% CI 41-64) than following a randomly selected non-concussive injury from the group of players that did not report a concussion during the study period (114 days, 95% CI 85-143; figure 4.2). Further samples of random injuries gave consistent findings (set 2: 99 days, 95% CI 70-128, $p=0.006$; set 3: 104 days, 95% CI 75-133, $p=0.003$). Mean severity of the first subsequent injury following concussion was 19 (95% CI 16-23) days compared with 17 (95% CI 16-18) days following other injuries. The injury types for subsequent match injuries were not different between those players who had sustained a concussion versus other injuries. Thirteen players sustained a concussion as their first injury after returning to play following an initial concussion.

Table 4.1: Match incidence rates (injuries/1000 hours) in players with a diagnosed concussion and those that did not have a diagnosed concussion, incidence rate ratios used to determine effect size. * shows significant difference versus the reference group

Player Group	All Injuries	Exposure (hours)	Incidence (95% CI)	IRR ^a (95% CI)
Players without diagnosed concussion (n=660)	1398	18500	75.6 (71.7-79.7)	Ref^b
<i>Players with diagnosed concussion (n=135)</i>				
Post-injury (following return to play)	119	976	122.1 (105.8-141.0)	1.6* (1.4-1.9)
Pre-injury (before the concussion)	67	799	83.9 (66.0-106.6)	1.1 (0.8-1.5)

^aIRR = Incidence rate ratio; ^bRef = denotes reference group for IRR calculations

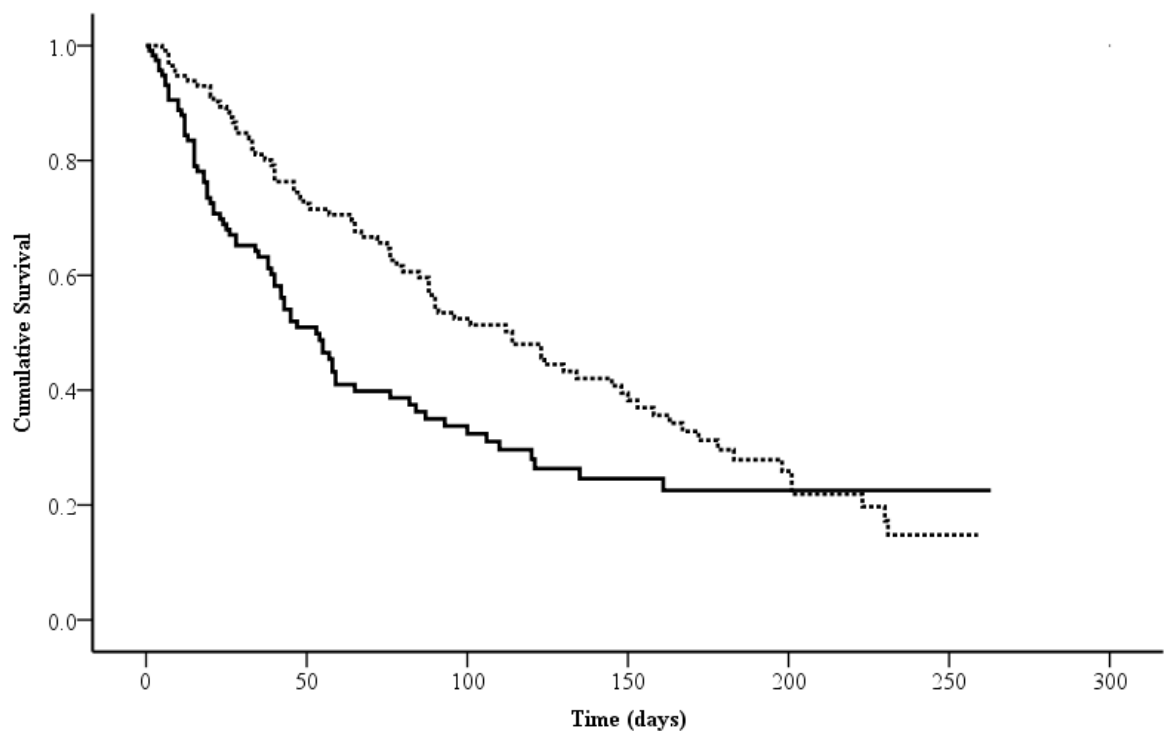


Figure 4.2: Time to subsequent injury following return to play in players who reported concussion (solid line) and an equal number ($n=135$) of randomly selected injured players who did not report a concussion (dashed line).

4.4.2 Acute clinical features post-concussion

Of the 181 reported concussions, 64 (35%) were excluded from this analysis as all sections of the initial SCAT2/3 assessment were not provided, leaving complete data for 117 concussion injuries. The SCAT2/3 test scores immediately post-injury 86 (95% CI 84-88) were significantly lower than baseline 93 (95% CI 92-94; $p<0.001$). The mean number of symptoms reported on the graded symptom checklist during post injury assessment was 7 (95% CI 6-8, range 0-22), with a mean symptom severity score of 16 (95% CI 13-19, range 0-103). The most common symptom was headache (figure 4.3), which was present in 95 (81%) cases. Balance error score immediately following the injury (mean errors 3.0, 95% CI 2.0-4.0) was higher than baseline (mean errors 1.0, 95% CI 0.7-1.1) in 92 (79%) of cases. Loss of consciousness (LOC) was observed in 26 cases (22%), and 19 (16%) were associated with amnesia (13 retrograde, 3 anterograde and 3 with both retrograde and anterograde). Only 4 cases (3%) were associated with both LOC and amnesia.

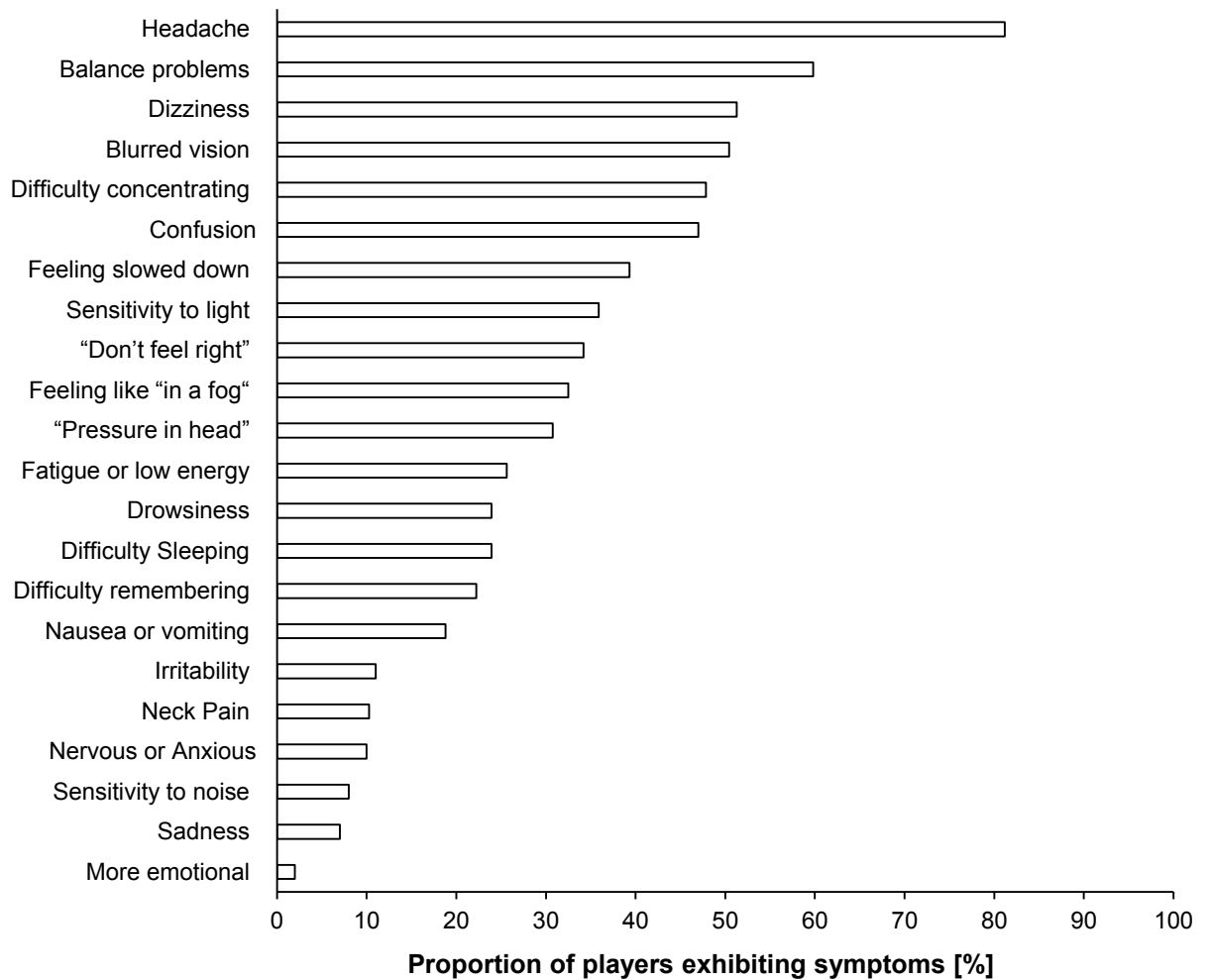


Figure 4.3: The proportion of players exhibiting each individual symptom upon initial SCAT3 testing post (within 1 hour) concussive event (n=117).

4.4.3 Time course of clinical recovery

Of the 117 concussions described above, a further 17 were excluded from the analysis as 16 provided insufficient follow up and 1 player left the club before returning to play leaving 100 concussion injuries. The proportion of players that reported resolution on components of the SCAT2/3 at 7, 14 and 21 days was; symptoms (85%, 96% and 99%), cognitive (87%, 99% and 100%) and balance (73%, 88% and 99%). The proportion of players that made a full clinical recovery at 7, 14 and 21 days was (25%, 82% and 95%; figure 4.4).

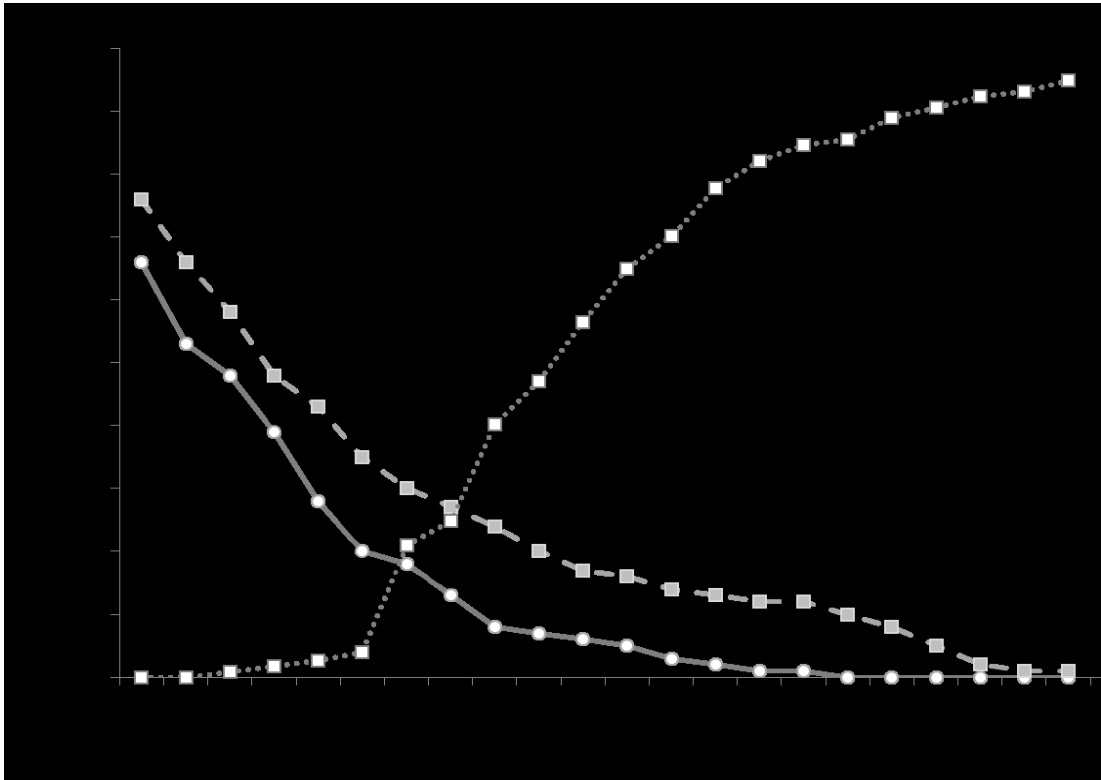


Figure 4.4: Proportion of players exhibiting symptoms (closed circles), cognitive deficit (open circles) and impaired balance (closed squares). The proportion of players reaching full clinical recovery (open squares) is also shown over the course of the first 21 days post-concussion (n=100).

A higher symptom burden (OR 1.17, 95% CI 1.01 – 1.31) and a raised balance error score (OR 1.33, 95% CI 1.06-1.66) were predictive of a protracted recovery (>14 days). An increase in the number of self-reported ‘head cluster’ symptoms was associated with a shorter (<14 days) recovery (OR 0.90, 95% CI 0.82-0.98; figure 4.5).

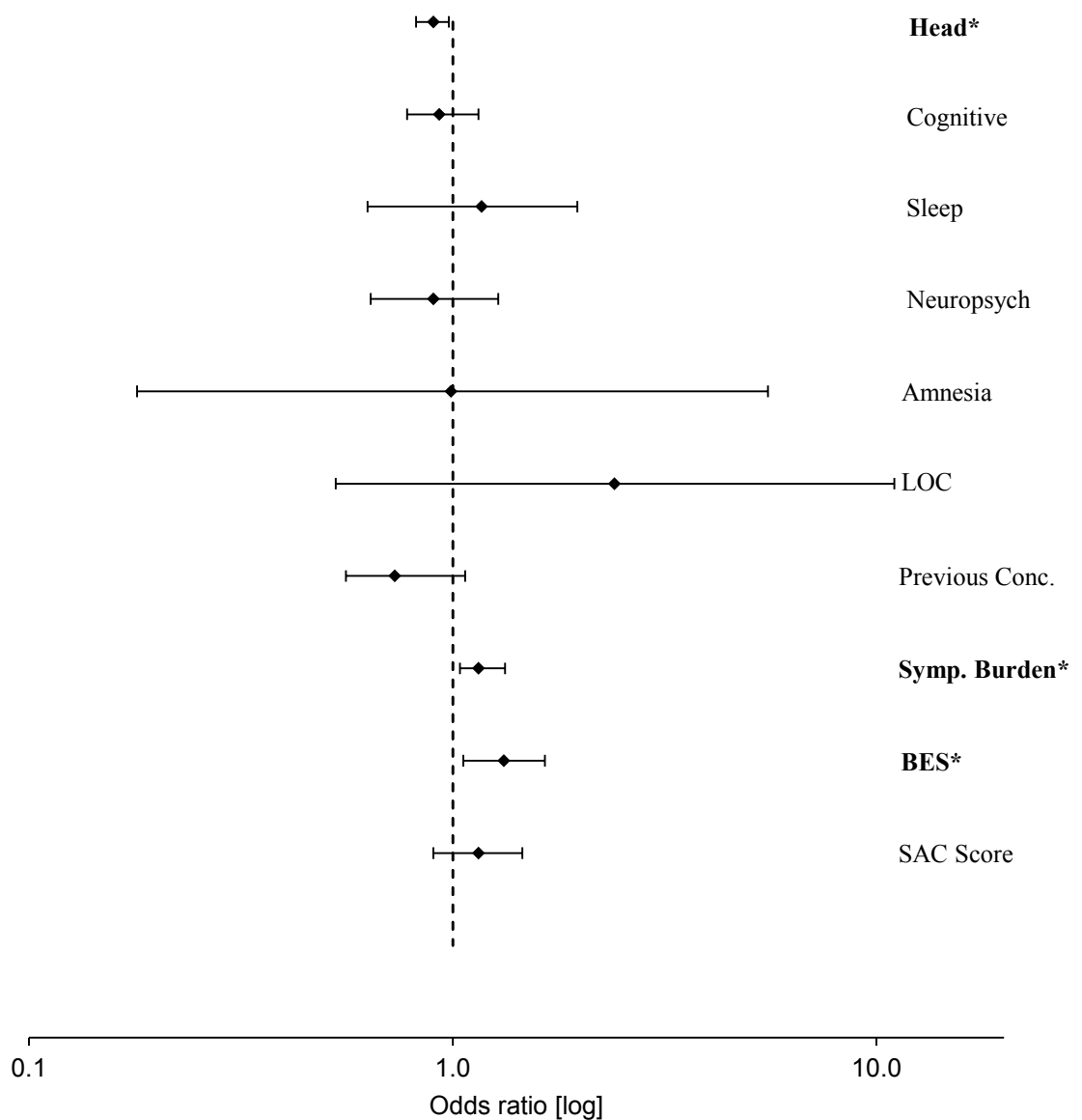


Figure 4.5: Odds Ratios for the symptoms clusters, clinical signs and concussion modifiers as predictors of protracted recovery (n=100). LOC=Loss of consciousness, BES= Balance error score and SAC= Standardised assessment of concussion.*significant predictor.

4.4.4 Graduated return to play pathway

Of the 117 players for whom graduated return to play data were available, 105 progressed through the six stages as per World Rugby guidelines. Of those that did not, one player retired, two players left their club and 9 missed a stage or merged stages on the same day. Of the 105 players, 24 players only reported symptoms on the day of injury and progressed through stages 1-6 spending the minimum 24 hours at each stage. Of those who reported symptoms that lasted beyond the day of injury, 36 players completed the graduated return

to play protocol in the minimum time for stages 2-6. Twenty-seven players reported a recurrence of symptoms after exertion during stages 2-5. The mean number of days spent at each stage of the graduated return to play protocol was: Stage 1: 3.5 (95% CI 2.9-4.1), Stage 2: 1.3 (95% CI 1.2-1.4), Stage 3: 1.4 (95% CI 1.2-1.6), Stage 4: 2.0 (95% CI 1.6-2.4) and Stage 5: 1.0 (95% CI 0.9-1.1; figure 4.6). The time spent at stage 1 was significantly greater than all other stages, which likely reflects the heterogeneity of symptom resolution. Similarly, the time spent at stage 4 was significantly greater than stages 2, 3 and 5. At stage 4, six players became symptomatic and twenty-four players required multiple neurocognitive tests (19 didn't meet their baseline score and 5 declared symptoms during the test).

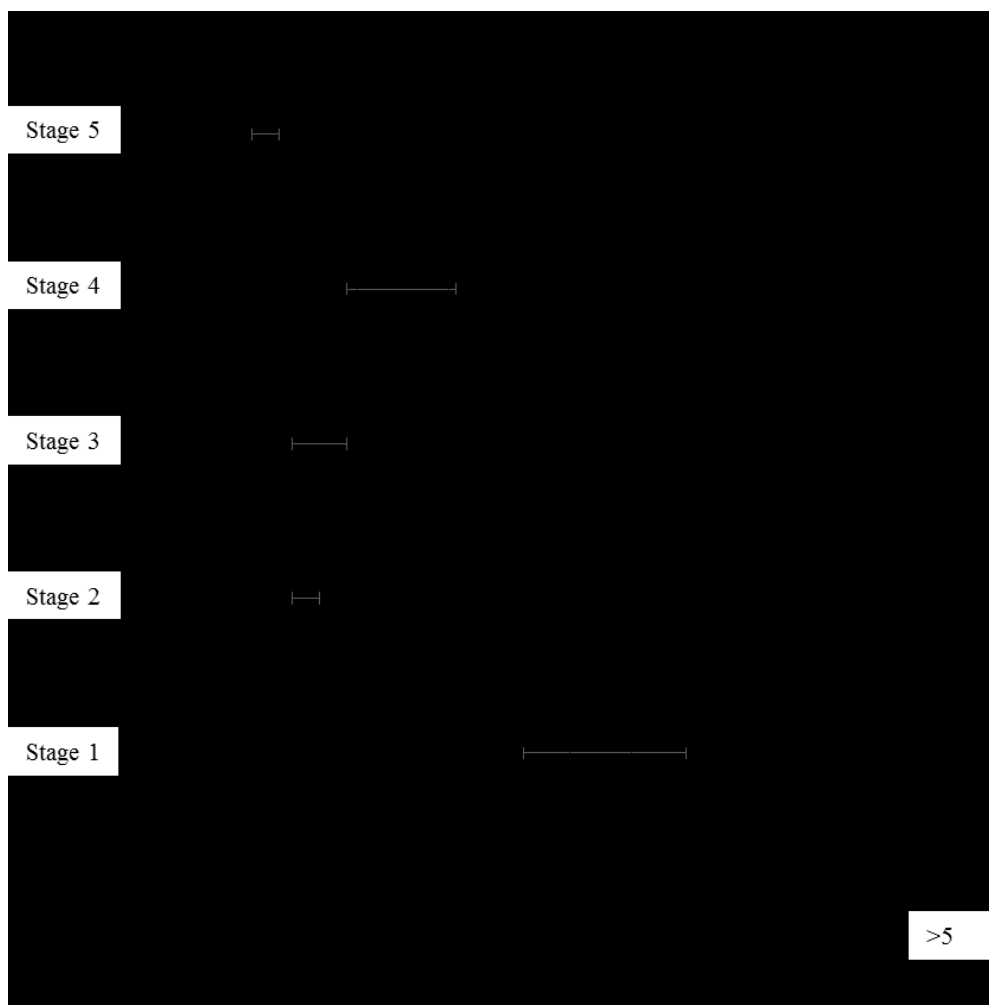


Figure 4.6: Number of days spent at each stage of the graduated return to play (n=105). Each bar represents the mean time (days) spent at each stage with error bars showing 95% confidence intervals. The bubbles represent the proportion of players spending the corresponding number of days at each level.

4.5 DISCUSSION

This study investigated the incidence of concussion, subsequent injury risk on return to play following concussion, clinical features at the time of initial diagnosis and the time course of clinical recovery in a professional English Premiership Rugby Union cohort. Match concussion incidence (8.9/1000 player hours) was approximately double that previously reported in professional Rugby Union (Kemp et al., 2008, Fuller et al., 2015). Players returning from a diagnosed concussion were ~60% more likely to suffer a subsequent injury of any type in the same season than players that did not sustain a concussion. Furthermore, players returning from a diagnosed concussion had a shorter time until subsequent injury than players returning from injuries other than concussion (53 versus 114 days).

In agreement with chapter 3 of this thesis, the incidence of reported concussion of 8.9/1000 player hours (2012-13, 6.8/1000 hours; 2013-14, 11.0/1000 hours) is greater than previously reported for 2002-2006 (4.1/1000 hours; Kemp et al., 2008) and 2007-2011 (4.6/1000 hours; Fuller et al., 2015). The incidence rates reported in this study are slightly different to those reported in chapter 3 as data from the A-league competition were included in this study. It is important to note that the possible reasons for the observed increase in incidence during this study are likely to be consistent with those already presented in more detail in chapter 3. In synopsis, the increase in concussion match incidence has occurred in the absence of a similar increase in other contact-related match injuries in this cohort. It is possible that specific changes in player actions might influence the likelihood of exposure to head impacts, but more general changes in the demands of the game in relation to the time the ball is in play, the number of contact events and the size of players are known to have developed more gradually and over a longer period of time (Fuller et al., 2013, Quarrie and Hopkins, 2007). It is therefore unlikely that changes to the demands of the game have prompted the sharp rise in concussion incidence observed. Overall, it is more likely that the biggest contributor to the increase in incidence is improved reporting behaviour due to greater awareness of issues surrounding concussion. The introduction of World Rugby's pitch-side concussion assessment process (now known as the head injury assessment process; see Appendix C1 for the latest version), a focus on concussion in the scientific and medical literature and noteworthy media comment on the management of specific cases have all likely contributed to more consistent identification of cases of concussion. However, it is important to note that, given the evidence of under-

reporting of sports-related concussion (Fraas et al., 2014), even the incidence rates reported here are probably a minimum estimate.

In this study, players who returned to play after a diagnosed concussion were ~60% more likely to sustain any subsequent injury during that season than those who had not sustained a concussion. The median time to subsequent injury for players who sustained a concussion was also significantly shorter than for players who did not sustain a concussion with the greatest difference in risk between the two groups observed in the weeks immediately following return to play. These findings are similar to those in soccer whereby injury risk increased by about 50% following a concussive episode (Nordström et al., 2014) and in college athletes where concussed athletes were almost twice as likely (OR 1.97) to sustain an acute lower extremity musculoskeletal injury in the year following return to play than before they suffered a concussion (Lynall et al., 2015). In the present study, the severity of the initial concussion did not significantly alter subsequent injury risk, although the study was not powered for this comparison and this warrants ongoing data collection.

Identifying the underlying mechanisms for an increase in injury risk following concussion was beyond the scope of the current study. However, changes to an athletes postural and neuromuscular control may contribute to the increase in injury rates following return to play from concussion (Lynall et al., 2015, Nordström et al., 2014). More specifically, the potential for deficits in gait following concussive injury have been suggested (Parker et al., 2005, Parker et al., 2006) as well as changes in dynamic balance, with recovery of balance control reported to regress after returning to play (Howell et al., 2014). When considering the high cognitive and physical demands of Rugby Union, it is plausible that even subtle changes to a players gait or balance may contribute to an increase in the risk of injury. Overall, it remains unclear whether it is the primary concussive injury that is the main determinant of subsequent injury risk, or whether the way that recovery is managed can mitigate any adverse effects.

The finding that a higher symptom severity score (OR 1.17) and balance error score (OR 1.33) were associated with a protracted recovery and that the predominance of head symptoms (OR 0.90) may be associated with a shorter recovery is of clear clinical importance. It is not possible to set numeric thresholds that will predict a protracted recovery, but these findings will assist clinicians in better identifying cases that may be associated with a more protracted recovery and may also aid in the implementation of

symptom or sign specific treatments to optimise recovery (Lau et al., 2011b). Studies within this area exist in other sports (Collins et al., 2003, Erlanger et al., 2003, Lau et al., 2009, Lau et al., 2011a, Lau et al., 2011b, McCrory et al., 2013b, Meehan et al., 2014) but comparing results between studies remains difficult due to the heterogeneous nature of the methods used (Scopaz and Hatzenbuehler, 2013) in particular, a lack of consensus in the definition of protracted recovery. The finding that a greater balance error score is predictive of a protracted recovery is novel, although on-field dizziness has previously been reported to be a predictor of protracted recovery following concussion (Lau et al., 2011b). There is also support in a previous study for the finding that symptom burden (Meehan et al., 2014) is indicative of prolonged recovery from concussion. The finding that self-reported head symptoms appear to be associated with a shorter recovery time is surprising as they have been associated with protracted recovery in previous studies (Asplund et al., 2004, Makdissi et al., 2010) although both of these studies cited prolonged headache rather than initial head symptom cluster as a risk factor.

It has been reported that the majority of symptom, cognitive and balance deficits resolve within 7-10 days of injury for most athletes (Echemendia et al., 2001, McCrea et al., 2003). The findings in this study are in agreement, with symptom, cognitive and balance deficits resolving in 85%, 87% and 73% of players, respectively, within 7 days. Analysis of the graduated return to play pathways showed that the majority of players for whom all data are available were managed in adherence with current recommended guidelines for return to play in Rugby Union. However, the findings highlight the diverse, and sometimes complex, resolution of the injury. During the graduated return to play protocol, 38% of players reported a recurrence of symptoms during stages 2-5 or failed to achieve a valid neurocognitive test performance after-injury. In fact, although neurocognitive assessment tools have been reported as having low-moderate test-retest reliability, in this instance 18 players who reported no symptoms were prevented from returning to play as a result of neurological deficit when compared to baseline (Elliott, 2007). It is possible that players are still symptomatic when they enter stage 2 of the protocol but these symptoms are not recognised or reported, but become apparent later in the recovery process. However, it is noteworthy that the current graduated return to play protocol for concussion is markedly different than for the majority of musculoskeletal injuries. There is a far greater emphasis on recovery and rest, with the addition of graded exercise principally designed to assess the extent to which symptoms can be re-provoked rather than as part of a functional rehabilitation and reconditioning process. There is also much less emphasis on re-

development of neuromuscular control, proprioception and co-ordination. Perhaps as a result of the different focus, the typical time to return to play after concussion in professional rugby players is shorter than for the majority of other injuries (Brooks et al., 2005a). It is therefore possible, that the timescale of the graduated return to play protocol is too short and that the focus on symptom assessment once a player has progressed to stage 2 is overly narrow. It is therefore proposed that there is a need to explore the effect of a longer, more comprehensive graduated return to play protocol.

The focus on symptom recovery is largely influenced by the lack of sufficiently sensitive or repeatable tools to detect subtle symptom, balance and cognitive deficits following concussion (Nordström et al., 2014). Novel approaches employing quantitative EEG (Baillargeon et al., 2012), advanced functional neuroimaging (Mayer et al., 2015) and blood biomarkers (Shahim et al., 2015) to aid concussion diagnosis and return to play decision making hold promise but currently remain primarily in the research domain (Kutcher et al., 2013). Therefore, at the present time, individualised system focused clinical support (e.g., neurological, vestibular or psychological) would be prudent for those cases where symptoms take significant time to resolve, symptoms reoccur during stages 2-5 or where players fail to match baseline neurocognitive performance (Makdissi et al., 2013a).

The main limitation of this study was that of the 181 concussions, only 117 (65%) could be included in the majority of analysis (compliance was better in the second season of the study; 2012-13, 59% and 2013-14, 71%). It is not known whether those concussions for which data were not available were managed according to recommended return to play guidelines, or whether the included cases were representative of the assessment, management and outcomes of the whole cohort. However, this study included a sufficiently large sample size that allowed statistically significant and clinically meaningful differences to be investigated. The findings from this study are generalisable for all professional Rugby players, but comparisons with other age groups or playing levels should proceed with caution.

4.5.1 Conclusion

This is the first study to investigate the short and medium term clinical post-concussive outcomes of professional Rugby Union players. The most significant finding is the substantially greater risk of all time-loss match injuries for players following return to play in the same season after a diagnosed concussion. It is suggested that the effect of a more

conservative and comprehensive graduated return to play protocol, with a greater emphasis on active rehabilitation of the systems likely impacted by concussive injury (vestibular and autonomic) should be investigated.

CHAPTER 5: The Influence of In-Season Training Loads on Injury Risk in Professional Rugby Union

5.1 ABSTRACT

Aim: To explore the association between in-season training load measures and injury risk in professional Rugby Union players.

Methods This was a one-season prospective cohort study of 173 male professional Rugby Union players from four English Premiership teams. Training load (duration x session-RPE) and time-loss injuries were recorded for all players for all pitch and gym based sessions. Generalised estimating equations were used to model the association between in-season training load measures and injury risk in the subsequent week.

Results: Injury risk increased linearly with one-week loads and week-to-week changes in loads, with a 2 standard deviation (SD) increase in these variables (1245 AU and 1069 AU, respectively) associated with odds ratios of 1.68 (95% CI 1.05-2.68) and 1.58 (95% CI: 0.98-2.54). When compared with the reference group (<3684 AU), a significant non-linear effect was evident for four-week cumulative loads, with a likely beneficial reduction in injury risk associated with intermediate loads of 5932 to 8651 AU (OR: 0.55, 95% CI: 0.22-1.38; this range equates to around four weeks of average in-season training load), and a likely harmful effect evident for higher loads of >8651 AU (OR: 1.39, 95% CI: 0.98-1.98).

Conclusions: Players had an increased risk of injury if they had high one-week cumulative loads (1245 AU), or large week-to-week changes in load (1069 AU). In addition, a 'U-shaped' relationship was observed for four-week cumulative loads, with an apparent increase in risk associated with higher loads (>8651 AU). These measures should therefore be monitored to inform injury risk reduction strategies.

5.2 INTRODUCTION

The aim of training is to optimise performance through the mastery of sport specific skills and advancing physical conditioning. However, the process of applying appropriate training loads (a product of training intensity, volume/duration and frequency) is a constant challenge for coaches, particularly in the context of season-long team sports (Gastin et al., 2013). Whilst increasing training loads is generally thought to improve athletic performance (Foster et al., 1996), it may also increase player fatigue and injury risk (Austin et al., 2011b). Injury impacts on individual's ability to train and compete, and higher injury burden has been associated with poorer team success in professional football cohorts (Hägglund et al., 2013b, Williams, 2015b). As such, the prescription of appropriate training loads requires a careful consideration of the positive (fitness and skill development) and negative (fatigue and injury risk) response (Calvert et al., 1976).

Many studies have looked at the training load-performance relationship in sport (Foster et al., 1996, Gastin et al., 2013, Mujika et al., 1995), but a far smaller number have investigated the association between training loads and injury in contact sports, especially within an elite population. Previous studies (Gabbett, 2004b, Gabbett, 2010, Gabbett and Domrow, 2007, Austin et al., 2011b) have shown that a reduction in training load in-season resulted in a reduction in the incidence rate of injuries. One of these studies (Gabbett, 2010) suggested that a player's threshold (the amount of training load that could be sustained by the player before an injury occurred) decreased during the season, potentially as players became fatigued when compared to pre-season thresholds. Higher weekly and two weekly cumulative loads and absolute week-to-week changes in load have been associated with an increased risk of injury in Australian Football (Rogalski et al., 2013). Players who experienced a change in previous to current week load of >1250 AU (arbitrary units; the product of training duration and intensity) or, approximately a 75% change were 2.58 times more likely to be injured in comparison with the reference group of a <250 AU (~15% change). Furthermore, elevated three-weekly cumulative loads derived from Global Positioning Systems (GPS) measurements were also associated with an increased risk of injury in this population (Colby et al., 2014).

A small number of studies have investigated the relationship between training volume (duration of training) and injury risk in Rugby Union (Brooks et al., 2008, Viljoen et al., 2009). Brooks and colleagues (Brooks et al., 2008) found that the mean training volumes for pre-season and in-season were 9.2 and 6.3 hours respectively with more time spent on

conditioning in pre-season and skills training in season (Brooks et al., 2005b). The lowest number of days lost due to injuries occurred during weeks of intermediate training volume (6.2 - 9.1 hours per week). A higher training volume (> 9.1 hours per week) did not increase injury incidence rates but did increase the severity of match injuries. In addition, Viljoen and colleagues (Viljoen et al., 2009) recorded training volumes within a professional team over a three year period and concluded that a reduction in training volume over three seasons was associated with slight reduction to in-season injury rates. However, it was noted that the team's league position also changed from 3rd to 7th (2002-2004) and thus, did not recommend reducing training volumes too much as the players may no longer be exposed to the required training stimulus in order to be able to compete effectively during matches.

It is likely that the training load-injury relationship for each sport is unique, given the different periodisation patterns and physical demands of training and match-play imposed upon players. To date, training load has not been investigated as a modifiable risk factor for injury in Rugby Union. Advances in the understanding of this area will enable coaching staff to have more confidence that the training loads that they prescribe do not significantly increase a player's risk of injury. Accordingly, the purpose of the present study was to determine if any associations between selected training load measures and injury risk exists professional Rugby Union players.

5.3 METHODS

5.3.1 Participants

This was a prospective cohort study of Professional Rugby Union players registered in the first team squad of four teams competing at the highest level of Rugby Union in England (English Premiership). Data were collected for 173 male professional players (team A = 43 players, team B = 41 players, team C = 46 players, team D = 43 players) over one season (2013-14). The study was approved by the Research Ethics Approval Committee for Health at the University of Bath and written informed consent (Appendix A3) was obtained from each participant.

5.3.2 Procedures

All time-loss injuries were recorded by the medical personnel at each team using the Rugby Squad medical database (The Sports Office UK, 2011). A modified version of the Orchard sports injury classification system OSICS (Rae and Orchard, 2007) was embedded within the medical system and was used to code each injury diagnosis. Reported time-loss

injuries were included in the study if they occurred in training or 1st or 2nd team competitive matches and if they met the 24-hour time-loss definition (Fuller et al., 2007b).

The intensity of all training sessions (including rehabilitation sessions) were estimated using the modified Borg CR-10 Rate of Perceived Exertion (RPE) scale (Foster et al., 2001; Appendix D1), with ratings obtained from each individual player within 30 minutes after the end of each training session (Kraft et al., 2014). A member of each club's strength and conditioning staff was allocated to be in charge of the club's data collection, they were provided with a data collection spread sheet and were briefed on the intensity scale (all clubs were given the same scale to use during the season). Each player had the scale explained to them by their strength and conditioning coach before the start of the season and players were asked to report their RPE for each session confidentially to the strength and conditioning coach without knowledge of other players' ratings. Session RPE in arbitrary units (AU) for each player was then derived by multiplying RPE and session duration/volume (min). Session RPE has previously been shown to be a valid method for estimating exercise intensity (Impellizzeri et al., 2004b) and returned positive correlations of 0.89 and 0.86 with training heart rate and training blood lactate concentrations, respectively, during typical Rugby League training activities (Gabbett and Domrow, 2007). Thus, the session RPE method was an inexpensive, simple and highly practical approach that allowed valid and reliable measures of each player's internal response to both pitch-based and gym-based training sessions (Clarke et al., 2013). These data were collated and sent to the project leader on a monthly basis by strength and conditioning staff.

The competitive season was split into two distinct phases for descriptive purposes, namely: 'pre-season' (between 8-11 weeks dependent on when each club commenced their season) and in-season (36 weeks). The in-season phase was then split into 'early-competition' (first 18 weeks of the competitive season) and 'late-competition' (last 18 weeks of the competitive season), to ascertain if there were any differences in training loads between these phases as differences may exist in training objectives between early and late in-season competition (Gabbett, 2010). In addition to weekly training load (sum over each 7-day period, commencing Monday of: session intensity [RPE] x session duration [mins]), a number of other training load measures were derived based on previous studies: a) cumulative two, three and four weekly loads calculated by the sum of the previous weeks' training loads (Rogalski et al., 2013); b) week-to-week change in loads (absolute change in a players current load from that of the previous week; Rogalski et al., 2013); c) weekly training monotony (weekly mean/standard deviation; Foster, 1998b); d) weekly training

strain (weekly training load x training monotony; Foster, 1998b); and e) training stress balance (a player's acute (one week) workload divided by their chronic (four week rolling average) workload; Hulin et al., 2013).

5.3.3 Data Analysis

Data were analysed in SPSS Version 22.0 (IBM Corporation, New York, USA). A two-way (Phase × Team) mixed analysis of variance (ANOVA) was used to identify differences in training loads between phases of the season, and between teams. Generalised estimating equations were used to model the association between in-season (early and late competition phases combined) training load measures and injury in the subsequent week, using a binary distribution, logit link function, first-order autoregressive (AR1) working correlation structure, and offset for players' individual match exposure. Based on the data supplied by one team in this study, observations suggest there is very little variation in reported RPE for matches (i.e. the vast majority of players reported 9-10), and so match exposure was the key distinguishing element between players. Individual match exposure was therefore accounted for, but did not contribute to training load values. This model was selected for its ability to account for intra-player and intra-team cluster effects (Ghisletta and Spini, 2004). If assessment of a quadratic trend between the training load measure and injury risk was significant ($P \leq 0.05$), training loads were sorted from smallest to largest and the measure was split into quartiles for analysis, with the lowest load range being the reference group to enable us to compare the risk of injury at intermediate, higher intermediate and high loads compared with low loads. Otherwise, linear effects for continuous predictor variables were evaluated as the change in injury risk (Odds Ratio [OR]) associated with a two standard deviation increase in the training load measure (Hopkins et al., 2009). Correlation coefficients between the training load measures, alongside Variance Inflation Factors (VIF), were used to detect multicollinearity between the predictor variables. A VIF of ≥ 10 was deemed indicative of substantial multicollinearity (Kutner et al., 2004).

Magnitude-based inferences were used to provide an interpretation of the real-world relevance of the outcome (Batterham and Hopkins, 2006). The smallest worthwhile increase in risk (i.e. harmful effect) for time-loss injuries was an odds ratio of 1.11, and the smallest worthwhile decrease in risk (i.e. beneficial effect) was 0.90 (Hopkins, 2010). An effect was deemed unclear if the chance that the true value was beneficial was $>25\%$, with odds of benefit relative to odds of harm (odds ratio) of <66 (or vice versa). Otherwise, the effect was deemed clear, and was qualified with a probabilistic term using the following

scale : <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely (Hopkins, 2007).

5.4 RESULTS

In total, 465 time-loss injuries (303 match, 162 training) were reported across the 4 teams during the season. Overall, match injury incidence was 101.7/1000 hours, 95% CI: 90.9-113.8) and training injury incidence was (3.3/1000 hours, 95% CI: 2.8-3.8). The total match and training volumes reported during the season were 2980 hours and 51653 hours respectively.

The two-way mixed ANOVA showed significant ($P<0.01$) effects for Team, Phase, and Phase \times Team. Average weekly training loads decreased from pre-season (2175 ± 380 AU), to in-season, with no significant differences between early-competition (1522 ± 203 AU) and late-competition (1581 ± 317 AU) phases (figure 5.1).

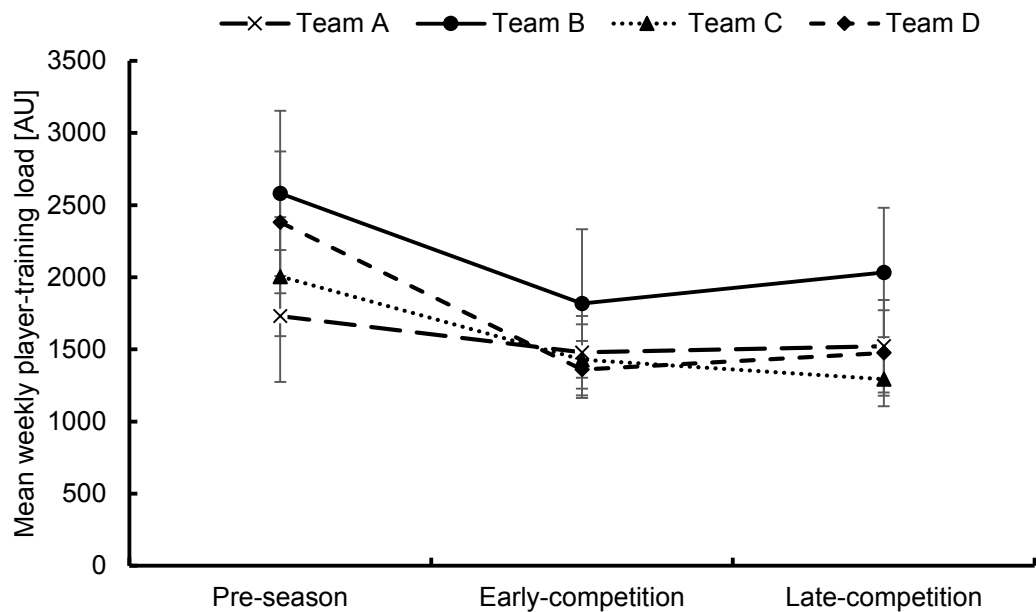


Figure 5.1: Mean weekly training loads (AU) by team for each phase during the 2013-14 season with error bars showing standard deviation (e.g. four sessions of RPE=7 and 45 minute duration would produce a training load of 1260 AU).

Weekly training strain and two- and three-weekly cumulative loads displayed substantial multicollinearity with other training load measures, and so were excluded from the analysis. The small number of injuries ($n=24$) and match exposure (200 hours) during the

pre-season period in this study produced unstable estimates (i.e. large standard errors) thus; the pre-season loading data are only presented for information and were not included in the model. As there was no significant difference in the training loads between in-season early and late competition phases, all in-season loads were included in the model. During the in-season phase, risk of injury in the subsequent week increased linearly with one-week loads and absolute change in loads, with a two standard deviation rise in these variables (1245 AU and 1069 AU, respectively) being associated with an increase in the odds of injury of 1.68 (95% CI 1.05-2.68) and 1.58 (95% CI: 0.98-2.54), respectively (Table 5.1). The change in injury risk associated with a two standard deviation increase in training monotony (0.39AU) and training stress balance (172%) was unclear. A significant non-linear effect was evident for four-week cumulative loads (Figure 5.2), with a likely beneficial reduction in injury risk associated with 'high intermediate' loads of 5932 to 8651 AU (OR: 0.55, 95% CI: 0.22-1.38), and a likely harmful effect evident for 'high' loads of >8651 AU (OR: 1.39, 95% CI: 0.98-1.98) compared with the reference group of 'low' loads (<3684 AU).

Table 5.1: Training load risk factors for injury in professional Rugby Union.

Load calculation	2 SDs	Effect of 2 SD increase	95% Confidence intervals		P-Value	Inference	% likelihood effect is beneficial trivial harmful
		[Odds ratio]	Lower	Upper			
1 week cumulative load	1245 AU	1.68	1.05	2.68	0.003	Very likely harmful	0 1 99%
Absolute change (±)	1069 AU	1.58	0.98	2.54	0.06	Likely harmful	1 6 93%
Monotony	0.39	1.22	0.84	1.78	0.29	Unclear	5 26 69%
Training stress balance	172%	1.41	0.60	2.80	0.42	Unclear	15 14 71%
4 week cumulative load							
<3684 AU (reference)		1.00					
3684 to <5932 AU		0.79	0.48	1.29	0.34	Unclear	70 21 9%
5932 to <8651 AU		0.55	0.22	1.38	0.20	Likely beneficial	85 8 7%
≥8651 AU		1.39	0.98	1.98	0.06	Likely harmful	1 9 90%

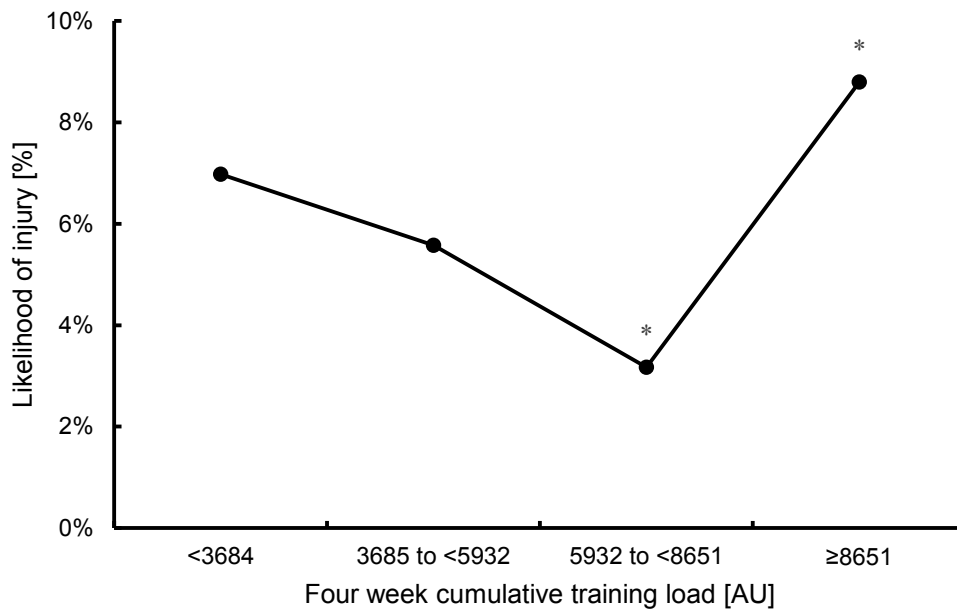


Figure 5.2: Four weekly cumulative training load quartiles and the likelihood of injury [%]. * denotes substantial change in injury risk in comparison with reference group (<3684 AU).

5.5 DISCUSSION

This is the first study to investigate the association between training load measures and injury risk in professional Rugby Union players. The results of this study suggest that a positive linear relationship exists between both weekly training load and absolute week-to-week changes in load and subsequent injury risk during the in-season phase. In addition, a ‘U-shaped’ relationship between four-week cumulative loads and injury risk was identified. These findings suggest that weekly training loads, week-to-week changes in load, and 4-week cumulative loads could be adapted by professional Rugby Union teams in order to reduce injury risk in this setting.

The mean weekly training loads described in this study were smaller than those previously described in professional Rugby Union (Bradley et al., 2014) and Rugby League (Austin et al., 2011b), but were similar to those observed in professional Australian Rules Football (Rogalski et al., 2013). A two standard deviation (or 80% based on an average in-season week) increase of in-season weekly load (1245 AU, approximately a 4 hour increase of an average in-season training intensity [RPE=5] was associated with around a 70% increase in injury risk in the subsequent week. This finding is consistent with the majority of previous research in contact sports (Gabbett, 2004b, Austin et al., 2011b, Rogalski et al., 2013), and

may be related to the impact of fatigue and concomitant changes in neuromuscular control (De Ste Croix et al., 2015).

In agreement with the findings of Rogalski and colleagues (Rogalski et al., 2013) absolute changes in week-to-week loads increased the risk of injury, with an absolute change in load of 1069 AU (about 3.5 hours of average in-season training intensity during this study) associated with an approximate 60% increase in the risk of injury the following week. This is important from a practical perspective as sudden training load increases could be imposed on players who are returning to training from injury. Equally, sudden decreases in week to week load could be associated with players who have to undertake modified training regularly, often in order to manage a chronic injury. Clubs should re-integrate players (injured or otherwise) back into training in a conservative manner, whilst carefully monitoring their training load in order to prevent a high weekly change in load and ultimately reduce the risk of injury (or subsequent injury in the case of injured players). Indeed, a recent review as highlighted the importance of considering an athletes acute and chronic workload (training stress balance) before integrating a player into full participation. Players should build up enough chronic workload (fitness demand) to be able to cope with the acute workload (fatigue demand) during the week that they return to training and/or match play (Blanch and Gabbett, 2015). However, it is noted that in practice the consistent application of this recommendation can prove difficult as coaches typically hope that any player will be able to train without restriction with the rest of the training squad as soon as they are able to do so. Training stress balance, which expresses acute workloads (i.e. 1-week data) against chronic workloads (i.e. 4-week rolling average), may be a useful means of monitoring this aspect of loading. The association between training stress balance and injury risk in the present study was unclear, and so further data are required to confirm its utility in this setting.

Previous studies in professional contact sport have reported a positive linear relationship between cumulative loads and injury risk (Colby et al., 2014, Rogalski et al., 2013). The present study is the first to present a non-linear association between cumulative training loads and injury risk, but a similar relationship has been observed previously with average weekly training volume (duration only) and injury risk in professional Rugby Union players (Brooks et al., 2008). A 'U-shaped' relationship between four-week cumulative loads and injury risk was identified. Four-week loads were associated with a decrease in the likelihood of injury in the 'high intermediate' quartile (5932 to <8651 AU) in

comparison to the 'low' reference quartile (<3684 AU), however injury risk increased substantially thereafter for 'high' loads (≥ 8651 AU). Given that the mean in-season weekly training loads were ~ 1500 AU, four weeks of training would equate to ~ 6000 AU and would sit within the third quartile of four week cumulative loads. It can be reasonably assumed that the players within this quartile are likely to have been training regularly during the four week period and will have acquired an appropriate level of fitness and physical robustness, which may explain the reduction in injury risk for this group. It is likely that the training loads exhibited in the 'high intermediate' quartile group reflect a training load that best allows players to adapt to a performance training stimulus without substantially increasing injury risk (Rogalski et al., 2013, Veugelers et al., 2015). The increase in risk associated with players in the 'high' quartile for load (> 8651 AU) suggests that players are likely to have an individual range, above which they are substantially more likely to incur an injury. The pre-season training loads reported in this study (2175 ± 380) AU are around half of those previously reported in professional rugby league (Austin et al., 2011b). These low pre-season loads may have meant that players were unable to tolerate in-season training loads in the highest 4-week quartile as they had not been exposed to similar loads previously. Conversely, excessive cumulative fatigue (adaptation without sufficient recovery) may lead to a reduction in the amount of stress that tissues can cope with and thus, beyond a certain threshold of load, the risk of injury increases (Kumar, 2001). It is not possible to say if the increase in in-season injury risk observed in the highest quartile is due to insufficient recovery time during high cumulative loads or, if players were inadequately prepared to cope with the loads in this quartile due to the low level of pre-season training loads prescribed. It is likely that both these factors contributed to an increase in injury risk in this study.

There is a clear requirement for coaches to achieve a balance between simultaneously allowing exposure to an adequate training stimulus in order to prepare the player for the specific demands of their sport and to subsequently improve performance (Foster et al., 1996, Viljoen et al., 2009) whilst limiting a player's load in order to prevent injury. This is particularly important in contact sports whereby practitioners need to prepare players to be able to cope with the demand of contact events whilst managing their overall risk of contact injury. One way that this might be achieved in practice is by reducing training monotony. It has been suggested that players may be able to manage high daily training loads as long as they are dispersed between lower load training days and/or a day off during the training week (Foster, 1998b). The association between training monotony and

injury risk in the present study was unclear, and this measure should be explored with larger samples in future studies.

Factors in addition to training and match load are likely to impact upon an individual's injury risk, such as previous injury (Hägglund et al., 2006) and psychological stressors (Ivarsson et al., 2013), and these were not accounted for in the analysis. Given that only a small number of reported injuries and match exposure was reported during the pre-season phase, these training loads were not included in the model used to investigate the association between training load measures and injury risk. The impact of this phase should be investigated in future studies. The day, week and phase of the season were reported clearly by all clubs, however, only total load values were collected rather than information pertaining to the specific type of training modality used in each session. Unfortunately, it was therefore not possible to describe the training load values of specific session types in this study. The study was underpowered to study the possible differences in the training load-injury association, it is also likely that RPE scores given by backs and forwards would be different depending on the type of session undertaken and the players physiological profile (e.g forwards may give a higher relative score for a speed session than backs). In addition, information regarding the association between training load and specific types of injury (e.g. soft tissue injuries) could not be investigated due to the sample size (and associated statistical power) available in the current study, this warrants future investigation. No meaningful conclusions could be drawn regarding training monotony or training stress balance as risk factors for injury. These load variables should be investigated in future using a more statistically powerful sample. Furthermore, whilst the session-RPE method has been proposed as an acceptable method of quantifying training load in collision sports (Clarke et al., 2013), GPS measures might provide additional data regarding external total training load. In this context, some training activities (skills, wrestling, strongman and speed sessions) may be better quantified using a combination of internal- and external-load measures.

This study is the first to provide an indication of how players' weekly training load is associated with injury risk in professional Rugby Union. Team coaches should monitor a player's weekly load, week-to-week changes in load and four-week cumulative load, when planning and implementing training to optimise performance whilst minimising injury risk. Given that these findings suggest that a high load and a large absolute change in load increase the risk of injury in professional Rugby Union players, trying to periodise training schedules with alternating heavy and light training weeks is not recommended (as opposed

to alternating heavy and light days which requires further investigation). One way that this may be achieved in practice is for coaches to prescribe stable and consistent weekly loads throughout the season in order to prevent any spikes in acute workload. These results also suggest that professional players may have a four-week cumulative training load limit, and that exceeding this threshold is associated with a substantial increase in injury risk. Strength and conditioning coaches should use these findings as a starting point for planning and monitoring individual player training thresholds. It should be noted that the physiological demands and movement patterns of different sports vary significantly and any application of these findings in other populations should be performed with caution.

5.5.1 Conclusion

Players were at an increased risk of injury if they had a high one week cumulative load or a large week-to-week change in load. A ‘U-shaped’ association between four-week cumulative loads and injury risk was identified. The ‘high intermediate’ quartile of four-week cumulative load 5932 to <8651 AU (in a practical sense, the lower limit of this range equates to around four weeks of average in-season training load) would appear to be beneficial in reducing injury risk in this population. These measures should therefore be individually monitored in professional Rugby Union players, as a potential means of informing risk reduction strategies in this setting.

CHAPTER 6: The Epidemiology of Time-loss Illness in Professional Rugby Union

6.1 ABSTRACT

Aim: To describe the prevalence, incidence, severity and type of time-loss illnesses in English professional Rugby Union

Methods: This was a two-season prospective cohort study of 764 male professional Rugby Union players equating to a total of 1140 player seasons or 331,728 player days of exposure. Data was reported in the form of counts and then descriptive statistics were used to analyse the number, proportion/percentage and incidence (including 95% confidence intervals) of illnesses in the total sample, as well as for specific illnesses in the most commonly affected systems. Time-loss illness incidence was calculated as the number of illnesses per 1000 player days.

Results: Almost a quarter (24%) of players reported a time-loss illness during the study, equating to an incidence of 0.8/1000 player days. There was a rise in the reported illness incidence during the months of September and December, although these increases were not statistically significant. The mean severity of illness during the study period was 12 days, with an increase in severity observed during the 2014-15 season. The respiratory, digestive and skin systems accounted for 38%, 27%, and 20% of reported time-loss illnesses, respectively. Specifically, the most common diagnosis of illness were upper respiratory tract infection and runner's diarrhoea both accounting for 12% of all time-loss illnesses in this cohort.

Conclusions: This is the largest and first multi-season study to date investigating the nature of time-loss illness in professional Rugby Union. Although the reported incidence of time-loss illness was low, the fact that the reported severity of illness in this study was higher than reported previously in Rugby Union and also than in other sports highlights the need to continue to monitor illness data in this cohort.

6.2 INTRODUCTION

Both injury and illness surveillance play an integral part in the protection of athlete health (Junge et al., 2008). It has been suggested that in an elite multi-sport competition, medical staff may spend as much as 50% of their time treating illness (Derman, 2009), with the remaining time treating injuries. However, the reporting of illness data remains in its infancy, particularly in team sports, with the majority of surveillance systems focusing primarily on the collection of injury data (Clarsen and Bahr, 2014). Currently, unlike for reporting injury data (Fuller et al., 2007b), there is no consensus statement on the reporting of illness in Rugby Union. Encouragingly, given the potential burden from illness, the last five years have seen more emphasis directed to the collection of illness data at major sporting events and tournaments (Dvorak et al., 2011, Engebretsen et al., 2013, Engebretsen et al., 2010) in order to better understand the short and long-term risks of participation in a particular sport (Steffen et al., 2011).

Rugby Union requires elite players to regularly participate in a variety of physiologically demanding training modalities (see chapter 5) and match activity (Roberts et al., 2008). It has been suggested that training consistently under physiological stress may indirectly render players more susceptible to illness (Budgett, 1998). Despite this assertion, only two previous studies have explicitly investigated the incidence of illness amongst professional Rugby Union players. Cunniffe et al. (2009) studied 30 professional Rugby Union players from one club over a 48-week season using a self-reported web-based player diary. Illnesses were included if the player reported symptoms for at least 2 days and could have included both time-loss and non-time loss illnesses. It was suggested that 92% of players sustained at least one Upper Respiratory Tract Infection (URTI) during the study period and on average, players reported four URTIs during the season. It is unclear whether the self-reported nature of the study led to an overestimation of URTIs as considerably more URTIs were self-reported (n=118) than those reported to medical staff (n=23). In addition, 25 gastrointestinal tract complaints (0.8 per player) were recorded throughout the season. More recently, Schwellnus et al. (2012a) collected illness data (non-time loss and time-loss) from 259 elite rugby players across eight teams, during one season of the 16-week Super 14 rugby competition (22676 player days). The incidence of all illnesses in the cohort was 20.7/1000 player days, 95% CI: 18.5-23.1; the incidence for >1 day time-loss illness was 1.3/1000 days, 95% CI: 0.9-1.9 or 6% of all illnesses. The most commonly affected systems were the respiratory system (6.4/1000 days 95% CI: 5.5-7.3), gastrointestinal system (5.6/1000 days, 95% CI: 4.9-6.6) and the skin and subcutaneous

tissue (4.6/1000 days, 95% CI: 4.0-5.4). It is important to note that the Super Rugby competition is unique within Rugby Union as teams are required to undertake large amounts of travelling as the competition involves clubs from South Africa, Australia and New Zealand. Travelling more than 5 time zones was associated with a 3-fold increase in illness in this population (Schwellnus et al., 2012b) and therefore, the incidence in players involved in more domestic elite club competitions may not be as high.

There is a paucity of research concerning the incidence and severity of time-loss illness information in professional Rugby Union, and as of yet, no study has investigated illness incidence over multiple seasons of competition, or in a competition where the majority of matches are solely contested in one country. Consequently, the impact of illness upon player welfare remains unclear in this setting. Information of this type may provide insight as to the number of appropriate medical personnel that need to be employed based on the clinical requirements of the team and further insight into the relative burden of player days lost to illness compared with injury. Thus, the aim of this study was to describe the prevalence, incidence, severity and overall burden of time-loss illness and also, to highlight what type of illnesses occur amongst professional Rugby Union players.

6.3 METHODS

6.3.1 Participants

All participants were male professional Rugby Union players registered as a first team squad player in the highest level of Rugby Union in England (English Premiership; comprising 12 teams). Data were collected for two seasons (2013-14 and 2014-15), 764 players were included in the study (202 players took part during season 2013-14 only, 186 players took part in season 2014-15 only, and 376 players took part in both seasons), giving rise to a total of 1140 player seasons or 331,728 player days. The study was approved by the Research Ethics Approval Committee for Health at the University of Bath and written informed consent (Appendix A1) was obtained from each participant.

6.3.2 Procedures

Before the start of each season, players were asked to provide their primary playing position (the position that they play in most). The time-loss illness definition used in this study was “Any non-trauma related signs or symptoms that prevented a player from taking a full part in training and/or match play typically planned for that day for a period of greater than 24 hours after the day that the illness was reported”. Time-loss illnesses were

coded using the Orchard Sports Injury Classification System (OSICS, version 10.1; Rae and Orchard, 2007) and were reported through clubs' online medical records system (Rugby Squad, The Sports Office, UK). The final diagnoses in all cases were made by the team physician; any other reported symptoms to physiotherapists or other medical staff that did not result in a definitive diagnosis were not reported in this study. The medical staff at each club were briefed at the beginning of the 2013-14 season to outline the study and the operation of the online reporting system. To account for the potential changes in medical personnel at each club, each club was briefed again at the beginning of 2014-15.

6.3.3 Data Analysis

Data were in the form of counts (the number of illnesses contracted, assumed to have a Poisson distribution). Standard descriptive statistical analyses were conducted, these included number, proportion/percentage and incidence (including 95% confidence intervals) of illnesses in the total sample, as well as for specific illnesses in the most commonly affected systems. Time-loss illness incidence was calculated as the number of illnesses per 1000 player days. This methodology, which takes into account athlete exposure days, allows for comparison between tournaments of different durations, different sports, different positions, and other factors that may affect illness and has been used in a previous study concerning the incidence of illness (Schwellnus et al., 2012a). All players were included in the calculation of player days regardless of whether they had sustained an injury, as injured players could also sustain and subsequently report an illness. The total 'player days' for each team per week was calculated as the product of: weekly team size x number of days in that week. These weekly totals were then summed for all of the weeks of the season to provide the total number of 'team player days'. Thus, the overall number of 'player days' for the study was calculated as the sum of all 12 sets of 'team player days'. For all teams, the number of days in each week was usually 7, apart from the first and last weeks of the season where clubs may not complete a full week of training. In addition, each team had a different length of season (number of weeks) depending on when pre-season began and how far they progressed within the competition, the total number of player days during the season for each team was therefore variable. In order to be able to directly compare the burden of illness with injury in a way that was meaningful and that accounted for the different denominators in each case (1000 player days versus 1000 player hours), the total days lost during each season was calculated. Illness severity was defined as 'the number of days that have elapsed from the date of illness to the date of the player's return to full participation in team training and availability for match selection.

Significant differences in values for incidence and severity for player position and phase of the season were assumed if the 95% confidence intervals (CI) for the variables did not overlap.

6.4 RESULTS

A total of 764 players sustained 267 time-loss illnesses from the 331,728 days of player exposure reported in this study, giving rise to an incidence of 0.8/1000 player days (table 6.1). One hundred and eighty-five players reported at least one time-loss illness during the study period (133 players = 1 illness, 33 players = 2 illnesses, 15 players = 3 illnesses, 1 player = 4 illnesses 2 players = 5 illnesses and 1 player = 7 illnesses). The prevalence of illness was therefore 24%. There was no significant difference in the incidence of illnesses between seasons, but the mean severity of illness was higher in 2014-15 (15 days, 95% CI: 13-17), than in 2013-14 (8 days, 95% CI: 6-10; table 6.1). The overall mean severity of illnesses during the study period was 12 days (95% CI: 10-14). During the study period, a total of 3182 days were lost due to time-loss illness.

The most commonly affected system for illness was the respiratory system followed by the digestive system and then dermatological illness (38%, 27%, and 20% of total illnesses, respectively; table 6.2). The most common specific illness diagnoses were upper respiratory tract infections and runner's diarrhoea, each contributing 12% of all illness (table 6.3). Dermatological illnesses were the most severe, causing an average of 17 (95% CI: 13-22) days absence per case (table 6.3).

Table 6.1: The incidence and severity of illness during seasons 2013-14 and 2014-15

	2013-14	2014-15	Total
Exposure (total player days)	164,106	167,622	331,728
Illnesses (n)	112	155	267
Illness Incidence (1000 player days)	0.7 (95% CI: 0.6-0.8)	1.0 (95% CI: 0.8-1.1)	0.8 (95% CI: 0.7-0.9)
Mean Severity (days absence)	8 (95% CI: 6-10)	15 (95% CI: 13-17)*	12 (95% CI:10-14)
Burden (total days lost)	931	2251	3182

*Indicates significant difference to 2013-14

Table 6.2: The incidence and proportion of illnesses by affected system.

Affected System	Number (n)	Incidence ^a	Proportion (%)
Respiratory/ENT	104	0.31	38
Digestive	75	0.23	27
Dermatologic	55	0.17	20
Neurologic/Psychiatric	19	0.06	7
Other	13	0.04	5
Genitourinary	5	0.02	2
Cardio-Vascular	2	0.01	1
Metabolic	2	0.01	1
Haematological	2	0.01	1

^aincidence displayed as number of illness/1000 player days

Table 6.3: The most common illness diagnosis and their severity in the four most affected systems.

Illness	Cases (n)	Proportion (%)	Severity (95% CI)
Respiratory/ENT	104	38	13 (11-16)
<i>URTI</i>	33	12	14 (10-20)
<i>ENT Illness - undiagnosed</i>	19	7	14 (9-22)
<i>Tonsillitis</i>	14	5	10 (6-17)
Digestive	75	27	9 (7-11)
<i>Runners Diarrhoea</i>	34	12	3 (2-4)
<i>Viral Gastroenteritis</i>	19	7	5 (3-8)
<i>Bacterial Gastroenteritis</i>	9	3	11 (6-21)
Dermatologic	55	20	17 (13-22)
<i>Skin Infection - undiagnosed</i>	15	5	12 (7-20)
<i>Skin Infection - Lower Leg</i>	9	3	26 (14-50)
<i>Skin Infection - Head & Neck</i>	7	3	13 (6-27)
Neurologic/Psychiatric	19	7	13 (8-20)
<i>Tired Athlete</i>	8	3	12 (6-24)
<i>Headache</i>	4	1	4 (2-11)
<i>Rheumatological Disease</i>	2	1	40 (10-160)

During the study period, the incidence of reported illnesses was highest in September and December (both 1.1/1000 player days, 95% CI: 0.8-1.5) although these values were not statistically different to other months (figure 6.1).

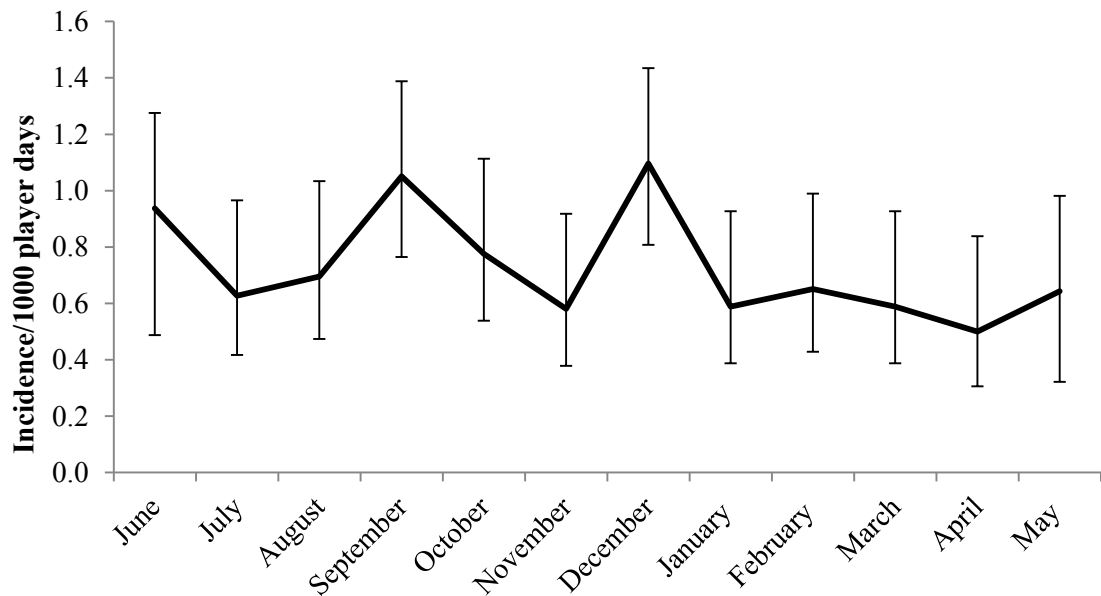


Figure 6.1: The incidence of reported illnesses per month during 2013-15. Error bars represent 95% confidence intervals.

6.5 DISCUSSION

The aim of this study was to describe the incidence, severity and type of time-loss illness in English professional Rugby Union. Almost a quarter of players (24%) reported a time-loss illness during the study, equating to an incidence of 0.8/1000 player days. There was a rise in the reported illness incidence during the months of September and December, although these increases were not statistically significant. The mean severity of illness during the study period was higher than previously reported in other sports (Dvorak et al., 2011, Engebretsen et al., 2013), with an increase in severity observed during the 2014-15 season. In total, 3182 days were lost due to time-loss illness during the study. The most commonly affected systems were the respiratory, digestive and skin systems accounting for 38%, 27%, and 20% of reported time-loss illnesses, respectively. Specifically, the most common diagnosis of illness were upper respiratory tract infection and runners diarrhoea both accounting for 12% of all time-loss illnesses in this cohort.

In agreement with our working hypothesis, the reported incidence of time-loss illness in this study was lower than the 1.3/1000 player days previously reported in elite Rugby

Union (Schwellnus et al., 2012a) and was also lower than the 1.5/1000 player days recently reported in a large surveillance study in professional European soccer (Bjørneboe et al., 2016). This comparison of the time-loss illness incidence between the two studies was possible due to the number of time-loss illness (>1 day) being reported separately by Schwellnus et al. allowing the incidence of time-loss illness to be estimated. Although a full analysis of the reasons for this difference in reported incidence are beyond the scope of this study, it should be noted that travelling more than 5 time zones has been previously associated with a 3-fold increase in illness risk in the Super Rugby cohort (Schwellnus et al., 2012b). Furthermore, it has been suggested that frequent international travel in the Super Rugby competition regularly exposes players to a variety of environmental and climatic conditions (Schwellnus et al., 2012a) that are uncommon in the English Premiership competition. In addition, the differences in the structure (Gannon et al., 2015) and physiological demand (Austin et al., 2011a) between the English Premiership and Super Rugby competitions have been described previously, proposing that the Super Rugby competition is shorter (14 weeks versus 34 weeks of competition) but requires more intensity in order to be competitive in matches (on average more time is spent by players completing high-intensity activities with less recovery time). These differences may provide further clarity regarding the lower incidence of time-loss illness reported in this study.

What constitutes a 'recordable event' is arguably the most important methodological factor that impacts the results of both injury and illness surveillance (Clarsen and Bahr, 2014). The divergent nature of the primary definitions of illness (medical attention versus time-loss >1 day) used in these studies highlights the difficulties faced when trying to make inter study comparisons in the absence of a recognised consensus statement on the definitions and data collection procedures of illness. A consensus statement (Fuller et al., 2007b) is already well established with regards to the reporting of injury data, and has significantly improved the consistency of reporting in Rugby Union (Williams et al., 2013). Therefore, it would seem logical that a similar influence could be made regarding the reporting of illness data in Rugby Union in the future, and thus, the formation of such a consensus statement is recommended in order to nullify any potential inconsistencies between illness studies in Rugby Union and in other sports.

The impact of illness on an athlete's ability to train and compete can be just as significant as that of an injury (Engebretsen et al., 2013). However, there is a paucity of information available regarding the burden of illness in professional sport. This is most likely due to the

fact that the majority of studies have utilised a medical attention definition of illness (i.e. the majority of illnesses did not result in any absence from training or match play). During the study period, the total days lost due to time-loss illness in this study was only 5% of the total days lost due to time-loss injury (61,616 days; data not shown). Clearly, this finding indicates that the burden of time-loss injury in this setting is far more significant than time-loss illness in professional Rugby Union and is in agreement with a recent paper in professional soccer that concluded that illness is not a major contributor to time-loss (Bjørneboe et al., 2016). However, it should be noted that the severity of illness reported in this study appears to be higher than reported in the previous studies available in other sports (Dvorak et al., 2011, Engebretsen et al., 2013). In the 2010 FIFA World Cup, the mean severity of time-loss illness during the tournament was approximately 2 days (Dvorak et al., 2011) and in a recent study of 73 professional European soccer clubs, the mean severity of time-loss illness was 3 days (Bjørneboe et al., 2016) but in this study it was 12 days. This could be explained in part by the differences in the demands of the sport, the structure (season versus tournament), the duration of each competition and being at home versus being in a training camp with access to a doctor all of the time. However, it may also highlight the possibility that the majority of players during this study were unwilling to report an illness to their club doctor, reporting only the most severe of illnesses and as a consequence, illnesses that were less severe went unreported. In order to try to encourage the reporting of all illnesses in the future, club doctors should highlight the importance of reporting symptoms early so that appropriate steps can be taken to reduce the possibility of the spread of infection within the squad. Furthermore, there was a significant increase in the severity of illness in 2014-15 when compared with 2013-14. The reason for this increase is unknown, thus, longitudinal monitoring is needed to further understand the natural variation of the incidence and severity of illness over time.

During this study, there was an observed increase in the number of reported illnesses during September and December. Although the current study was not appropriately powered to allow for any statistically significant variations to be identified, these observed increases in illness incidence during the season are clearly of interest for medical practitioners when planning medical provision throughout the season. Although it was beyond the scope of this study to investigate the reason for these increases, there is a long standing association between chronic exertion and the incidence of illness (Foster, 1998a). The highest workloads in this cohort have been shown to be exhibited during the pre-season macrocycle (see chapter 5; Cross et al., 2015). It is therefore plausible that these

high workloads in combination with the sudden change in match demand at the beginning of the season contributed to a rise in the reported incidence of illness in this cohort during September. Further research that a) includes a larger sample to ascertain if these differences are significant from a statistical perspective and b) includes measures of training load (such as those presented in chapter 5) to investigate any potential associations between training load and illness risk is essential to be able to provide further clarity in this area. Indeed, a recent study in professional Rugby League players has highlighted that increases in internal training load measures (weekly training load, training monotony and strain) best predict the likelihood of self-reported illness (Thornton et al., 2015). From a practical perspective, it is recommended that athletes, coaches and medical staff pay particular attention to player recovery and nutritional strategies during periods of intense physical stress in order to try and mitigate any increases in the risk of illness.

It is well-known that the risk of illness, and in extreme cases death, increases during the winter months (Eccles, 2002) with the incidence of specific illnesses such as seasonal influenza (Public Health England., 2015) and upper respiratory tract infections (the most common diagnosis in this study) peaking during the months of December and January in the UK (Eccles, 2002). In the case of upper respiratory tract infections, cold air and a decrease in temperature and humidity has been shown to be a specific risk factor for contracting infection (Mäkinen et al., 2009) and it is therefore plausible that this general increase in illness risk rather than any specific rugby related activity *per se* has led to the rise of reported time-loss illness observed in December in this cohort.

There were also some similarities between the findings in this study and those presented previously by Schwellnus and colleagues, specifically regarding the types of illness sustained during competition periods. The most commonly affected systems were identical in both studies, with the respiratory, digestive and dermatological systems the most affected. The finding that infections to the respiratory and digestive systems are commonplace is consistent with other team sports such as soccer (Dvorak et al., 2011) and at major tournaments such as the Winter Olympics (Engebretsen et al., 2010). Although, there is no single method that completely eliminates the risk of infection, practical suggestions for minimising this risk have been suggested previously (Gleeson and Walsh, 2012) and include regular hand washing, individual water bottles and the quick isolation of individuals who start to exhibit symptoms. In addition, probiotic supplementation has been shown to reduce the incidence of infection in elite Rugby Union players and therefore should be considered (Haywood et al., 2014). The implementation of simple and practical

guidelines such as those listed, are likely to reduce the risk of illness and specifically, the spread of infection in this setting. The fact that skin infections were also very common provides support to a similar finding by Schwellnus and colleagues and further highlights a potential issue concerning player health in Rugby Union that, at this stage, appears to be unique to the sport. The importance of personal hygiene is clear, especially for players that spend most of their time in a restricted team environment with shared facilities and participating in training and match play where player to player contact is a frequent occurrence (Schwellnus et al., 2012a). Furthermore, there is growing interest in the use of artificial turf in professional Rugby Union with elite clubs beginning to utilise the surface for competitive matches (Williams et al., 2015). Recently, abrasion injuries have been shown to be significantly more common on artificial turf when compared with natural grass in this cohort (Williams et al., 2015). Although only a small number resulted in time-loss injury, the number that resulted in time-loss due to illness were not reported and therefore, the impact that artificial turf may have on dermatological illness remains unclear and should be explored in the future. Furthermore, dermatological illnesses were also the most severe of the illness groupings in this study and thus, it is recommended that team doctors are trained in the identification, treatment and management of this type of illness or, alternatively, have immediate access to an appropriately trained medical professional in order to support the return to play process following these types of infection.

The main limitation of this study was that the incidence and type of non-time loss illnesses were not reported. In the super 14 competition, 83.8% of illnesses did not result in any time lost from training or match-play and therefore it can be assumed that the majority of illnesses were not reported in this study. However, the reliability of reporting non-time-loss illness has not been established and given that it has been suggested that the reliability of reporting mild injuries may be poor (Rae and Orchard, 2007), non-time-loss illnesses were excluded on the same basis. Nevertheless, if the reporting reliability of these illnesses is demonstrated to be acceptable in the future, the benefit of the inclusion of this information is obvious as it will provide further insight into the clinical demand of illness in this setting. In addition, it is not known if players always sought consultation with their club doctor every time that they felt unwell. If a player felt that reporting an illness at their club may have impacted upon their selection, it would be reasonable to think that he may have sought treatment from his own GP rather than the club doctor and thus not all illnesses may have been reported. Furthermore, behavioural or even subjective measures of sleep were not included in this study. There is growing evidence to suggest that short sleep duration

and poor sleep quality are associated with both acute and chronic illness (Prather et al., 2015). Indeed, sleep latency and efficiency have already been shown to be abnormal in an elite Rugby Union population when compared with that expected in a general population (Shearer et al., 2015). Future studies that provide insight into the association between sleep measures and the risk of illness in elite Rugby Union are likely to provide the basis for important player welfare recommendations for both coaches and players in the elite game.

6.5.1 Conclusion

This is the largest study to date investigating the nature of time-loss illness in professional Rugby Union. The reported incidence of time-loss illness presented in this study was low and the burden of illness was far less significant than that caused by time-loss injury. However, the fact that the reported severity of illness in this study was higher than reported previously in Rugby Union and also than in other sports highlights the need to continue to monitor illness data in this cohort.

CHAPTER 7: Discussion

7.1 Introduction

The aim of this thesis was to investigate the epidemiology and risk factors for injury and illness in male professional Rugby Union with a view to informing injury reduction strategies. In order to achieve this primary aim, a number of novel research questions were proposed in chapter one and subsequently a methodical programme of research was undertaken. This chapter summarises the key findings that have emerged from the research undertaken in chapters 3-6 and then will outline how this thesis has made an original contribution to this area of study. Following this, the main strengths and limitations of the methodological approach to this research will be discussed. Finally, the potential impact of the findings from this thesis upon player welfare is explored and suggestions concerning the future directions of research and policy elaborated.

7.2 Summary of findings

A clear understanding of injury risk is fundamental to any sport governing body's risk management strategy and subsequent player safety initiatives. Therefore, the primary aim that underpinned all of the chapters in this thesis was to improve the understanding of pertinent injuries and risk factors for injury and illness in professional rugby. Injury surveillance in this population began in 2002 and has since resulted in a number of publications (Brooks et al., 2005a, Brooks et al., 2005b, Brooks and Kemp, 2011, Brooks and Kemp, 2008, Fuller et al., 2015, Fuller et al., 2013, Kemp et al., 2008, Taylor et al., 2014). However, the review of extant literature in chapter 2 of this thesis identified a paucity of research in areas of study which were then addressed within experimental chapters 3-6. The research questions and key findings from these chapters are summarised below:

- i. **What is the current incidence and time to return to play following concussion in professional Rugby Union for the period 2011-15 and has this changed when compared with previously reported data from 2002-11?**

Key findings:

The reported incidence of match concussion in this study during 2011-15 was 8.9/1000 hours, almost double the incidence previously reported in this cohort from 2002-11. In addition, concussion increased from being the 4th most common injury between 2002 and 2011 to the most common match injury for the period 2011-15. When compared with 2002-11, the number of players returning to play earlier than the recommended minimum

guideline of 6 days in 2011-15 was reduced by more than half from 40% to 19% respectively. Since 2009-10, this number has reduced year-on-year, with only 6 players (6%) returning in less than 6 days in season 2014-15.

ii. Are players who report a concussion at an increased risk of subsequent time-loss injury?

Key findings:

Players who reported a concussion were approximately 60% more likely to sustain another injury of any type in the same season following return to play than those players that were diagnosed with an injury other than concussion. In addition, the median time to subsequent injury (survival time) in players who reported a concussion was around half that of players who did not report a concussion, 114 days versus 53 days.

iii. What is the time course of symptom resolution, balance impairment and cognitive deficit after concussion and do specific clinical features predict a prolonged recovery time?

Key findings:

The resolution of the symptom, cognitive, and balance components and the proportion of players that made a full clinical recovery at 7, 14 and 21 days was as follows; symptoms (84%, 95% and 99%), cognitive (82%, 98% and 100%), balance (70%, 87% and 99%) and full clinical recovery (25%, 82% and 95%). A higher symptom severity score (OR 1.17, 95% CI 1.01 – 1.31) and raised balance error score (OR 1.33, 95% CI 1.06-1.66) at initial assessment were predictive of protracted recovery (>14 days) in this cohort. Thirty-nine percent of players reported a recurrence of symptoms or failed to match their baseline neuropsychological test at the first attempt during the graduated return to play protocol.

iv. Is there any association between specific training load measures and injury risk in professional Rugby Union?

Key findings:

Injury risk increased linearly with one-week loads and week-to-week changes in loads, with a 2 standard deviation (SD) increase in these variables associated with odds ratios for injury risk of 1.68 and 1.58 respectively. When compared with the reference group (<3684 AU), a significant ‘U’ shaped relationship (non-linear effect) was evident for four-week

cumulative loads, with a likely beneficial reduction in injury risk associated with intermediate loads of 5932 to 8651 AU and a likely harmful effect evident for higher loads of >8651 AU.

v. What are the prevalence, incidence, severity and overall burden of time-loss illness and what type of illnesses occur amongst professional Rugby Union players in England?

Key findings:

The prevalence of time-loss illness was 24%, equating to an incidence of 0.8/1000 player days. There was a rise in the reported illness incidence during the months of September and December, although these increases were not statistically significant. The mean severity of illness during the study period was 12 days with an increase in severity observed during the 2014-15 season. The most commonly affected systems were the respiratory, digestive and skin systems accounting for 38%, 27% and 20% of reported time-loss illnesses, respectively; specifically, the most common diagnosis of illness were upper respiratory tract infection and runner's diarrhoea, both accounting for 12% of all time-loss illnesses in this cohort.

7.3 Original Contributions to Research

This thesis makes a number of original contributions to the current scientific knowledge and understanding in this field. Over the last decade, concussion has rapidly become the principal player welfare issue faced by collision sports (Calderwood et al., 2015). Importantly, chapter 3 of this thesis highlights the high and increasing incidence of reported concussions in professional Rugby Union; with concussion now the most commonly reported time-loss match injury in professional Rugby Union. Although it is not possible to separate improvement in reporting practice from any inherent increase in concussion risk, this chapter proposes that the primary reason for this observed increase in incidence is an improvement in reporting behaviour and an overall increase in the awareness of concussive injury. Concurrently, the operational definition of concussion in Rugby Union was widened and, as a consequence, the threshold for definitive diagnosis was lowered (this process is explained in more detail in chapter 3). It is probable that this increase in incidence is not unique to Rugby Union (Lincoln et al., 2011) and as such these findings reinforce a) that concussions are common in contact sport and governing bodies should focus on funding research into the prevention of concussion as part of their risk

management strategy, and b) the importance of the continued implementation of player education initiatives in order to promote a transparent reporting culture across all sports.

Subsequently, chapter 4 was the first study to investigate the short and medium term clinical outcomes following return to play from concussion in professional Rugby Union. This area of research is clearly one of fundamental importance as it has been suggested that premature return to play from concussion has been reported to increase the likelihood of protracted recovery following subsequent concussions (McCrory and Johnston, 2002b). One of the findings from this chapter highlighted an increase in subsequent injury risk following return to play from concussion in professional Rugby Union players compared with players who did not report a diagnosed concussion. This finding paves the way for trials of more conservative and comprehensive graduated return to play protocols. It is important to also consider that this phenomenon seems to be generalisable, with similar moderate to large increases in subsequent injury risk observed in both soccer (Nordström et al., 2014) and collegiate sports (Lynall et al., 2015), highlighting the need to explore the current return to play paradigm (both in terms of the length the content) at a global level. If such changes are made in the future (for example, if a more conservative return to play guideline means that a player diagnosed with a concussion will need to miss the next match) it will place even more importance on the stakeholder education and player welfare initiatives highlighted in chapter 3 to ensure adherence. Furthermore, this chapter highlighted that a reduced balance error and/or symptom burden score may indicate a protracted recovery, a finding that could help achieve earlier identification and consequently earlier clinical intervention in protracted cases of concussion. This finding may also be generalisable to the management of concussions in the wider sporting and public health context.

In this cohort, the severity of training injuries has increased for the last two seasons, in the absence of any change in training volume (Rugby Football Union, 2015). Chapter 5 provided the first investigation into training load as a modifiable risk factor for injury in professional Rugby Union and highlighted the linear association between one week loads and week-to-week change in load and the non-linear association of 4 week cumulative loads and injury risk in this cohort. When considering the findings outlined in chapter 4, the association between absolute week-to-week change in load and injury risk is of particular interest. It is noteworthy that the current graduated return to play protocol for concussion is markedly different in nature than for the majority of musculoskeletal injuries and there is a far greater emphasis on recovery and rest. As a result, players are often

subjected to sharp increases in training load when returning from concussion and it would therefore seem logical that training load (alongside the changes to an athletes postural and neuromuscular control proposed in chapter 4 and previously by Lynall et al (2015) and Nordstrom et al (2014)) may be associated with an increased risk of injury when returning to play following concussion.

Chapter 6 of this thesis provides the first description of the epidemiology of time-loss illness in this cohort and is the first study to compare the burden of time-loss illness and time-loss injury in a professional Rugby Union setting. Although the overall burden of time-loss illness was low when compared with that of time-loss injury, the reported severity of illness was significantly higher than previously reported in other team sports, highlighting the importance of continued monitoring of illness in this cohort. Interestingly (although our study was underpowered to establish any statistically significant difference), the findings from this chapter appear to indicate a peak in the incidence of illness following the pre-season macrocycle. Given the association between chronic exertion and the incidence of illness (Foster, 1998a) and that a number of sports (including Rugby Union; data presented in chapter 5) have previously reported the highest training loads during the pre-season period (Gabbett and Jenkins, 2011, Rogalski et al., 2013), it would appear essential for all team sport strength and conditioning practitioners to carefully consider the prescription of training load, recovery and nutrition during this period of athlete vulnerability in order to mitigate against the risk of illness.

Overall, this thesis presents a number of novel findings that have the potential to a) reduce the burden of injury and illness in professional Rugby Union and b) improve clinical practice in this setting. In addition, a number of the findings outlined above can be generalised to the wider research setting (both in other sports and also in a public health setting) and as such it is anticipated that this thesis will make a significant contribution to both research and practice.

7.4 Strengths and Limitations of the Methodological Approach

All of the injury data used in this thesis was collected via the England Premiership Rugby Injury Surveillance Project (PRISP). One clear advantage of utilising the data provided by this system was the level of reporting quality and consistency (compliance, sample size and methodology) that has been maintained since the inception of the surveillance project. This allowed for year-on-year comparisons and primary data analysis to be performed with confidence. In order to be able to make player welfare decisions based on surveillance

data, it is important that the majority of the target population are represented. Whilst each individual player had to voluntarily consent to participate in the surveillance project, all English Premiership clubs are required to take part in the project in order to comply with the minimum standards criteria of their competition agreement. Consequently, ~99.5% of the total available study population (English Premiership players) has participated in the project since 2002.

The reporting practices employed by the injury surveillance project were largely consistent with those recommended by the consensus statement for reporting injuries in Rugby Union (Fuller et al., 2007b). One minor difference was the exclusion of any injuries and illnesses that resulted in ≤ 1 day of time-loss. It could therefore be argued that a large proportion of injuries and illnesses were not reported (for example those that did not result in any time-loss) and therefore, the findings presented herein may not fully reflect clinical practice and demand in professional Rugby Union. It has been suggested that since understanding the risk of injury requires consideration of both the incidence and severity of an injury (van Mechelen et al., 1992), injuries that are mild in severity may appear less important however, the incidence of these injuries may mean that they have a high impact on the game and also the welfare of the players. Thus, the exclusion of such injuries may often lead to ‘tip of the iceberg phenomenon’ commonly seen in epidemiological studies (Walter et al., 1985). During this research programme, the injury surveillance system was expanded to allow for the reporting of non-time-loss injuries and illnesses so that these data can be investigated in the future. However, the reliability of less severe injuries have been brought into question (Orchard and Hoskins, 2007) and until the reliability of reporting these injuries and illnesses can be established in this setting (see future directions below), their inclusion would likely jeopardise the accuracy of the data presented. Given that the selection of an appropriate injury severity threshold is essential to enabling a balance of reporting reliability, accurate reflection of injury risk and an understanding of clinical demand in a given context (Orchard and Hoskins, 2007), the definition employed throughout this thesis would appear to be the most appropriate choice at this time.

All of the studies presented in this thesis were fully supported by the Rugby Football Union, Rugby Players Association and Premiership Rugby. As a result, this is likely to have improved the compliance in recording the additional study parameters that were not already reported through the injury surveillance project (concussion and training load). Despite this, only 65% of the reported concussions processed through the analysis in chapter 4 provided all of the additional information requested. Consequently, it is not

known whether those concussions for which data were not available were managed according to recommended return to play guidelines, or whether the included cases were representative of the assessment, management and outcomes of the whole cohort. However, this study included a sufficiently large sample size that allowed statistically significant and clinically meaningful differences to be investigated; highlighting the importance of obtaining high compliance especially in a clinical setting.

A further consideration for chapters 3 and 4 is the current subjective nature and potential variability in practice surrounding the diagnostic decision making for concussion. Currently, no recognised operational definition of concussion exists (Quarrie and Murphy, 2014). The Zurich consensus suggests that the diagnosis of concussion should remain a clinical decision based upon multi-modal assessment (McCrory et al., 2013b), and thus, this definition has been translated widely as the operational definition of concussion in research studies in the field. Whilst this approach is clearly logical in the absence of any diagnostic criterion, for the purpose of injury surveillance, this approach is problematic because the typical validity or interclinician and intraclinician reliability of making such a diagnosis is unclear (Quarrie and Murphy, 2014). The majority of clinical decision making (in this cohort and in other sports) is made based upon comparing the players SCAT3 score to a pre-season baseline. The SCAT3 (derived from the Zurich consensus meeting) is considered the 'gold standard' multi-model assessment tool but whilst sections of the SCAT3 have been validated previously (Guskiewicz et al., 2013), the assessment tool as a whole entity has not been validated. Accordingly, the sensitivity and specificity of the SCAT3 regarding concussion diagnosis is still to be established.

7.5 Potential Research Impact

The overarching aim of this thesis was to investigate the epidemiology and risk factors for injury in professional Rugby Union with a view to informing injury reduction strategies. In order for this thesis to have an impact in this area, it was important from the outset that the research questions outlined in chapter 1 could provide real-world applicable findings that had the potential to be utilised in future interventions and player welfare initiatives. It is well known that the majority of sports injury research is not disseminated widely and is often not adopted by those who can use it to improve clinical practice and subsequently, player welfare (Finch, 2011). This section aims to show how the studies included in this thesis are already shaping education and policy within professional Rugby Union and also to highlight where this research aims to bridge the research to practice gap in the future.

7.5.1 Concussion

The findings presented in chapter 4 of this thesis have already been used to inform policy and education in the professional rugby setting and have also prompted research collaboration in this area. Following the recommendation regarding the need to explore a more conservative and active return to play protocol, this research has been used to inform stakeholders how important it is to manage the return to play from concussion effectively. The majority of the findings presented have been included in an online education module that required mandatory completion for all professional players (n=1166), medical staff, coaches and support staff (n=282) and referees (n=20) that operate within the premiership and championship league structure. Within 2 months, the module reported 100% completion from all aforementioned stakeholder groups. It is likely that the information provided in this module has contributed to the significant reduction in the number of players returning sooner than the recommended minimum number of days, as observed in chapter 3. In addition, the general findings from chapters 3 and 4 have also been used to inform an open access community education module launched in March 2015 for approximately 2,000,000 registered players in England. Furthermore, the finding that higher symptom burden and balance error scores are related to a protracted recovery (>14 days) have now been included in the professional Rugby Union risk stratification process. It is hoped that this will aid the clinicians in identifying players that are at risk of protracted recovery so that they can be managed accordingly. The data collection procedures and review processes put in place during chapters 3 and 4 have provided the framework for the concussion audit framework that was implemented at the beginning of the 2014-15 season.

7.5.2 Training Load

The results presented in chapter 5 afford a number of league-wide practical player-welfare implications for the way in which strength and conditioning coaches may structure and implement future training practices. Firstly, the pre-season loads in this study appeared lower than in other collision sports (Gabbett and Jenkins, 2011). Therefore, it could not be determined if the increase in injury risk observed in the highest 4-week quartile was due to a) insufficient recovery time during high cumulative loads or b) inadequately prepared players due to the comparatively low level of pre-season training loads prescribed. It is most likely that the increase in risk was due to a combination of these factors; therefore, coaches should gradually increase pre-season loads and aim to reduce 4 week cumulative loads during the season in order to reduce the risk of injury in this setting. Secondly,

coaches should re-integrate players conservatively when returning from injury or who have been training within other squads when the player's acute training load is unknown. Thirdly, coaches should try to plan consistent weekly loads (for non-injured players) to prevent any acute spikes in training load. Fourthly, coaches should consider the individual nature of the dose-response relationship of training. Players are likely to have varying individual training thresholds that should be accounted for when planning training and recovery throughout the season. It is hoped that these findings and those from other ongoing studies are combined in the future in order to put together the first training periodisation guidelines for Premiership strength and conditioning coaches.

7.5.3 Illness

Chapter 6 of this thesis described the first study to look at the epidemiology of time-loss illness in this cohort. The findings from this study have confirmed the importance of continued longitudinal monitoring of the incidence and severity of time-loss illness and as such, the Premiership rugby injury surveillance reporting system has been expanded to include the reporting of both injury and illness. In addition, it is hoped that a number of the findings from this chapter will impact upon both research and practice in the future. There is a clear need for the formation of a consensus statement for illness reporting to ensure long-term reporting quality and consistency in the field. It is also hoped that the level and distribution of reported time-loss illness during the season is considered as part of the conception of the minimum staffing level Premiership wide guidelines that are currently being created to form a welfare standard for all English Premiership clubs. Similarly, the high number of respiratory, digestive and dermatological illnesses (the latter appears to be unique in Rugby Union) highlights the need for adequate support for club doctors in these specific areas. With a recent increase in the number of clubs utilising artificial turf for match play and training practices, it is expected that this finding will be considered by the artificial surface steering group in the planning of future research strategy.

7.6 Future Directions

In order to expand the novel findings presented in this thesis, a number of areas for future research have been identified. The following section focuses primarily on outlining a number of specific recommendations and considerations for applied research in the coming years. In addition to these, it is likely that a number of more controlled mechanistic studies will be required in order to progress beyond stage 2 of the TRIPP model and to encourage the formation of targeted injury prevention strategies in this setting, with the overall aim of reducing the risk of injury in professional Rugby Union. I have identified a research

program below in more detail that will build upon the findings from this thesis and will provide a research strategy in order to further both the knowledge and understanding of injury and illness epidemiology and prevention in this setting.

Concussion is the most common match injury in professional Rugby Union and the incidence of the injury continues to rise (chapter 3). Furthermore, the long-term implications of concussion on neurological function remains unclear but the legal implications for the inadequate disclosure of potential long-term risks of participation have been highlighted in American Football (National Football League, 2014). Thus, at the time of writing, concussion is clearly the number one player welfare issue in professional Rugby Union and as such, future research should be directed accordingly.

The long-term implications of injury or illness acquired through sporting careers may restrict physical activity during later life. Therefore, investigations that are aimed towards improving the understanding of the impact of long-term injury or illness are essential (Webborn, 2012). Perhaps the biggest challenge faced by researchers over the next decade is to further the current understanding regarding the potential relationship between participation in Rugby Union and long-term neuropsychological disease. The potential negative impact of both concussion and low-grade sub concussive events have been suggested previously (McCrea et al., 2014), and further attention is warranted in Rugby Union following a recent case study of a former professional player who reportedly diagnosed with CTE (Stewart et al., 2015). However, the difficulties in conducting research in this area are clear, explicitly; a) chronic traumatic encephalopathy can only be diagnosed post-mortem, b) the incidence and prevalence of this condition are unknown in both the general population as well as the sporting population, c) some professional players may also take part in a number of other risk-taking behaviours or vices that may contribute to neurological decline, making it difficult to attribute any changes to participation alone. Currently, there is a dearth of evidence in this area, largely due to the absence of any appropriately powered longitudinal or prospective studies. Studies of this nature in addition to future studies that advance promising initial studies focused on creating imaging technology that increases the potential for an ante mortem diagnosis of CTE should be investigated.

Furthermore, reducing the number of concussions that occur in this cohort is clearly of importance. From chapter 3 and previous studies (Fuller et al., 2015, Kemp et al., 2008), the majority of concussions occur in the tackle. Therefore, it would seem logical that this

area is most likely to afford the best opportunity for concussion prevention. The first step in order to be able to inform mitigation strategies in the game would be to commission a video analysis study that aims to compare injury mechanisms between concussed and non-injured tackle cohorts. Similar work has shown some promise in preliminary study in professional Rugby League (Gardner et al., 2015b) with a recommendation that further investigations with a larger sample size are conducted. Another area that would be interesting to explore would be the association between neck strength and concussion risk. Early work in professional Rugby Union has shown that higher neck strength was associated with a reduction in head accelerations during a the tackle (Dempsey et al., 2015) which may or may not have implications upon players' risk of concussion. Firstly, any possible associations between neck strength and concussion should be explored in order to inform possible future game-wide prevention strategies.

Additional research questions relevant to concussion in professional Rugby Union have also been identified. Previously, Fraas et al (2014) noted that the most commonly cited reasons for professional Rugby Union players to not report a concussion were: not thinking the injury was serious enough, not knowing that the injury sustained was a concussion, and thinking that concussions were part of the game. Therefore, further investigations into the knowledge, culture, and attitude of elite players and coaches towards concussion are recommended, to provide evidence and direction for future welfare initiatives (Fraas et al., 2014) and these are likely to influence how well best-practice guidelines are adhered to in the future (Donaldson et al., 2014).

Chapter 4 highlighted the increased risk of subsequent injury following return to play from concussion when compared with those players who did not sustain a reported concussion during the same season. The reasons for this difference remain unclear but it has been postulated that changes to an athlete's postural and neuromuscular control may contribute to the increase in injury rates following return to play - specifically deficits in gait (Parker et al., 2005, Parker et al., 2006) as well as changes in dynamic balance (Howell et al., 2014). Future studies focused on a) the use of balance and gait analysis as a potential means of objectively assessing the recovery of a player following concussion and b) the efficacy of active rehabilitation protocols focused on motor-control and proprioception during players' graduated return to play is recommended. In addition, this study did not have the statistical power needed to fully ascertain whether the severity of the initial concussion or the player's position was correlated with an individual's subsequent injury

risk. This is worthy of future investigation with a larger sample size as it may have an impact on the clinical management of concussed players in the future.

Analysis of the graduated return to play pathway highlighted the diverse, and sometimes complex, resolution of concussion. Thirty-eight percent of players reported a recurrence of symptoms during stages 2-5 or failed to achieve a valid neurocognitive test performance after-injury. It is therefore possible that the timescale of the graduated return to play protocol is too short. Accepting that evidence to support the current graduated return to play protocol is limited (Broglia et al., 2015b) but that the use of return to play guidelines are integral to athlete health and recovery following a concussion (Echemendia et al., 2015), future research that explores the effect of a longer, more comprehensive graduated return to play protocol on the number of players that report symptoms during recovery would be beneficial and may go some way to resolving the existing ambiguity that currently surrounds this topic (Patricios and Makdissi, 2014).

Although an increase in subsequent injury risk following return to play from concussion was identified, the effect of sustaining a concussion on performance following return to play in professional Rugby Union is yet to be established. In the first instance, key performance indicators for players could be coded for time-matched periods for both pre and post-concussion and subsequently, any differences could be investigated. Understanding this relationship could provide important information that could likely influence the decision making of players and coaches. For example, if the resultant findings of such a study suggested that returning to play earlier than the recommended guidelines had a negative impact on a player's performance, it is likely that the player or coach would not want to return to play early and jeopardise the team performance. Research in this area has the potential to inform future strategies upon culture and education in professional Rugby Union.

Aside from advancing research in the concussion domain, a number of other areas for future research have been highlighted as a result of this thesis. Chapter 5 was the first investigation that explored the association between injury risk and training load in professional Rugby Union. Whilst the session-RPE method has been proposed as an acceptable method of quantifying internal training load in collision sports (Clarke et al., 2013), GPS measures may also be useful in providing additional external load data in this setting. Some training activities (skills, wrestling, strongman and speed sessions) may be better quantified using a combination of internal- and external-load measures and thus, this

should be investigated in the future. During this study, match loads were estimated based on the reported sRPE values of one team that participated in the study. Whilst, this was an acceptable method for the purpose of this study, it is likely that future studies that consider both match loads, training loads and match and training loads combined will provide further information regarding injury risk that can be translated into practice by coaches. In addition, this study was under-powered to determine any associations between training monotony and injury risk. It has been suggested that players may be able to manage high daily training loads as long as they are dispersed between lower load training days and/or a day off during the training week (Foster, 1998b). Therefore, exploring this training load variable further with a larger sample could also provide clear practical implications for coaches. Moreover, the main outcome measure of success in this setting is performance. Thus far, the impact of training loads on performance in professional Rugby Union has not been investigated and remains unclear. This information is important so that coaches can consider the consequences of modifying training loads upon a) injury risk and b) performance outcome. Future studies that model match outcome with training load variables and that accounts for covariates such as league position and number of days between matches would further understanding at the fundamental level of performance (winning and losing). It has been suggested that, from a player welfare sense, elite sport is concerned with injury risk minimisation rather than injury risk elimination (Orchard and Best, 2002) and therefore, future research that accounts for both of the injury and performance consequences pertaining to training load are more likely to be adopted into practice.

The aim of chapter 6 was to describe time-loss illness in professional Rugby Union. This chapter provided a first look at illness data in this cohort and as such, was able to highlight some areas for future research. The finding that both respiratory and digestive infections were the most common cause of time-loss illness warrants further investigation. In order to fully understand the demands placed upon the medical staff at this level, it would be important to also be able to describe non-time loss illness. Information of this nature would likely provide insight into the clinical demand for the medical employees at the club and would aid club directors in decisions regarding the planning and preparation for forthcoming competitions. Ultimately, this study may be able to inform future league minimum standards policies regarding the minimum levels of medical employers required to meet an acceptable level of medical support at each club. Additionally, the association between training load and injury risk discussed in chapter 5 of this thesis coupled with the

possibility that high levels of training may render players more susceptible to illness (Budgett, 1998) clearly highlights the importance of future investigations directed towards the training load-illness relationship in this setting which currently remains unclear.

7.7 Conclusion

The aim of this thesis was to further current understanding of injury risk in professional Rugby Union. In order to achieve this aim, five novel research questions were posed and answered, utilising data from the RFU Premiership Rugby Injury Surveillance Project and newly created concussion and training load data collection systems. Concussion was identified as the most common time-loss injury in the English Premiership making it the number one player welfare priority in Rugby Union. Thus, the high and ever evolving incidence of concussion identified in this setting highlights the need for continued mitigation strategies in this area. Players who sustained a concussion had a greater subsequent injury risk when compared with players who sustained other injuries. It is important that the reasons for this phenomenon are investigated in order to inform any future concussion education and care guidelines and that different rehabilitation modalities are in turn, explored. In addition, this thesis provided evidence to suggest that the current recommended return to play guidelines may require further refinement for use in Rugby Union, and as such the use of a more conservative protocol for return to play should be investigated. It is noteworthy that the main findings from chapters 3 and 4 have already informed a nationwide concussion education initiative. Alongside concussion, it has been suggested that inappropriate training load significantly increases a player's risk of injury in professional Rugby Union; however, until now this has largely been based on anecdotal evidence. The finding that injury risk in the subsequent week increased linearly with one week load, absolute week to week changes in load and non-linearly with 4-week cumulative loads provides strength and conditioning coaches with benchmark values for planning and monitoring player training thresholds. Subsequently, this chapter makes a number of important and applicable player management recommendations for reducing injury risk in this setting. Finally, chapter 6 confirms that time-loss illness is prevalent in professional Rugby Union and an important construct to consider regarding player health. This chapter provides a "first look" regarding the epidemiology of illness in this cohort and although further longitudinal analysis is recommended, this two-season study clearly highlights a) the utility of future research in this area and b) important areas where player welfare strategies can have an impact in the future. Overall, the novel studies included in

this thesis confirm the importance of continued injury prevention efforts in professional Rugby Union.

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APPENDICES

Appendix A1: Injury and illness surveillance information and consent form

An investigation of injuries and illnesses sustained by professional rugby union players at English Premiership clubs.

Principal Investigator: Keith Stokes

Lead researcher: Matthew Cross

You are invited to take part in an ongoing research study of injuries and illnesses sustained during training and matches involving all first team squad players registered with English Premiership rugby clubs and/or England representative teams. The study is fully supported by the Rugby Football Union, Premiership Rugby and the Rugby Players' Association. Before deciding whether to take part, it is important that you understand why the study is being undertaken and whether it will affect you. Take time to read the following information carefully; if there are any aspects of the study that you do not understand, please discuss them with a member of your medical team or contact us for further information. When you have read and fully understood the information and you wish to be included in the study, please sign the player consent form for the 2014-15 season at the bottom of this document. The principal investigator responsible for the study is Dr. Keith Stokes at the University of Bath and he has been/is involved in similar injury surveillance studies in rugby union.

Background to the study

The aim of this study is to determine the incidence, types and causes of time-loss (>24 hours absence from match play or training) and non time-loss (incidents that require a medical consultation with no absence from match play or training) injuries and illnesses sustained by Premiership and/or England rugby union players. Time-loss injury data collected will enable comparisons to be made with similar data collected since 2002 and illness data will build upon data collected in 2013-14. The collection of these data will allow us to start gain an insight into the impact that non time-loss injury and illness has during the course of a competitive season on player welfare and clinical provision. The definition of an illness that will be used for the purpose of this study is 'any new or recurrent illness for which the player seeks medical consultation regardless of outcome'. Injury surveillance studies of this type provide data that helps to monitor levels of injury and illness risk and to develop injury prevention, treatment and rehabilitation programmes in rugby union.

What does the study involve?

Medical personnel at will record the details of all match and training injuries and illness sustained by Premiership rugby players. These data will be analysed by researchers in the Department for Health at the University of Bath

Who is being asked to participate in the study?

All first team squad players at English Premiership rugby clubs and also players involved in England representative teams are being asked to take part in the study.

Do players have to take part?

Participation in the study is voluntary. You do not have to take part in the study but the more players who do take part, the more comprehensive the data will be. If you decide to take part, you must sign the consent form below that confirms you have been provided with this information and you agree to be included in the study. You are free to withdraw from the study by contacting us at any time without giving a reason.

What do I have to do?

There is nothing you have to do. Medical staff will record the information about any injuries and illnesses you sustain during training and competition.

Are there any risks from taking part?

There is no increased risk of taking part in this study above your normal rugby activities with the club.

Will information about my injuries be kept confidential?

In accordance with the Data Protection Act, we must obtain your permission to collect information about your injuries and illnesses during the course of this study. All information collected in the study is recorded and stored anonymously using a player identification code on a database at the University of Bath.

What will happen to the data obtained from the research study?

These data collected will be collated and analysed by researchers at the University of Bath in order to produce summary information about the incidence, severity, types and causes of injuries and illnesses sustained in the Rugby Premiership and representative teams in England.

Player consent form

I confirm that I have read and understood the player information sheet for the above study and that I have had an opportunity to ask questions.

I agree to take part in the above study and give my consent for doctors, physiotherapists, medical administrators and fitness/ conditioning staff to supply medical and training information to the University of Bath. I acknowledge that such information will only be used for research, statistical and other analysis purposes, and that personal references shall not be made in any report or other published material.

I understand that all the information provided on my injuries and training will be treated in strict confidence and will remain anonymous. I understand that I have the right to withdraw from this study at any stage and that I will not be required to explain my reasons for withdrawing.

Signature

Date

Appendix A2: Concussion study player information and consent form

A Prospective investigation of outcomes following concussive injury in elite Rugby Union

Principal Investigator: Keith Stokes

Other Investigators: Matt Cross, Grant Trewartha, Andy Smith, Simon Kemp

Introduction

We are asking you to take part in a study investigating recovery from concussion and outcomes following return to play from concussion in elite Rugby Union. The study is supported by the Rugby Football Union, Premiership Rugby and the Rugby Players' Association. Before deciding whether you would like to take part, you should know why the study is being done and how it might affect you. Please take time to read the information carefully. If there is anything that you do not understand, either speak to a member of your medical team or contact us for more information via the email address at the bottom of this document. When you have read and understood the information, if you wish to take part in the study, you will be asked to sign the attached Consent Form.

Background to the study

In the last three seasons, reported concussions have been the most common injury during matches in professional Rugby Union in England and in 2013-14, concussions accounted for 12.5% of all match injuries in the English Premiership. Most players return to play without problems, but it has been suggested that if players return to play too quickly after concussion they are at greater risk of poor performance, subsequent injury prolonged symptoms and the possibility of long-term effects.

World Rugby and Rugby Football Union provide individual best practice return to play guidelines for concussion based on the international concussion consensus statement. The aim of this study is to find out whether a player who sustains a concussion (and who is managed using these guidelines) is at more risk of another concussion, other injury or poor performance following return to play than players who have not sustained a concussion. This information will also allow us to get a better understanding of the timing of recovery of symptoms after concussion. This information is important for the further development of diagnostic tools to enable improved identification and management of concussion injuries. This study started in the 2012-2013 season and will continue in 2015-2016.

Standard tests and the Head Injury Assessment (HIA) process

As part of the Rugby Football Union's and Premiership Rugby's best practice concussion management, various assessments will be carried out whether you take part in the study or not. Consenting to this study will however allow us to collect and analyse the data from these assessments.

1) During pre-season, you will have a baseline Cogstate Sport test. Medical staff at your club will also administer a short sport concussion assessment tool (SCAT version 3).

2) World Rugby has introduced the Head Injury Assessment (formally PSCA) process into law for season 2015-16 following a three year trial. This process outlines how you should be managed in the event of a head injury and allows team doctors to temporarily remove you from play following a head injury in order to undertake an off-field triage assessment when the diagnosis is unclear. If you have signs consistent with HIA criteria for permanent removal from play you will be removed from the game and not allowed to return to play (you will still be asked to complete an HIA for research purposes).

3) If you are immediately removed from the match, if head injury diagnosis is not immediately apparent (and you go through an HIA) or if you sustain a delayed concussion with symptoms presenting after the game, you will also be asked to complete two HIA follow up forms that will assess your symptoms and cognition; the first is carried out immediately post-match and the second is completed 36-48 hours later.

4) Before you are able to return to full contact training you will be asked to complete a Cogstate sport text that will be compared to your baseline test that you will have completed during pre-season. Depending on the result, your team-doctor will make a decision about whether or not you can return to full-contact training.

In addition to these assessments, consenting to this study will give permission for the collection of some additional data:

1) If a concussion is definitively diagnosed by your club, your medical team will ask you to complete a SCAT3 assessment every day until you are symptom free.

2) You will also be taken through the Graduated Return to Play (GRTP) process and a form will be sent back to us outlining your activities and pathway to return to play.

What does the study involve?

The study itself does not require you to do anything other than consent to researchers at the University of Bath processing your data. Whether or not you get a concussion during the season, we will collect information about your baseline CogSport and SCAT3 tests, the amount of match time you play and any other injuries that you sustain during this period. If you sustain a concussion in a match, if a head injury diagnosis is not immediately apparent or if a concussion evolves after the game, information about your Head Injury Assessment will be sent to us. We will also collect information on your progress through the Graduated Return to Play (GRTP) process and results of the standard CogSport testing that is carried out on the day that your club doctor confirms that you are fit to return to contact training.

If you sustain a concussion in a match where the HIA is not being used, we will collect all of the information above, apart from the HIA information. If you get a concussion during training, no extra information will be collected, but the injury will be reported through the RFU injury surveillance project. In all scenarios, you will get standard care from your club's medical team.

Video and performance statistics will also be obtained to inform future concussion prevention strategies.

Who is being asked to participate in the study?

First team squad players at English Premiership rugby clubs and players in England representative squads.

Do I have to take part?

It is up to you whether you take part. You do not have to take part, but the more players who do, the more we will find out about concussion in rugby. If you want to take part, you must sign a consent form that confirms you have read this information and that you agree to be included in the study. You can withdraw from the study by contacting us at any time without giving a reason by emailing: m.cross@bath.ac.uk

Are there any risks from taking part?

There are no risks from taking part in this study over and above your normal rugby activities.

Will information about me be kept confidential?

The Data Protection Act says that we must have your permission to collect the information we need for this study. All of the information will be stored using a code number rather than your name on a database at the University of Bath.

What will happen to the information from the study?

The information will be analysed by researchers at the University of Bath. We will produce a report about concussion injuries and the typical timing of recovery, as well as the effect that concussion has on performance and injury risk when returning to play. This information will be used by World Rugby and RFU/Premiership Rugby/RPA to help develop guidelines for the management of concussion.

Player consent form

I confirm that I have read and understood the player information sheet for the above study and that I have had an opportunity to ask questions.

I agree to take part in the above study and give my consent for doctors, physiotherapists and fitness/ conditioning staff to supply medical and training information to the University of Bath. I acknowledge that such information will only be used for research, statistical and other analysis purposes, and that reference to individuals shall not be made in any report or other published material.

I understand that all the information provided on my injuries and training will be treated in strict confidence and will remain anonymous.

I understand that I have the right to withdraw from this study at any stage and that I will not be required to explain my reasons for withdrawing.

Name	Date	Signature
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Appendix A3: Training load player information and consent form

The influence of training and match load on injury and illness in elite rugby union

Principal Investigator: Keith Stokes

Other Investigators: Matthew Cross, Sean Williams, Grant Trewartha

You are invited to take part in a research study that will investigate training and match loads as a risk factor for time-loss and non time-loss injury and illness in elite rugby union. The study is fully supported by the Rugby Football Union, Premiership Rugby and the Rugby Players' Association. This study will be fully aligned with the RFU professional rugby injury surveillance project, this will allow for the collection of time-loss and non time-loss match and training injuries during the competitive season for use in this study. Before deciding whether to take part, it is important that you understand why the study is being undertaken and how it might involve you. Take time to read the following information carefully; if there are any aspects of the study that you do not understand, please discuss them with a member of your medical team or contact us for further information. When you have read and fully understood the information and you wish to be included in the study, you will be asked to sign a consent form.

Background to the study

A player or team's training load has been highlighted as a potential risk factor for injury in other collision sports. Although a small number of studies have investigated training duration as a risk factor for injury in rugby union, at the time of writing no publications could be found that combined training duration and intensity to investigate the effect of training load on injury occurrence and severity. Without this information it is difficult to determine best practice for calculating appropriate training loads for the season on a week to week basis. It is thought that, in the long-term, training load and the accumulation of training load over time may also play an important role in the management of overtraining and subsequently career longevity. This study will allow for a better understanding of the management of training load throughout a competitive season and will also contribute to improving player welfare.

The aim of this study is to determine the relationship between training load and the incidence/severity of injury and illness. This particular study will aim to look at whether acute (recent) loads, chronic loads (loads accumulated over recent weeks), and changes in loads are risk factors for injury and illness. The information that this study provides will be an important and valued component in the continued development of training programmes for coaches. Data will be collected for this study during the 2013-14 season.

What does the study involve?

Daily training load, match load and time-loss and non time-loss injury and illness data will be collected for all full-time contracted players that participate in the study. You will be asked to complete a questionnaire at the start of the season. This questionnaire will be included as part of your baseline information (date of birth, height, weight) that is provided

at the start of the season by medical personnel. To be able to calculate training load, you will be asked to submit an RPE (Rating of Perceived Exertion) score (on a scale of 1 to 10) within 30 minutes after the end of each training session and match. The strength and conditioning coach at the club will then submit the duration of each session so that this can be matched to each RPE score to allow a value for training/match load to be calculated. Your time-loss injury and illness data such as incidence, type, severity and causation will be reported by your medical staff using a secure online only medical system. In addition to the collection of these data, the RFU English Professional Rugby Union Injury Surveillance Project will also allow for the collection of non time-loss injury data. These are injuries that require medical attention for but do not cause you to have any absence from match play or training. For the purpose of this study illness will be defined as 'any new or recurrent illness for which the player seeks medical consultation regardless of outcome'. This data will be analysed by researchers in the Department for Health at the University of Bath.

Who is being asked to participate in the study?

All first team squad players at English Premiership rugby clubs and England representative teams are being asked to take part in the study.

Do I have to take part?

Participation in the study is voluntary. You do not have to take part in the study but the more players who take part, the more comprehensive the data will be. If you decide to take part, you must sign a consent form that confirms you have been provided with this information and you agree to be included in the study. You are free to withdraw from the study by contacting us at any time without giving a reason.

Are there any risks from taking part?

There is no increased risk associated with this project over and above your normal rugby activities with the club.

Will information about my injuries be kept confidential?

In accordance with the Data Protection Act, we must obtain your permission to collect information about your injuries during the course of this study. All information collected in the study is recorded and stored anonymously using a player identification code on a database at the University of Bath.

What will happen to the data obtained from the research study?

The data collected will be analysed by researchers at the University of Bath to produce summary information about the influence of training load on the incidence and severity of injury and/or illness. This information may be used by the RFU/Premiership Rugby/RPA for the formation of guidelines for the management of training load in the future.

Player consent form

I confirm that I have read and understood the player information sheet for the above study and that I have had an opportunity to ask questions.

I agree to take part in the above study and give my consent for doctors, physiotherapists and fitness/ conditioning staff to supply medical and training information to the University of Bath. I acknowledge that such information will only be used for research, statistical and other analysis purposes, and that reference to individuals shall not be made in any report or other published material.

I understand that all the information provided on my injuries and training will be treated in strict confidence and will remain anonymous.

I understand that I have the right to withdraw from this study at any stage and that I will not be required to explain my reasons for withdrawing.

Name

Date

Signature

Appendix B1: SCAT3 Form

SCAT3™

Sport Concussion Assessment Tool – 3rd Edition

For use by medical professionals only



Name _____

Date/Time of Injury: _____
Date of Assessment: _____

Examiner: _____

What is the SCAT3?¹

The SCAT3 is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged from 13 years and older. It supersedes the original SCAT and the SCAT2 published in 2005 and 2009, respectively². For younger persons, ages 12 and under, please use the Child SCAT3. The SCAT3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Recognition Tool³. Preseason baseline testing with the SCAT3 can be helpful for interpreting post-injury test scores.

Specific instructions for use of the SCAT3 are provided on page 3. If you are not familiar with the SCAT3, please read through these instructions carefully. This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. Any revision or any reproduction in a digital form requires approval by the Concussion in Sport Group.

NOTE: The diagnosis of a concussion is a clinical judgment, ideally made by a medical professional. The SCAT3 should not be used solely to make, or exclude, the diagnosis of concussion in the absence of clinical judgement. An athlete may have a concussion even if their SCAT3 is "normal".

What is a concussion?

A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific signs and/or symptoms (some examples listed below) and most often does not involve loss of consciousness. Concussion should be suspected in the presence of **any one or more** of the following:

- Symptoms (e.g., headache), or
- Physical signs (e.g., unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour (e.g., change in personality).

SIDELINE ASSESSMENT

Indications for Emergency Management

NOTE: A hit to the head can sometimes be associated with a more serious brain injury. Any of the following warrants consideration of activating emergency procedures and urgent transportation to the nearest hospital:

- Glasgow Coma score less than 15
- Deteriorating mental status
- Potential spinal injury
- Progressive, worsening symptoms or new neurologic signs

Potential signs of concussion?

If any of the following signs are observed after a direct or indirect blow to the head, the athlete should stop participation, be evaluated by a medical professional and **should not be permitted to return to sport the same day** if a concussion is suspected.

Any loss of consciousness?	<input type="checkbox"/> Y	<input type="checkbox"/> N
"If so, how long?" _____		
Balance or motor incoordination (stumbles, slow/laboured movements, etc.)?	<input type="checkbox"/> Y	<input type="checkbox"/> N
Disorientation or confusion (inability to respond appropriately to questions)?	<input type="checkbox"/> Y	<input type="checkbox"/> N
Loss of memory:	<input type="checkbox"/> Y	<input type="checkbox"/> N
"If so, how long?" _____		

1 Glasgow coma scale (GCS)

Best eye response (E)

No eye opening	1
Eye opening in response to pain	2
Eye opening to speech	3
Eyes opening spontaneously	4

Best verbal response (V)

No verbal response	1
Incomprehensible sounds	2
Inappropriate words	3
Confused	4
Oriented	5

Best motor response (M)

No motor response	1
Extension to pain	2
Abnormal flexion to pain	3
Flexion/Withdrawal to pain	4
Localizes to pain	5
Obeys commands	6

Glasgow Coma score (E + V + M) of 15

GCS should be recorded for all athletes in case of subsequent deterioration.

2 Maddocks Score³

"I am going to ask you a few questions, please listen carefully and give your best effort."

Modified Maddocks questions (1 point for each correct answer)

What venue are we at today?	0	1
Which half is it now?	0	1
Who scored last in this match?	0	1
What team did you play last week/game?	0	1
Did your team win the last game?	0	1
Maddocks score	of 5	

Maddocks score is validated for sideline diagnosis of concussion only and is not used for serial testing.

Notes: Mechanism of Injury ("tell me what happened?"):

BACKGROUND

Name: _____ Date: _____

Examiner: _____

Sport/team/school: _____ Date/time of injury: _____

Age: _____ Gender: M F

Years of education completed: _____

Dominant hand: right left neither

How many concussions do you think you have had in the past? _____

When was the most recent concussion? _____

How long was your recovery from the most recent concussion? _____

Have you ever been hospitalized or had medical imaging done for a head injury? Y N

Have you ever been diagnosed with headaches or migraines? Y N

Do you have a learning disability, dyslexia, ADD/ADHD? Y N

Have you ever been diagnosed with depression, anxiety or other psychiatric disorder? Y N

Has anyone in your family ever been diagnosed with any of these problems? Y N

Are you on any medications? If yes, please list: Y N

SCAT3 to be done in resting state. Best done 10 or more minutes post exercise.

SYMPTOM EVALUATION

3 How do you feel?

You should score yourself on the following symptoms, based on how you feel now.

	none	mild	moderate	severe			
Headache	0	1	2	3	4	5	6
Pressure in head	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
Don't feel right	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6

Total number of symptoms (Maximum possible 22) _____

Symptom severity score (Maximum possible 132) _____

Do the symptoms get worse with physical activity? Y N

Do the symptoms get worse with mental activity? Y N

self rated self rated and clinician monitored

clinician interview self rated with parent input

Overall rating: If you know the athlete well prior to the injury, how different is the athlete acting compared to his/her usual self?

Please circle one response:

no different very different unsure N/A

COGNITIVE & PHYSICAL EVALUATION

4 Cognitive assessment

Standardized Assessment of Concussion (SAC)⁴

Orientation (1 point for each correct answer)

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1

Orientation score _____ of 5

Immediate memory

List	Trial 1	Trial 2	Trial 3	Alternative word list					
elbow	0	1	0	1	0	1	candle	baby	finger
apple	0	1	0	1	0	1	paper	monkey	penny
carpet	0	1	0	1	0	1	sugar	perfume	blanket
saddle	0	1	0	1	0	1	sandwich	sunset	lemon
bubble	0	1	0	1	0	1	wagon	iron	insect

Total _____

Immediate memory score total _____ of 15

Concentration: Digits Backward

List	Trial 1	Alternative digit list			
4-9-3	0	1	6-2-9	5-2-6	4-1-5
3-8-1-4	0	1	3-2-7-9	1-7-9-5	4-9-6-8
6-2-9-7-1	0	1	1-5-2-8-6	3-8-5-2-7	6-1-8-4-3
7-1-8-4-6-2	0	1	5-3-9-1-4-8	8-3-1-9-6-4	7-2-4-8-5-6

Total of 4 _____

Concentration: Month in Reverse Order (1 pt. for entire sequence correct)

Dec-Nov-Oct-Sept-Aug-Jul-Jun-May-Apr-Mar-Feb-Jan 0 1

Concentration score _____ of 5

5 Neck Examination:

Range of motion Tenderness Upper and lower limb sensation & strength

Findings: _____

6 Balance examination

Do one or both of the following tests.

Footwear (shoes, barefoot, braces, tape, etc.) _____

Modified Balance Error Scoring System (BESS) testing⁵

Which foot was tested (i.e. which is the non-dominant foot) Left Right

Testing surface (hard floor, field, etc.) _____

Condition

Double leg stance: _____ Errors

Single leg stance (non-dominant foot): _____ Errors

Tandem stance (non-dominant foot at back): _____ Errors

And/Or

Tandem gait^{6,7}

Time (best of 4 trials): _____ seconds

7 Coordination examination

Upper limb coordination

Which arm was tested: Left Right

Coordination score _____ of 1

Appendix C1: World Rugby head injury assessment (HIA) form



Head Injury Assessment – Form 1

HIA1

Player's name		Player's number	
Date of injury		Physician's name	
Team		Opposition	
Competition			
Time of injury	<input type="checkbox"/> Quarter 1	<input type="checkbox"/> Quarter 2	<input type="checkbox"/> Quarter 3 <input type="checkbox"/> Quarter 4

COMPLETE EITHER SECTION 1 OR SECTION 2

SECTION 1 - Immediate and permanent removal from field and no return to play - identify reason(s) below	
<input type="checkbox"/> Tonic posturing	<input type="checkbox"/> Convulsion
<input type="checkbox"/> Confirmed loss of consciousness	<input type="checkbox"/> Suspected loss of consciousness
<input type="checkbox"/> Balance disturbance / ataxia	<input type="checkbox"/> Player not orientated in time, place or person
<input type="checkbox"/> Clearly dazed	<input type="checkbox"/> Definite confusion
<input type="checkbox"/> Definite behavioural changes	<input type="checkbox"/> On field identification of sign or symptom of concussion
<input type="checkbox"/> Oculomotor signs (e.g. spontaneous nystagmus)	

Removal requested by: Team doctor Match Day Doctor Physiotherapist
 Referee Tournament Doctor Following in-game video review

Video available? Yes No

SECTION 2 - Pitch-side Head Injury Assessment - identify reason(s) for HIA below		
<input type="checkbox"/> Head impact where diagnosis not immediately apparent	<input type="checkbox"/> Possible behaviour changes	
<input type="checkbox"/> Possible confusion	<input type="checkbox"/> Injury event witnessed with potential to result in a concussive injury	
<input type="checkbox"/> Other (identify):		
Pitch-side Head Injury Assessment (if unable to perform a specific test please record reason in the appropriate section)		
ANSWER ALL QUESTIONS – Any column 1 answer = NO return to play	1	2
Maddocks Questions - Orientation	Incorrect	Correct
What venue are we at today?	<input type="checkbox"/>	<input type="checkbox"/>
Which half is it now?	<input type="checkbox"/>	<input type="checkbox"/>
Who scored last in this match?	<input type="checkbox"/>	<input type="checkbox"/>
What team did you play last week/game?	<input type="checkbox"/>	<input type="checkbox"/>

SECTION 2 - Pitch-side Head Injury Assessment - continued		
ANSWER ALL QUESTIONS – Any column 1 answer = NO return to play	1	2
Immediate memory (ABNORMAL result is a score < 12 or less than baseline)	Abnormal	Normal
Option 1 - elbow / apple / carpet / saddle / bubble	<input type="checkbox"/>	<input type="checkbox"/>
Option 2 - candle / paper / sugar / sandwich / wagon	<input type="checkbox"/>	<input type="checkbox"/>
Option 3 - baby / monkey / perfume / sunset / iron	<input type="checkbox"/>	<input type="checkbox"/>
Digits backwards (ABNORMAL result is a score < 3 or less than baseline)	Abnormal	Normal
Option 1 numbers: 4-3-9 / 3-8-1-4 / 6-2-9-7-1 / 7-1-8-4-6-2	<input type="checkbox"/>	<input type="checkbox"/>
Option 2 numbers (if needed): 6-2-9 / 3-2-7-9 / 1-5-2-8-6 / 5-3-9-1-4-8	<input type="checkbox"/>	<input type="checkbox"/>
Tandem gait (NORMAL result is one score ≤ 14 seconds)	Abnormal	Normal
Tandem gait results in seconds 1_____ 2_____ 3_____ 4_____	<input type="checkbox"/>	<input type="checkbox"/>
Symptom checklist	Yes	No
Do you have a headache?	<input type="checkbox"/>	<input type="checkbox"/>
Do you have any dizziness?	<input type="checkbox"/>	<input type="checkbox"/>
Do you have any 'pressure in your head'?	<input type="checkbox"/>	<input type="checkbox"/>
Do you feel nauseated or do you feel like vomiting?	<input type="checkbox"/>	<input type="checkbox"/>
Do you have any blurred vision?	<input type="checkbox"/>	<input type="checkbox"/>
Does the light or noise worry you?	<input type="checkbox"/>	<input type="checkbox"/>
Do you feel as though you are slowing down?	<input type="checkbox"/>	<input type="checkbox"/>
Do you feel like you are 'in a fog'?	<input type="checkbox"/>	<input type="checkbox"/>
Do you feel unwell?	<input type="checkbox"/>	<input type="checkbox"/>
Delayed Recall (ABNORMAL is a score < 3 or less than baseline)	Abnormal	Normal
Test recall of immediate memory words	<input type="checkbox"/>	<input type="checkbox"/>
Clinical signs	Yes	No
Emotional - sad, anxious, nervous, irritable	<input type="checkbox"/>	<input type="checkbox"/>
Drowsy / has difficulty concentrating	<input type="checkbox"/>	<input type="checkbox"/>
Doctor performing HIA suspects concussion despite above tests being normal	<input type="checkbox"/>	<input type="checkbox"/>
Requested by	Completed by	Player removed
<input type="checkbox"/> Team Doctor <input type="checkbox"/> Physiotherapist <input type="checkbox"/> Match Day Doctor <input type="checkbox"/> Tournament Doctor <input type="checkbox"/> Referee	<input type="checkbox"/> Team Doctor <input type="checkbox"/> Match Day Doctor <input type="checkbox"/> Tournament Doctor <input type="checkbox"/> Assistant Team Doctor	<input type="checkbox"/> No <input type="checkbox"/> Yes, pitchside HIA abnormal <input type="checkbox"/> Yes, player removed for another injury

- 1 Complete Section 1 if the player is removed immediately and permanently from the field of play.
- 2 Complete Section 2 if player requires a pitchside Head Injury Assessment.
- 3 If sections of the pitchside HIA are not fully completed please identify why in that area.
- 4 Section 2 of the pitchside HIA is designed to assist Team Doctors assess head injury where the diagnosis is not immediately apparent.
- 5 The player must not return to play following a pitchside HIA if any answer in column 1 is selected.
- 6 A doctor's clinical judgement overrules any 'negative' sideline neurological test.
- 7 Return to play decisions remain the responsibility of the doctor.
- 8 The team doctor should continue to monitor all athletes who have had a negative pitch-side HIA during and after the game for symptoms and signs of a delayed concussion.

Immediate removal criteria definitions

SUSPECTED LOSS OF CONSCIOUSNESS can be identified by one of the following:

- Cervical hypotonia observed immediately following impact.
- The player stays on the ground without movement until first support arrives on scene.
- Reported loss of consciousness by witnessing own team players or match officials.

BALANCE DISTURBANCE / ATAXIA is identified when an athlete is unable to stand steadily unaided or walk normally and steadily without support in the context of a possible concussive mechanism of injury.

HIA tool assessment instructions

IMMEDIATE MEMORY - select option 1, 2 or 3 and test this option three times.

Instructions

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order."

Repeat the same procedure using the same words three times:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order."

Complete all three trials regardless of score on trial 1 and 2. Read the words at a rate of one per second.

The maximum score is 15.

DIGITS BACKWARDS - start with either option 1 or option 2 numbers.

"I am going to read you a string of numbers and when I am done, you repeat them back to me backwards, in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."

Start with the 3 digit string length from trial 1. If correct move to increasing string lengths, scoring one point for each correct sequence. If incorrect, read trial 2 with the same string length. Remove from play if incorrect on both trials of three numbers. The digits should be read at the rate of one per second. Score one point for each correct string, so the maximum score is 4 points.

DELAYED RECALL - test recall of the same immediate memory words.

"Tell me as many words from the list of words read to you earlier in any order."

TANDEM GAIT

Participants stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 metre line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. **Hands can be placed on hips or held freely at the player's side.** One trial of less than 14 seconds equals a normal result and no further trials are required. Athletes are allowed 4 trials to achieve a time of less than 14 seconds.

Appendix D1: The Modified CR-Borg 10 rating of perceived exertion (RPE) scale

0	Rest
1	Very, very easy
2	Easy
3	Moderate
4	Somewhat hard
5	Hard
6	
7	Very hard
8	
9	
10	Maximal