INJURIES IN PROFESSIONAL RUGBY UNION: A STUDY OF FIVE YEARS OF INJURY DATA WITH TRAINING LOADS AND TRAVEL AS CO-VARIATES

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgements.

Chapters 2 to 4 of this thesis represent three separate papers that are to be submitted to peer-reviewed journals for consideration for publication. My contribution and the contribution by the various co-authors to each of these papers are outlined at the beginning of each chapter and in the "candidate contributions to co-authored papers" table. All co-authors have approved the inclusion of the joint work in this Masters' thesis.

Kara

Stephen Kara

August 2013

CANDIDATE CONTRIBUTIONS TO CO-AUTHORED PAPERS

Chapter 2 Kara, S.D, Hume, P.A, Hopkins, W.G, Williams, S. Epidemiological Injury Data from Super 14 Rugby Union – An Observational Study over 5 Years (2006-2010).To be submitted to *British Journal of Sports Medicine.*	Kara 80%, Hume 10%, Hopkins 5%, Williams 5%
Chapter 3 Kara, S.D, Hopkins, W.G, Williams, S, Hume, P.A. The Temporal Effect of Prior Cumulative Team Training and Match-Load and Acute Training Load on In-Season Injury Risk in Elite Contact Sports. To be submitted to *British Journal of Sports Medicine.*	Kara 75%, Hopkins 10%, Williams 10%, Hume 5%
Chapter 4. Kara, S.D, Hopkins, W.G, Williams, S, Hume, P.A. The Effect of Travel on Injury Risk – How Much Is This a Factor? To be submitted to *British Journal of Sports Medicine.*	Kara 80%, Hopkins 10%, Williams 5% Hume 5%

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The path that led me to further post-graduate study was one that came to me, rather than me seeking it out. Through the initial contact with AUT University staff via the New Zealand Rugby Union, and the insistence of my friend and colleague Dr Chris Hanna, the path that I was about to take was thrust in my direction. However it is one that I am thankful to those of you who have assisted as embarking upon further study ensured a ‘dust off’ of the neurones and the re-connection of long forgotten synapses.

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ETHICAL APPROVAL

Ethical approval was granted by the Health and Disability Ethics Committees of New Zealand, Northern Y Regional branch, and Auckland University of Technology Ethics Committee (AUTEC). Separate approvals were required due to the use of health information obtained from the participants. The ethics approval references were:

Chapters 2, 3 and 4:

- Reference NYT/11EXP/032. **The incidence of Rugby Union Injuries in a Professional Environment: Are we able to predict risk?** Approved on 22.07.2011 by Northern Y Regional Ethics Committee.
- Reference 11/283. **The incidence of Rugby Union Injuries in a Professional Environment: Are we able to predict risk?** Approved on 11.10.2011 by Auckland University of Technology Ethics Committee (AUTEC).

ABSTRACT

Rugby union has one of the highest reported incidences of injury amongst all professional team sports given collisions and tackles are a fundamental part of the game. The overarching question addressed in this thesis was "what has been the effect of changing match demands and competition expansion on current injury incidence?" Analysis of in-season training and injury data from 2006 – 2010 for a Super 14 Rugby team enabled this question to be evaluated. The thesis literature review established that previous epidemiological studies from the Super Rugby competition were outdated and formed the basis for the injury epidemiological analysis in Chapter 2. The effect of changing match demands and competition expansion on current injury incidence were compared to existing data from the professional rugby union literature, showing a higher incidence of match-related injuries over the five seasons. Additionally a higher incidence of training-related injuries was reported with the reasons for this finding less clear. An efficient injury recording and reporting regimen, as well as differences in training specifics, could have accounted for the higher injury incidence seen in trainings sessions.

Training load is an independent, but potentially modifiable, risk factor for injury and was analysed against injury risk in Chapter 3. Few studies have focused on the temporal relationship of prior cumulative training and match load on injury risk, with most studies focusing on the 'acute' effect of load and injury. An injury prediction model published in 2010[1] and developed for rugby league provided the stimulus for analysing our injury data against measured training loads. Using a novel application of over-dispersed Poisson regression analysis, actual daily and prior cumulative training load were compared against injury risk, and expressed as a magnitude based inference for effect. The effects for actual daily training load were not unexpected, where a higher training load was associated with a higher injury incidence and a higher total number of days lost, adding to the existing evidence. However a reduction in training-related non-contact soft tissue injury incidence and total days lost following periods of typically high versus typically low cumulative load were surprising, supporting a protective effect most likely due to adaptation. This protective effect was not seen in the analysis of match-related injuries where higher prior loads resulted in an increased risk of contact injuries. Post-training physical and mental factors presumably explain this effect and highlight the importance of tapering into a match.

Travel across multiple time zones is a unique feature of this competition in-season, with the literature unclear on the effects of travel on injury risk. Analysis of location and travel duration across time zones against injury, with training load measurement in each location, was the basis for Chapter 4. The limited data did not provide clear outcomes for injury risk as a function of location or travel duration but a trend towards an increase in incidence of match-related non-contact soft tissue injuries post long-haul (>5 hours) travel was observed.

This thesis provides practical information that can be used by medical personnel and strength and conditioning staff involved with teams from collision sporting codes.

CHAPTER 1

INTRODUCTION, RATIONALE FOR THE STUDIES BASED ON CRITIQUE OF THE LITERATURE, AND STRUCTURE OF THE THESIS (PREFACE)

Background

William Webb-Ellis, an English-American clergyman, is recognised as the famed inventor of Rugby Union in 1823 and has become immortalized in the game with the trophy bearing his name presented to the winners of the Rugby World Cup every four years. Since then, with the global growth of the game, there are now 100 member unions, 17 associate members (alphabetically from American Samoa to Zimbabwe)[*] and 6 regional associations making up the membership of the organisation entrusted to officiate and manage the game - The International Rugby Board (IRB).

The NZ Rugby Union (NZRU) represents our national game of rugby union in New Zealand. It has 26 provincial unions with over 146,000 active playing members[†], split into professional and amateur ranks since the commencement of professionalism in 1995. Professional players are selected or ‘drafted’ to one of five regional based franchise teams within New Zealand and compete in a southern hemisphere competition alongside professional teams from Australia and South Africa. This competition is governed under SANZAR (an organisation representing the three competing countries) and is currently marketed to the public as the Super Rugby competition. The impact *The All Blacks* brand presents in the global market, coupled with the success in Rugby World Cups, is not reflected in the international rugby union literature and served as the motivation to undertake this thesis.

Studies from professional rugby team physicians in this country are limited and the ability to utilise data stored within one Super Rugby franchise provided the means to embark on rugby union research. Whilst epidemiological studies are well represented in the literature, the majority originate in the northern hemisphere, with southern hemisphere studies representing earlier Super 12 professionalism. With the changing nature of the game and the differences in style of play between the hemispheres, a review of the current epidemiological situation was required.

As a team physician, injury prevention is one priority to assist with potential injury reduction and team success. Contact sports, whilst having an element of unmeasured risk, have potential injury risk factors that are modifiable, with training load being one such factor. The access to combined injury and training load data permitted analyses of the interaction between these two variables.

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[*] http://www.irb.com – Accessed August 2013

[†] http://www.nzru.co.nz – September 2010 statistics

Finally travel provides a unique challenge in the Super Rugby competition and the impact of long-haul travel on potential injury risk, particularly in matches, had not been studied. The supporting evidence for the risk of injury post-travel originates from occupational studies[2-4] and sports have 'adopted' these principles.

These areas of interest and/or the lack of published data led to the formulation of the themes for this thesis. Therefore the overarching question addressed in this thesis was "what has been the effect of changing match demands and competition expansion on current injury incidence?" Analysis of in-season training and injury data from 2006 – 2010 for a Super 14 Rugby team enabled this question to be evaluated.

Rationale for the studies based on the critique of the literature

The literature review aimed to critique and summarize knowledge about rugby injury epidemiology and the effects on injury of training loads and competition travel.

The following electronic databases subscribed to by AUT through the EBSCO host were searched: Web of Knowledge, MEDLINE, CINAHL®, Google Scholar, ProQuest Central, Scopus, PubMed, PEDRO and SportsDiscus®. Searches were limited to studies written in English with the following key words used in isolation or combinations: train* load, train* volume, game load, game volume, match load, match volume, injur*, rugby, rugby union, contact sport, collision sport, travel, jet lag, jet fatigue. Reference lists for each paper were also reviewed in order to identify additional relevant articles.

Our search design sourced 17 prospective cohort injury surveillance epidemiological studies, three reviews and one seasonal injury audit in the professional era (post 1995), with the study populations varying from amateur youth or community level players to international professionals (see Appendix 1 – Epidemiological Studies in Rugby Union). Amateur studies are not directly comparable with one another or with studies from professional rugby due to a lack of uniformity in study design which included differences in study populations, definitions of injury, methods of data collection and the format in which the results were expressed. The 2007 IRB Consensus statement on epidemiological studies in rugby union[5] provided a standard with which researchers could operate under to eliminate these previous issues. Separating the studies on this basis, there were 10 prospective injury surveillance epidemiological studies and one review article in the pre-2007 era; divided into Super Rugby (n = 2), UK Premiership teams (n = 2), international rugby (n = 3) and amateur or community based studies (n = 3) with a varying number of participants (range 25 – 803). Of the non-amateur studies, the majority involved professional rugby union players (n = 5) with the remaining involving both populations (n = 2). Three studies by Brooks et al.[6-8] from this era conformed to the 2007 Consensus statement as three of the authors were part of the Rugby Injury Consensus Group established by the IRB to agree on appropriate definitions and methodologies to standardize the recording of injuries and reporting in rugby union. However in the remaining studies, injury definition and the method of data collection (team medical staff = 5, questionnaires = 2) varied between the studies.

In the post-2007 era there were seven prospective injury surveillance epidemiological studies; divided into Super Rugby (n = 1), UK Premiership teams (n = 2), international rugby (n = 2) and amateur or community based studies (n = 2, with one of these being from international age grade competitions) with consistently larger participant numbers (range 210 – 941). Of the non-amateur studies, four studies involved professional rugby union players whilst one had a mixed population. In addition there were two review articles and one seasonal injury audit.

Therefore 10 prospective studies conformed to the 2007 Consensus statement (post-2007 = 7, pre-2007 = 3); divided into Super Rugby (n = 1), UK Premiership teams (n = 4), international rugby (n = 3) and amateur or community based studies (n = 2). Excluding the amateur studies (as these have lower injury incidence rates due to a lower level of competition)[9] the average incidence ranged from 83.9 – 96.3 injuries per 1000 player hours in matches and from 2.0 – 3.5 injuries per 1000 player hours in training sessions. Kemp et al.[10] in their 2009-10 UK Premiership Injury Report and Training Audit reported that the match-related incidence had varied between 75 – 100 injuries per 1000 player hours since the start of the study in 2002 to 2010. However the study by Brooks et al.[8] remains an 'outlier', reporting a match-related injury incidence of 218 per 1000 player hours and a training-related injury incidence of 6.1 per 1000 player hours in 53 professional international level rugby union players in the lead-up to the Rugby World Cup in 2003. The authors attributed this marked increase to a more vigilant recording of injuries due to the team doctor being present for all training sessions and matches as well as match specifics (longer 'ball in play' time). Additional studies identified ongoing changes in match specifics such as higher work to rest ratios, more time spent running and sprinting with greater distances attained and an increase in total high-intensity activities across all positions,[11] and increasing exposure through more 'ball in play' time,[12,13] more tackles[14] and rucks.[15] As these changes have not been associated with an injury incidence that approaches the figures reported by Brooks et al.[8] they should be considered with some caution. In addition, injury analysis by anatomical site, severity, mechanism and timing of match-related injuries varied little between these 10 studies regardless of study population. However injury risk with respect to individual playing position or grouping of playing positions varied widely with some trends noted. There was little difference between forwards and backs when grouped in this way. Given the changes in the nature of the game of rugby, it was considered that the previous epidemiological studies from the Super Rugby competition were outdated and that further injury epidemiological analysis was required. This formed the basis for Chapter 2 that contains a descriptive epidemiological review of injuries from the Super 14 Rugby competition. Data from the southern hemisphere at this level is limited to two prospective cohort injury surveillance studies from the Super 12 Rugby competition (1996-2005),[16,17] with an additional study assessing the impact of "Experimental Law Variations (ELV's)" on match-related injuries from

Super 14 (2008) and the South African national provincial championship (Vodacom Cup), with each competition trialing different ELV's.[14] No further Super Rugby studies were located.

The production of the first injury risk prediction model for non-contact soft tissue injuries in elite contact sports by Gabbett[1] provided the initial interest to compare our injury data from Chapter 2 to the prospective cohort of 91 professional rugby league players in Australia. Gabbett's 1st phase (two years) measured prospective training load and injury data over two seasons to determine the relationship between these two variables and develop thresholds for planned training load for the next phase (i.e. with a given training load what is the risk of a sustaining a non-contact soft tissue injury?). In the 2nd phase (next two years) injury risk was predicted using planned and actual training loads for individuals, finding that players were at higher risk of non-contact soft tissue injury if actual training load exceeded the planned loads. This led to the development of an injury prediction model with training reference ranges for injury risk in the pre-season, early and late competition stages (Figure 1.1).

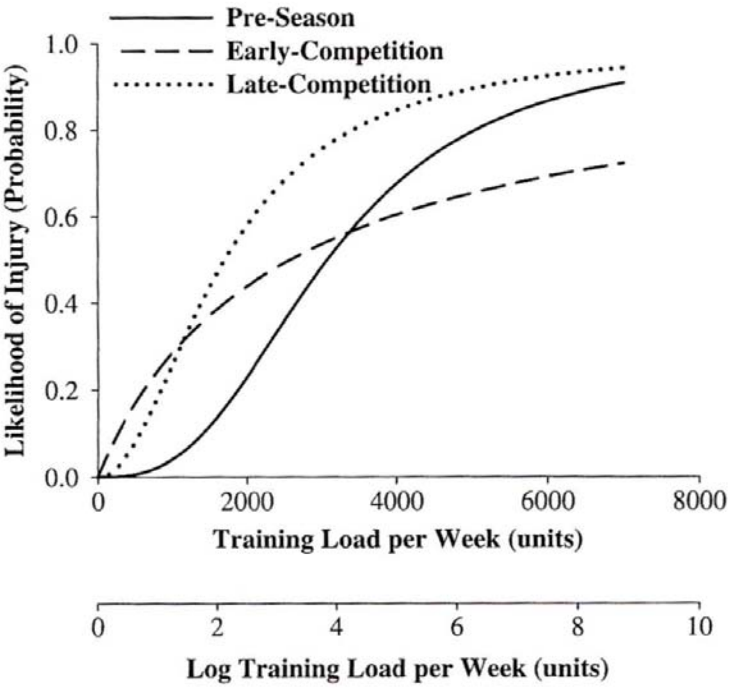

Figure 1.1: The relationship between training load, training phase and likelihood of injury in elite collision sport athletes. Reproduced from Gabbett[1] with permission.

With a sensitivity of 87%, a specificity of 98% and a positive predictive value of 62%, it was felt that this model would remove the guesswork for training-related injury risk. Given the similarities between rugby union and rugby league, the applicability of this model to rugby union provided the initial interest into researching this further. However as the statistical analyses evolved, the nature of the thesis too evolved and this led to challenging the restrictions that such a model may place upon training in athletes. With injury being our primary focus, the epidemiological overview was the starting point with progression to the impact both training load and travel have on injury risk.

The literature search design for Chapter 3, focused on the effects of training load on injury risk, resulted in 15 prospective cohort surveillance studies from the databases (see Appendix 2 – Summary of Studies Assessing Injury Risk as a Function of Load in Contact Running Team Sports). Studies involved varying participant numbers (ranging from 34 – 803), length of time (1 - 4 seasons), contact sports (rugby union = 5, rugby league = 7, Australian Football League (AFL) = 3), timing within the season (pre-season = 6, in-season = 9) and varying level of skill amongst the participants (professional, semi-professional or amateur). The definition of training load varied amongst studies, with six studies measuring volume (training duration) with the remaining studies calculating load as a function of duration x intensity. This inconsistency was also evident in the outcome measures, with injury being measured as incidence (n = 2), time-loss (n = 5), medical attention only (n = 4) or a combination of both time-loss and medical attention (n = 3). One study[18] was only available as an abstract and therefore the specifics around outcome measurement were not available. The lack of uniformity in study design, in particular measurement of training or match load, injury definition and outcomes, made direct comparisons of the effects of training load and match load difficult between these studies. Most studies[1,6,19-25] have related training injuries over a time period to the training load within the same time period (usually one week) and reported a direct linear relationship between training load and injury incidence. Not all studies have been able to show this relationship. Killen et al.,[26] in a study of 36 professional rugby league players over one pre-season period of 14 weeks, were not able to show a significant relationship between weekly training load and injury. However the small sample size and short duration of this study produced wide confidence intervals and lacked clear outcomes. For match-related injuries, authors have related this directly to the load in that match.[27] In a study over one season involving 79 semi-professional players across three grades (levels) of rugby league, Gabbett[27] showed an inverse relationship between training load and injury in some teams, postulating a reduction in active training time due to more injury stoppages to explain this effect. However, overall the training load was directly related to training injury rates.

Data from 11 of 13 English Premiership rugby union teams over two seasons were used by Brooks et al.[19] aiming to confirm their hypothesis that higher volumes of training were associated with a higher incidence in match injuries. With training load measured in hours only (duration) and split into weekly quintiles, they were not able to support this hypothesis but found that higher quintiles of training (>9.1 hours per week) did result in a higher severity of match-related injuries. However intermediate training (between 6.2 – 9.1 hours per week) produced the lowest number and severity of match-related injuries supporting a possible U-shaped effect of training load on match injury. The same data were utilized in two additional studies by the same authors with higher quintiles of training (>12.5 hours per week) increasing the risk of hamstring injuries in a match[28] and a higher training volume mirrored by a higher injury incidence in training.[6] Two further rugby union studies[29,30] surveyed a mixture of amateur and professional rugby players via either questionnaire or telephone interview in measuring weekly training load and seasonal injury diagnosis, questioning the accuracy of these outcomes.

Gabbett has authored or co-authored the largest number of published studies in the literature[1,20,23-27,31] regarding training load and injury risk predominantly from rugby league. There is consistency with measurement of training load (a function of duration x intensity) over all of these publications, but unfortunately the outcome measures have varied. Of those reporting injury as a time-loss measure, there is a consistent association between a higher weekly training load and risk of sustaining a training-related injury, reaffirming the effect that acute training load has on injury risk.

Other authors have considered the effects that prior cumulative training loads have on injury risk. Orchard et al.[32] established a delayed effect of previous workload and injury in cricket fast bowlers, introducing the concept that prior load affected subsequent injury risk. In a novel approach Hulin et al.[33] modelled effects of acute load (representing ‘fatigue’) and chronic load (representing ‘fitness’) on injury in cricket fast bowlers and reported that a negative training balance (where acute workload was greater than the 4-week rolling average chronic workload) increased the risk of injury in the subsequent week. These findings demonstrated that sudden increases in workload increased the injury risk in the following week, whereas higher chronic workloads resulted in a lower injury risk during the current week. The authors argued that positive physical adaptation reduced the influence of fatigue. In a recent article, Rogalski et al.[31] studied 46 professional Australian Football League (AFL) players over one season, measuring individual cumulative load derived from the sum of the training and match loads over designated weekly time constants (ranging from one to four weeks) and compared this with injury. In reporting a linear relationship between injury incidence and higher loads within both the one week and two weeks prior, they introduced the possibility that the prior load can have a priming effect on injury risk.

Chapter 3 provides analyses of the effects of actual and prior cumulative match and training load on count and total duration of training- and match-related injuries in 73 professional rugby union players from one Super Rugby team over five rugby seasons. Effects were estimated via a novel application of over-dispersed Poisson regression.

Chapter 4 provides an analysis of the effects of travel on injury risk. The extent of travel in the Super 14 competition is unparalleled, with no other elite level competitions covering the same distance whilst continuing weekly competition. The impact of travel on non-contact soft tissue injury risk was absent in the literature with no studies found in the databases searched. Therefore injury risk is implied only from occupational settings but studies have varied widely in design (see Appendix 3 – Summary of Studies Assessing the Effects of Airline Travel and Sleep

Deprivation on Performance). Akerstedt's[2] review of laboratory studies and field-based observations in night shift or shift workers and other workers exposed to extended working hours showed a reduction in simple performance measures similar to having an elevated blood alcohol level, or an increase in accidents from the transport industry or work errors from the medical fraternity. The timings of these performance reductions corresponded to the circadian rhythm determined low in basal temperature. Samuel et al.[34] studied long-haul aircrew and identified sleepiness or jet lag as the causative reasons for accidents, but this paper could only be found in abstract form and the exact methodology of the study was not able to be identified. A 2005 meta-analysis[4] on the effect of sleep loss on clinical tasks and cognitive performance reported on 60 studies (20 studies from resident physicians and 40 studies from non-physicians). Acute and partial chronic sleep loss had the largest effect on vigilance and performance indicators whilst non-physicians performed worse when the cohorts were compared. Similarly the effects of travel and performance were found in our database search and are included in Appendix 3. Leatherwood and Dragoo[35] published a recent systematic literature review on this topic. From the 106 studies that met the inclusion criteria, they concluded that airline travel had a negative effect on team performance but reinforced that the direction of travel, timing of the matches or events and time resynchronization strategies were important co-factors. A mixture of retrospective and prospective studies from across a wide variety of sports[36-42] have used varying outcomes to measure performance with a mixture of results and made it difficult to compare their results directly. A comprehensive search for further evidence on the effects of travel and occupation / sleep deprivation on performance was not performed as these topics were only indirectly relevant to Chapter 4.

Structure of the thesis

This thesis (see Figure 1.2) therefore consists of three chapters reporting results from data analysis that culminate in an overall discussion. Chapters 2-4 are to be submitted for publication in journals so each chapter is presented in the wording of the journal. Consequently, there is some repetition in the introduction and methods between the chapters. References are not included at the end of each chapter, rather as required by Auckland University of Technology (AUT) for thesis submission an overall reference list from the entire thesis has been collated at the end of the final chapter.

Chapter 5 consists of a general discussion of findings from the presented research projects, comments on limitations to the research studies, provides areas for future research, and provides some concluding statements on the key findings from the thesis.

Figure 1.2: Overview of thesis chapter flow.

CHAPTER 2

EPIDEMIOLOGICAL INJURY DATA FROM SUPER 14 RUGBY UNION – AN OBSERVATIONAL STUDY OVER FIVE YEARS (2006-2010)

This chapter comprises the following paper to be submitted to be to *British Journal of Sports Medicine*.

Kara, Stephen; Hume, Patria A.; Hopkins, Will G.; Williams, Sean. Epidemiological injury data from Super 14 Rugby Union – an observational study over five years (2006 - 2010). To be submitted to *British Journal of Sports Medicine.*

(Author contribution percentages: SK 80%, PH 10%, WH 5%, SW 5%)

Overview

Rugby union is a high impact collision sport with previous epidemiological studies clearly defining risk to players. Limited injury surveillance studies exist in the literature involving the Super Rugby competition, with those existing now outdated due to changing match demands and competition expansion. The effect of these factors on current injury incidence in this competition are analysed and compared to current existing data from the professional rugby union literature. A prospective injury surveillance study was conducted over five Super Rugby seasons (2006-2010) amongst 73 professional rugby union players from one New Zealand based Super 14 rugby team. The main outcome measures were injury incidence for mechanism (contact vs. non-contact), location (game vs. training), playing position, anatomical site and injury severity. Injury was defined as time loss from training sessions or match play in accordance with the international consensus statement for epidemiological studies in rugby union.[5] The overall injury incidence was 113.6 (match-related injuries) and 6.3 (training-related injuries) per 1000 player hours over the five seasons. Of the 154 injuries, 74% occurred in matches and 58% were contact-related. Injury incidence by playing position, severity and anatomical site were similar to incidences reported in literature. The lower limb contributed 66% of all injuries. Acute lower back training-related injury incidence (69%) was higher than reported in previous studies. The higher incidence of match-related injuries over the five seasons compared to earlier Super Rugby studies reflects the changes in match demands and an increasing number of matches. However the reason for a higher training-related injury incidence is unclear and could represent differences in the specific content of training sessions.

Introduction

Rugby union is an intermittent collision sport that requires participants to compete with a combination of muscular strength, stamina, speed, acceleration, agility, flexibility and aerobic endurance. There is a risk of musculoskeletal injury occurring from both match and training environments due to the number of physical collisions and tackles that are an integral part of the game. Injury risk appears to be higher than many other sports[43,44] with a linear association between injury incidence and competition level.[16,45-50] Foul play only accounts for 6% of all injuries.[7,46]

The Super Rugby competition is recognised as one of the more gruelling rugby competitions in the world[17] with competing teams from Australia, South Africa and New Zealand. Super Rugby has continued to expand since its inception in 1996 and currently has 15 teams, five from each country, resulting in longer playing seasons and greater exposure to injury through higher match play demands.[9,11] Previous studies have assessed injuries in the Super 12 competitions[16,17] but none since have measured the impact of this increase in season length and match demands via player injury surveillance studies.

Aim

The aim of this study was to analyse in-season epidemiological injury data from one Super 14 rugby team over five seasons (2006 – 2010) to determine the impact of competition expansion and increasing physical match demands on player injury rates.

Methods

This observational study consisted of in-season epidemiological injury data collected over five seasons (2006 – 2010) from all 28 full-time contracted players for each season studied from one professional New Zealand rugby union franchise. Injury data were divided into contact or non-contact injuries depending upon mechanism, match or training-related depending on location, severity, anatomical site and playing position. Ethical approval was granted by the Auckland University of Technology Ethics Committee (AUTEC) (Appendix 4) and Northern Y Regional Ethics Committee branch of the Health and Disability Ethics Committee of New Zealand (Appendix 5).

Participants

Twenty eight professional rugby union players (see Table 2.1 for player characteristics) were involved in this study each year over the five rugby seasons studied (i.e. contracted full-time for the study period within each season), giving a total of 140 player seasons. Players were categorized into five playing position groups: tight forwards (TF) consisting of props, hookers and locks; loose forwards (LF) consisting of No 8’s and flankers; inside backs (IB) consisting of halfbacks and No. 10’s; midfield backs (MB) consisting of the centres (inside and outside) and outside backs (OB) consisting of wingers and fullback.

Table 2.1: Player characteristics (mean ±SD) for five years of rugby union play.

Year	Age	Height (m)	Body Mass (kg)	Years in Super 14
2006	24.4 ±2.9	1.86 ±0.08	100.0 ±13.0	2.7 ±2.3
2007	25.4 ±3.4	1.86 ±0.07	103.9 ±11.7	3.7 ±2.7
2008	25.1 ±3.2	1.84 ±0.07	102.7 ±10.4	3.3 ±2.6
2009	24.7 ±3.0	1.88 ±0.07	104.9 ±10.6	3.1 ±2.5
2010	24.8 ±2.3	1.87 ±0.07	104.3 ±9.0	3.6 ±2.3
Average (5 yrs)	24.9 ±3.0	1.86 ±0.07	103.1 ±11.0	3.3 ±2.4

In season matches and training sessions

In season each player participated in three to four on-field training sessions per week (unit specific sessions and team training sessions) and two to four strength and conditioning sessions per week (gym based weight sessions and on field conditioning sessions). Matches were played weekly with the exception of bye rounds, with a total of 13 matches per season, except in 2007 where an additional match was played as part of the competition play-offs. Injury data were collected for each training session and match in-season only, as the pre-season period varied depending on the year.

Definition of injury

Consistent with the “time-loss” injury definition described by Fuller et al.[5] and accepted by the International Rugby Board (IRB), injury was defined as any injury sustained during a Super 14 campaign that prevented a player from taking full part in all training activities planned for that day and/or match play for more than one day following the day of injury. For example, if a player had been injured in a match on Saturday and was not able to take part fully in training on Monday then this was recorded as an injury. Injuries were coded to record severity (measured as duration: mild 0-7 days; moderate 8-28 days; severe >28 days), mechanism of injury (e.g. contact (with another player or object) or non-contact), where the injury occurred (match or training), anatomical site and playing position. Whilst there is some debate on the psychological and socio-cultural factors that may determine injury reporting amongst players,[51] we believe that the accuracy of injury reporting is aided by consistency of one key member who remained constant during the data collection period.

Results

Over the five seasons 150 injuries were directly attributable to matches, with 73% representing contact injuries and 27% non-contact injuries. The rate of competition-match injuries resulting in players' being unavailable for training or matches was 113.64 (95% CL 97 – 133) per 1000 player hours over the five seasons (2006-2010). The majority (79%) of the 54 injuries directly attributable to training were non-contact injuries. The rate of training-related injuries resulting in player unavailability for training or matches was 6.25 (95% CL 5.0 – 8.5) per 1000 player training hours over the five seasons (2006 – 2010). The individual season variation is expressed in Table 2.2.

Whilst there was individual variation between seasons, the greater percentage of injuries occurred in the early part of the competition season (1st half), with a mean of 56% over the five seasons.

Table 2.2: Match and training injuries per season.

Year	2006	2007	2008	2009	2010
Number of matches	13	14	13	13	13
Number of match injuries	35	23	28	34	30
No of match injuries per match played	2.6	1.6	2.1	2.7	2.3
Match injuries per 1000 player hours	130.8	82.1	107.7	134.6	115.4
Mean match injury duration in days	23.3	34.1	6.8	23.5	10.1
Number of training injuries	18	5	10	12	9
Training injuries per 1000 training hours	11.1	2.9	7.4	7.4	4.1
Mean training injury duration in days	9.8	18.0	23.6	32.3	23.9

Injury and playing position

Over the five seasons inside backs (14%) and midfield backs (13%) had the lowest total number of injuries whilst tight forwards had the highest (28%) with seasonal variation. Injury incidence by playing position was consistent with data presented in other studies.[12,13,30,47,52] As tight forwards represented five individual playing positions whilst midfield backs represented only two individual playing positions, the total injury counts over the five seasons were adjusted for playing position[16] showing that the tight forwards had the lowest number of injuries whilst outside backs had the highest (Table 2.3).

Table 2.3: Injury counts according to playing position per year.

Playing position (frequency)	2006	2007	2008	2009	2010	Total (Adjusted)
Tight forwards (5)	16	8	10	16	7	57 (11.4)
Loose forwards (3)	8	4	10	11	9	42 (14.0)
Inside backs (2)	10	4	4	5	6	29 (14.5)
Midfield backs (2)	6	5	5	2	8	26 (13.0)
Outside backs (3)	13	7	9	12		50 (16.7)
Total	53	28	38	46	39	204
Injury counts for forwards or backs per year						
Forwards (8)	24	12	20	27	19	99 (12.4)
Backs (7)	29	16	18	19	23	105 (15.0)

Midfield backs were more likely to have a contact-related injury (73%) rather than a non-contact injury, with contact-related injuries occurring predominantly in matches (Table 2.4) which is reflective of the high collision risk for midfield backs.[52-54] Outside backs were at higher risk for training-related injuries (33%) whilst inside backs had a higher adjusted incidence of match-related injuries despite a low overall incidence. In absolute numbers tight forwards alone accounted for 30% of all match-related injuries, with adjusted figures confirming higher risk for match-related non-contact injury, making tight forwards a key target for injury prevention strategies.[55] Interestingly no training-related contact injuries occurred in inside backs, but a much higher adjusted incidence of match-related non-contact injury was reported. Loose forwards were more likely to sustain an injury from a match-related contact event.

There were negligible differences between backs and forwards over this time period with the backs contributing to 52% of all injuries sustained.

Table 2.4: Injury counts for incidence type and mechanism according to playing position (injuries adjusted for the number of playing positions in each positional group).

	Tight forwards(5)	Loose forwards(3)	Inside backs(2)	Midfield backs(2)	Outside backs(3)	Total
Contact	27 (5.6)	28 (9.3)	16 (8.0)	19 (9.5)	28 (9.3)	118
Non-Contact	30 (6.0)	14 (4.7)	13 (11.5)	7 (3.5)	22 (7.3)	86
Match	44 (8.8)	32 (10.7)	23 (11.5)	19 (9.5)	32 (10.7)	150
Training	13 (2.6)	10 (3.3)	6 (3.0)	7 (3.5)	18 (6.0)	54
Match Contact	26 (5.2)	26 (8.7)	16 (8.0)	16 (8.0)	25 (8.3)	109
Match Non-Contact	18 (3.6)	6 (2.0)	7 (3.5)	3 (1.5)	7 (2.3)	41
Training Contact	1 (0.2)	2 (0.7)	0 (0.0)	3 (1.5)	3 (1.0)	9
Training Non-Contact	12 (2.4)	8 (2.7)	6 (3.0)	4 (2.0)	15 (5.0)	45

Injury anatomical site

The lower limb was the most common injury location representing 60 - 70% of all injuries (Table 2.5). The posterior thigh (hamstring) accounted for the highest number and incidence of injuries in training sessions and matches, with other lower limb sites (specifically the lower leg / Achilles region, ankle, knee and anterior thigh) represented, consistent with anatomical sites most commonly injured in rugby union.[6-10,17,45-48,56] Shoulder injuries and head/face injuries (predominantly concussions) were the only anatomical sites outside of the lower limb to feature as notable match-related injuries.

The posterior thigh and lower leg / Achilles regions had the highest training-related (on-field and gym based) injury incidence. Lower back injuries ranked third in our data and were acute gym-related lifting injuries, making this an area for improved education around technique as well as training supervision.

With playing position as a covariate, there were definite trends that identified specific at risk areas anatomical sites. Tight forwards accounted for 62.5% of the lower back injuries, whilst tight forwards and outside backs accounted for 60% of the lower leg and Achilles injuries. Of posterior thigh injuries, 73% were in tight forwards, outside backs and inside backs.

Table 2.5: Injuries according to anatomical site.

Anatomical Site	Injury Counts		Injury Incidence per 1000 hrs		
	Game	Training	Game	Training	Total
Posterior Thigh	25	12	18.94	1.42	3.78
Lower Leg / Achilles	23	12	17.42	1.42	3.57
Ankle	15	2	11.36	0.24	1.74
Knee	15	0	11.36	0.00	1.53
Head / Face	14	2	10.61	0.24	1.63
Shoulder / Clavicle	12	2	9.09	0.24	1.43
Anterior Thigh	10	1	7.58	0.12	1.12
Foot / Toe	7	3	5.30	0.35	1.02
Hip / Groin	7	2	5.30	0.24	0.92
Lower Back	5	11	3.79	1.30	1.63
Neck / Cervical Spine	5	0	3.79	0.00	0.51
Sternum / Ribs / Upper Back	5	1	3.79	0.12	0.61
Other	3	0	2.27	0.00	0.31
Elbow	1	0	0.76	0.00	0.10
Hand / Finger / Thumb	1	0	0.76	0.00	0.10
Upper Arm	1	0	0.76	0.00	0.10
Wrist	1	2	0.76	0.24	0.31
Sacrum / Pelvis	0	4	0.00	0.47	0.41

Injury severity

Over the five seasons, 87% of the injuries were either mild (51%) or moderate (36%), resulting in less than 28 days' time loss per injury but with seasonal variation as outlined in Table 2.6.

Table 2.6: Injury severity by prevalence per year.

Frequency (Days)	2006	2007	2008	2009	2010	Total
Mild (0-7)	27	9	30	18	20	104
Moderate (8-28)	19	14	4	20	16	73
Severe (>28)	7	5	4	8	3	27
Total	53	28	38	46	39	204

Injury severity as a function of anatomical site is presented in Table 2.7. Whilst lower limb injuries accounted for the highest number and highest incidence per 1000 hours, they were not injuries that caused the greatest time loss to players. Wrist injuries accounted for the longest absence with a mean duration of injury of 54 days, followed by the lower back and the shoulder

/ clavicle. The lower limb sites represented the remainder of the notable injuries by severity with the hip / groin and lower leg / Achilles accounting for more time loss than knee injuries.

Table 2.7: Injury duration (mean ±SD) according to anatomical site.

Anatomical Site	Number	Duration (Days)
Wrist	3	54 ±73
Lower Back	16	40 ±83
Shoulder / Clavicle	14	30 ±59
Hip / Groin	9	26 ±41
Lower Leg / Achilles	35	23 ±47
Knee	15	21 ±24
Posterior Thigh	37	18 ±28
Foot / Toe	10	18 ±39
Elbow	1	15 ±0
Ankle	17	12 ±8
Head / Face	16	10 ±9
Sternum / Ribs / Upper Back	6	10 ±4
Other	6	10 ±11
Neck / Cx Spine	5	9 ±7
Sacrum / Pelvis	4	7 ±7
Anterior Thigh	11	5 ±4
Hand / Finger / Thumb	1	5 ±0
Upper Arm	1	3 ±0

Discussion

Published studies involving the Super Rugby competition and injury are lacking, with only four studies[14,16,17,48] located using an extensive literature search of Web of Knowledge, MEDLINE, CINAHL®, Google Scholar, PubMed, Scopus and SportsDiscus® databases from 1995 – July 2013. Two studies used prospective cohort injury surveillance.[16,17] Using single season data from teams during the Super 12 competitions in 1997[16] and 1998[17] with similar study designs and definitions, these studies may now be considered out of date as the nature of the game continues to evolve. Targett[16] reported a combined training and match-related injury rate of 120 per 1000 player hours whilst Holtzhausen[17] separated these into match-related (55.4 per 1000 player game hours) and training-related injuries (4.3 per 1000 player training hours), and also expressed an overall injury-rate of 84 per 1000 player game hours. Inclusion criteria of requiring suturing, radiology or medication as part of their time-loss training- and match-related injury definition in both studies[16,17] possibly over-represented actual incidence. Despite this, the significantly lower match-related injury rates compared to ours reflects the changing nature of competitive rugby union since these original studies. Quarrie and Hopkins[15] analysed the change in match activities over three decades in elite rugby union matches showing an increase in ball-in-play time, rucks and tackles, thereby increasing exposure to injury risk. Austin et al.[11] through time in motion studies from Super 14 during 2008-2009, found there is more time spent running and sprinting with greater distances attained, higher work to rest ratios and an increase in total high-intensity activities across all positions compared to previous Super 12 studies and UK Premiership data from 2006 and 2008. Fuller et al.[14] analysing the impact of law variations on injury rates between the two hemispheres concluded that there were more tackles in Super 14 compared to the UK Premiership and Rugby World Cup. Injury risk is thereby increased owing to an increase in exposure from more ball-in-play time, more running and more contact events, and longer periods of activity within a match since the original studies from Super Rugby.[16,17] Therefore the higher incidence of competition-match related injuries in our study may well reflect these differences in match events.

UK Premiership Audit data from 2002 – 2010[10] showed a mean of 85.17 match-related injuries per 1000 player hours (95% CL 82.23 – 88.21). Similar rates occurred in previous Rugby World Cups (2003,[57] 2007[12] and 2011[13]). Our match-related injury data was higher than the UK Premiership Audit data by a factor effect of 1.33 (95% CL 1.13 – 1.57; very likely small).[58] With the majority of match-related injuries being contact in nature, a phenomenon which is well recognised in our study (53% of all injuries) and in others,[7-9,12,16,17,44-49,52,57,59] it is pertinent to review studies that may answer this discrepancy. Fuller[54,59] analysed the propensity of contact events in rugby union to cause injury, concluding that whilst the tackle is the most common event (injury counts), the scrum and the collision were more likely to result in significant injury (injury duration) further supporting differences in match events in causation.[11,14] Only one study showing a higher rate[8] of 218 match-related injuries per 1000 player hours from professional international rugby players has been reported. The authors concluded the higher rate was due to increased ‘ball-in-play’ time and vigilant reporting and data collection systems, but incidence rates these high have not been reported by others since. Whilst changes in player characteristics could be argued as additional factors, Fuller et al.[60] found significant changes in age, mean stature and mean body mass were limited to two positions only in rugby union in a recently published 10-year review.

Figures for our training-related injuries are similar to only one previous study[8] and are higher than those reported from the UK Premiership Audit data from 2006 – 2010[10] by a factor effect of 2.6 (95% CL 1.9 – 3.4; most likely moderate). UK Premiership Audit data from this period reported a mean of 2.53 training-related injuries/1000 player hours (95% CL 2.35 – 2.72; most likely large) with similar rates reported from previous Rugby World Cups,[12,13] Super 12 rugby[17,48] and similar studies.[6,9] Four out of five training-related injuries are non-contact injuries with skills based training being higher risk than conditioning type sessions.[6] The reasons for the higher rates in our study are unclear, as anatomical site locations were similar to previous studies[6,17] involving international rugby players.[8,12,13] An efficient injury reporting regimen, with the team doctor present at every training session and match, could have contributed to the higher injury rates reported in our study. However rugby union injury rates were markedly lower compared to professional rugby league[61] and could merely reflect differences in training specifics.

Playing position risk has been studied extensively[6,7,10,12,13,30,46,48,52,54] leading to the development of preventative exercises based on playing position.[55] The lack of difference in injury incidence between forwards and backs[6-9,12,13,47,55,56] compared to earlier Super rugby studies[16] reinforces the changing nature of rugby union over this time period. The individual playing position with the highest incidence of injury and the grouping of playing positions have varied widely between studies making direct comparisons difficult, but there were some consistent trends. Midfield backs were more likely to sustain a contact injury, findings shown by Fuller et al.[54] and Headey et al.[52] when tackling was the cause,[62] reflecting this being a high impact position. Non-contact injuries were more likely to occur in outside backs, inside backs and tight forwards, reinforcing prevention strategies for these positions.

Despite non–standardised reporting of injury severity prior to the consensus statement on injury definitions in 2007[5] results are similar to our current study and reflect little difference in injury severity over the years and between competitions.[6,7,12,13,47,48] In the only other Super Rugby studies published, Holtzhausen[17] reported 66% of injuries being either mild or moderate (<3 weeks duration) compared to 89.2% by Targett,[16] the difference reflecting a higher number of mild injuries in the latter study and possible under-reporting in the former. Brooks et al.[6,7] reported 71% and 80% of all training- and match-related injuries respectively from UK Premiership data as being mild or moderate using similar severity definitions.

Classification of injuries by anatomical site has also varied in the literature over the years making direct comparisons difficult. However trends were still evident when we grouped our data according to only anatomical site. We were unable to apply additional pathological coding, as coding with the Orchard Sports Injuries Classification System (OSIC Codes)[63,64] was not consistent over all of the years we collected data.

Injury sites were consistent with the reported literature[6-10,14,17,45,47,48,56] despite discrepancies in injury coding. Injury to the lower limb was the most common injury from both matches and training, predominantly affecting the thigh, knee and ankle. Posterior thigh injuries were associated with positions at highest risk of non-contact injuries (tight forwards, outside backs and inside backs). More extensive overseas data by Brooks and Kemp,[55] attributing injury prevention priorities according to playing position, support our playing position injury trends. Earlier studies[16,46,57] that reported head and facial injuries contributed a higher percentage to total injuries may have over-reported minor injuries prior to the development of the consensus guidelines for epidemiological studies in rugby union. Altered law changes pertaining to the tackle since 1997 may also have affected injury incidence reporting.

Injury severity by duration and anatomical site is similar to that reported from UK Premiership data[6,7,10,52] apart from the lower back. Injury to the lumbar spine most commonly occurs as an acute gym-based training-related injury (69% in our data), more frequently in forwards than in backs,[6] and remains an area for increased vigilance and injury prevention. Less time loss from knee injuries, due to higher number of anterior cruciate (ACL) and medial ligament (MCL) injuries[6,7,10] in other studies, and more time loss from groin and lower leg / Achilles could see the latter being an area for improved preventative therapy.

A measure of injury risk that considers both injury incidence and severity is a more pertinent indicator of the impact injuries have and should be the focus of injury prevention strategies. Brooks and Kemp[9] have shown these to be knee (ACL injury or meniscal injury) and shoulder (instability) for match injuries and lumbar disc, shoulder (instability) and hamstring injury for training injuries. The only anatomical site not represented was the wrist which in our study caused the greatest time loss, but with low actual numbers may well reflect unusual clinical scenarios rather than match specific changes.

Conclusions

Previous epidemiological studies have defined the risks associated for players in rugby union. This Super 14 injury surveillance study highlights the increase in injury incidence owing to competition expansion, law alterations and the changing match demands that players are now faced with. Match-related injuries occur more frequently than training-related injuries, with identifiable differences in risk depending on playing position. Previous studies from professional rugby union in the Super Rugby competition appear to be outdated. Whilst the differences in match-related injury rates between professional competitions may well reflect the differences in match events, injury prevention focus is unaltered.

CHAPTER 3

THE TEMPORAL EFFECT OF PRIOR CUMULATIVE TEAM TRAINING AND MATCH-LOAD AND ACUTE TRAINING LOAD ON IN-SEASON INJURY RISK IN ELITE CONTACT SPORTS

This chapter comprises the following paper to be submitted to be to *British Journal of Sports Medicine*.

Kara, Stephen; Hopkins, Will G.; Williams, Sean; Hume, Patria A. The temporal effect of prior cumulative team training and match-load and acute training load on in-season injury risk in elite contact sports. To be submitted to *British Journal of Sports Medicine.*

(Author contribution percentages: SK 75%, WH 10%, SW 10%, PH 5%).

Overview

Injury research in collision sport supports risk in training and matches from weekly training-related load. Here we analysed injury risk based on acute training load and prior cumulative training- and match-related loading. The effects of cumulative match and training load on count and total duration of training- and match-related injuries in 73 professional rugby union players from one Super Rugby team over five rugby seasons were estimated via a novel application of over-dispersed Poisson regression. The cumulative load was an exponentially weighted moving average, allowing for gradual decay of the effect of each match and training session. The time constant of the decay was varied over 2–20 days to establish the period during which prior cumulative load had most effect on injury. The cumulative load with a 10-day averaging period had the greatest effects on measures of injury. Following periods of typically high versus typically low cumulative load, a reduction in number of training-related non-contact soft-tissue injuries by a factor of 0.4 (90% confidence limits 0.2 – 0.7; possibly large) and in total duration by a factor of 0.3 (0.1 – 0.8; likely large) was seen, whilst match-related contact injury counts increased by a factor of 1.6 (1.1 – 2.4; possibly moderate). All training-related injuries increased with higher acute training load by a factor of 2.9 (2.0–4.4; most likely very large). This study supports the protective effects of higher cumulative training load on training-related injury risk over a 10-day prior period, whilst adding evidence of increased risk with higher acute load.

Introduction

The negative effects of training, such as illness, injury and overtraining, arising from excessive training load must be carefully monitored, as such effects can be detrimental to the individual or teams' success.[19] Training load is one of several potentially modifiable injury risk factors,[28] alongside various non-modifiable factors such as previous history of a similar injury,[65] playing experience,[18] playing position,[55] ethnicity[66] or level of competition.[6] Whilst there is familiarity with the concepts of loading, maintenance and tapering phases in any training regimen, production of an injury-prediction model for contact sports would allow more informed decisions upon which to balance the risk-benefit of training loads. Gabbett[1] presented the first injury risk prediction model for non-contact, soft-tissue injuries in elite contact sports and removed the guesswork from training, providing a reliable model to calculate ‘acceptable’ acute risk levels. With the total proportion of incorrect predictions being small the injury risk prediction model provided greater sensitivity than ‘intuition and gut feel’.

Gabbett has shown in previous papers[25,27] that increases in either match or training intensity or weekly training load is associated with an increased risk of injury in semi-professional and professional rugby league players. These findings are supported in studies from professional rugby union in the United Kingdom[6,28] with higher training volumes (presented as quintiles calculated in numbers of hours per week) resulting in more days lost per team per week from match injuries.[19] Similar results are seen in amateur rugby[29,30] where greater volumes of pre-season weekly physical exertion or training resulted in more in-season injuries. The association between training and injury has also been established in non-contact sports such as basketball,[67] cricket,[68] gymnastics,[69] orienteering[70] and triathlon.[71]

In these previous studies, injury has been attributed to an acute effect of each week's training or match load on injuries in that week, apparently without any attempts to account for any cumulative or priming effect of prior load. The delayed effect of load in previous weeks on injury risk has been shown in cricket fast-bowlers.[32] More recently Rogalski et al.[31] calculated prior cumulative load as the sum of training and game load for individual Australian Football League (AFL) players, showing the higher the prior cumulative load the greater the risk of injury. The present study builds upon this but features a novel analysis with the aim of determining the effect of prior cumulative load on injuries on a given training or game day, along with the acute effect of daily load.

Methods

This observational study is an extension of the epidemiological injury data collected over five seasons (2006 – 2010) from one professional New Zealand rugby union team. Daily training load and injury data were collected from all 28 full-time contracted players for each season over the five seasons studied. Injury data were divided into contact or non-contact (soft-tissue) injuries depending upon mechanism and either match or training-related. Ethical approval was granted by the Northern Y Regional Ethics Committee branch of the Health and Disability Ethics Committee of New Zealand (Appendix 5) and the Auckland University of Technology Ethics Committee (AUTEC) (Appendix 4).

Participants

Twenty eight professional rugby union players were involved in this study each year over the five rugby seasons studied (i.e. contracted full-time for the study period within each season), giving a total of 140 player seasons. The age, height, body mass and years of Super Rugby experience over the five years were 24.9 ±3.0 y, 1.86 ±0.07 m, 103 ±11 kg and 3.3 ±2.4 y respectively, with little change in between these years.

Training sessions

Weekly scheduling of training sessions was prepared one month in advance as the season progressed from pre-season to the end of competition. Each player participated in three to four on-field training sessions per week (unit specific sessions and team training sessions) and two to four strength and conditioning sessions per week (gym based weight sessions and on field conditioning sessions). Training load and injury data were collected for each session. Only in-season training session data were used in the analysis against injury data from competition-matches and training.

Measurement of loads for training and matches

The intensity of training sessions was calculated using the modified rating of perceived exertion (RPE) scale.[72] The ratings were elicited from a random sample of ten players at the end of each session to reflect overall team intensity, and averaged at the end of each training session by the same trainer over the study period. Data collection represents an overall team training load rather than an individual. RPE is a physiologically valid method for exercise intensity estimation[73,74] with correlations of 0.89 and 0.86 with training heart rate and training blood lactate concentrations[20] and training intensity in contact sports.[75]

Acute daily team training load was quantified by multiplying the RPE by the duration of the training session (varying from 30 – 90 minutes per session) and reported in intensity-minutes, a technique analogous to that used by Gabbett.[1] For non-zero in-season training days, actual loads ranged from 60 – 1100 intensity-minutes and session intensity from 1 – 8 depending on the year, with a mean in-season actual daily training load over the 5 years of 411 intensity-minutes and training session intensity of 5.4. Training loads for backs and forwards were averaged as differences between these groups were trivial. All matches were assigned an RPE of 9 (based on strength and conditioning staff opinion and individual player survey post-match) with match duration of 80 minutes, contributing 30% additional load to the average weekly training load.

Definition of injury

Injury was defined as any injury sustained during a Super 14 campaign that prevented a player from taking full part in all training activities planned for that day and/or match play for more than one day following the day of injury. For example, if a player had been injured in a match on Saturday and was not able to take part fully in training on Monday then this was recorded as an injury. This injury definition is consistent with the time-loss injury definition described by Fuller et al.[5] and accepted by the International Rugby Board (IRB). Injuries were coded to record severity (measured as duration: mild, 0-7 days; moderate, 8-28 days; severe, >28 days), mechanisms of injury (e.g., contact or non-contact / soft tissue) and where the injury occurred (match or training).

Statistical analyses

The original dataset consisted of an observation for each injury sustained on each training and match day over five years, with variables representing duration of the injury, duration and intensity of training or match play, number of players taking part in the training or match. Days without injury were included as a single observation with zero injury duration. To account for players not involved in training or the match, training and match loads were adjusted by a factor (squad size minus number unavailable for training or match)/squad size. Players were considered unavailable for training during the first 25% of the injury duration.

Injury incidence expressed as counts of injuries occurring on a given training or match day were analysed with the Statistical Analysis System (Version 9.2, SAS Institute, Cary NC) using a generalized mixed linear model (Proc Glimmix) procedure to specify a Poisson distribution. The analyses were performed with a log link to estimate effects as factors. An over-dispersion factor was included to account for interdependence of injuries occurring on the same day. A predictor variable representing cumulative load affecting injury risk on each training and match day was generated as an exponentially-weighted moving average[76,77] using a decay factor f with a value between 0 and 1, such that the cumulative load was given f×(the previous day's training load) + (1 - f)×(the cumulative load up to that point). The resulting cumulative load is effectively smoothed with a time constant given by 1/f,[78] which represents the period during which the load has most impact on injury risk. For example, for f = 0.1, the period is 10 d. The analysis was repeated with f values of 0.5, 0.2, 0.1 and 0.05 (time constants of 2, 5, 10 and 20 d) to determine which time constant produced the greatest effect of cumulative load on injury. In analyses of effects of cumulative load on injuries on a given training day, a predictor representing actual daily training load on that day was included in the model and its effects quantified in the same manner as for cumulative load. Further analyses showing little effect of the interaction between daily and cumulative loads are not presented here. The analysis of match injuries could not include a predictor for match load on the match day, because match load was constant.

Analyses with cumulative load included in the model as a quadratic predictor and as a nominal predictor parsed into quintiles revealed no evidence of a curvilinear effect on injury, so the analyses reported here are for its effect as a simple linear predictor. The effects are shown for the ratio of predicted risk for cumulative loads differing by two standard deviations (a typically high load versus a typically low load).[79]

Similar analyses were performed for the sum of the durations of injuries occurring on each training or match day, with the over-dispersion factor now also taking into account the mean duration of the injuries. Separate analysis of the mean duration of injuries was also undertaken with the general mixed model (Proc Mixed) in SAS. These analyses included a random effect for clustering of injuries on the same training or match day, and the injury duration was log transformed to estimate effects as factors.

Uncertainty in each effect was expressed as 90% confidence limits and as probabilities that the true effect was beneficial and harmful. These probabilities were used to make a qualitative probabilistic mechanistic inference about the true effect[58,80]: if the probabilities of the effect being substantially positive and negative were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported as the magnitude of the observed value, with the qualitative probability that the true value was at least of this magnitude. The scale for interpreting the probabilities was as follows: 25–75%, possible; 75–95%, likely; 95-99.5%, very likely; >99.5%, most likely. The thresholds for small, moderate, large and very large effects are those for risk ratios: 1.11, 1.43, 2.0, and 3.3 respectively.[81]

Results

Analysis of training load

Cumulative load had the greatest effect on the number of all injuries from matches for a time constant of two days. For all remaining measures of injury a time constant of 10 days produced the greatest effect of cumulative load. Table 3.1 shows the data for cumulative load with this time constant for each season. The load varied substantially over the five seasons. Similar seasonal variation was apparent for the acute daily team load (Table 3.1).

Table 3.1: 10-day cumulative smoothed daily team load and acute daily team load (intensity-minutes) over five years (mean ±SD).

Year	2006	2007	2008	2009	2010	Mean
Cumulative daily team load						
Training	325 ±59	281 ±69	273 ±50	274 ±41	358 ±59	301 ±66
Match	250 ±120	258 ±72	260 ±41	258 ±56	366 ±51	278 ±83
Acute daily team load						
Training	470 ±250	380 ±250	340 ±190	360 ±200	530 ±330	410 ±260

The acute match team load was 720 intensity-minutes over the entire study period.

Analysis of match injuries

Over five seasons 150 injuries were attributable to matches, 73% representing contact injuries and 27% non-contact soft-tissue injuries. The mean injury rate was 114 per 1000 player hours. The data for each season are shown in Table 3.2.

Table 3.2: Match and training-related injuries in each season.

	2006	2007	2008	2009	2010
Number of matches	13	14	13	13	13
Number of match injuries	35	23	28	34	30
Number of training injuries	18	5	10	12	9
Match injuries per 1000 player match hours	131	82	108	135	115
Training injuries per 1000 player training hours	11.1	2.9	7.4	7.4	4.1
Match injury duration (d) (mean ±SD)	23 ±46	34 ±69	7 ±7	24 ±35	10 ±9
Training injury duration (d) (mean ±SD)	10 ±18	18 ±16	24 ±43	32 ±64	24 ±41

For match-related injuries, there were clear harmful effects of cumulative load on the number of all injuries, attributable mainly to contact injuries (Table 3.3). In absolute numbers, this effect translates into approximately one additional contact injury per match. However there were no clear effects on injury duration (severity) or sum of injury duration (total time lost). Actual load is a constant for games and was not able to be analysed.

Table 3.3: Effect of 2 SD of 10-day cumulative smoothed daily load expressed as a factor effect on match-related injuries.

	Effect (90% CI)	Inference
Injury Counts		
All Injuries	1.32 (0.93 to 1.89)[a]	likely moderate harmful
Soft-Tissue	0.84 (0.44 to 1.60)	unclear
Contact	1.59 (1.05 to 2.40)	likely moderate harmful
Injury Duration		
All Injuries	0.52 (0.19 to 1.42)	unclear
Soft-Tissue	1.10 (0.23 to 5.39)	unclear
Contact	0.55 (0.18 to 1.65)	unclear
Sum of Injury Duration		
All Injuries	0.83 (0.43 to 1.57)	unclear
Soft-Tissue	1.43 (0.53 to 3.91)	unclear
Contact	0.69 (0.33 to 1.47)	unclear

[a] For a 2 day prior exposure period, the factor is 1.52 (1.1 to 2.09) – possibly moderate harmful.

Analysis of training injuries

Over the five seasons 54 injuries were attributable to training, the majority (79%) being non-contact soft-tissue injuries. The mean injury rate was 6.3 per 1000 player training hours. The data for each season are shown in Table 3.2.

The effects of actual load and cumulative load on training-related injuries are shown in Table 3.4. For actual load there were clear harmful effects on the number of injuries and the sum of the injury duration, these effects being stronger for soft-tissue injuries than for contact injuries. However, prior load had a protective effect, with at least a 50% reduction in the count and summed duration of soft-tissue injuries. There were unclear effects of actual or cumulative team load on injury duration (severity).

Table 3.4: Effect of 2 SD of actual daily load and of 10-day cumulative smoothed daily load expressed as factor effects on training-related injuries.

		Effect (90% CI)	Inference
Injury Counts			
Actual Load	All Injuries	2.96 (2.00 to 4.38)	very likely large harmful
	Soft-Tissue	2.85 (1.86 to 4.36)	likely large harmful
	Contact	2.29 (1.01 to 5.17)	possibly large harmful
Cumulative Load	All Injuries	0.56 (0.35 to 0.90)	possibly moderate beneficial
	Soft-Tissue	0.42 (0.25 to 0.70)	possibly large beneficial
	Contact	1.49 (0.63 to 3.51)	unclear
Injury Duration			
Actual Load	All Injuries	0.46 (0.13 to 1.61)	unclear
	Soft-Tissue	0.56 (0.14 to 2.21)	unclear
	Contact	0.30 (0.01 to 7.52)	unclear
Cumulative Load	All Injuries	2.51 (0.77 to 8.18)	unclear
	Soft-Tissue	1.73 (0.47 to 6.30)	unclear
	Contact	5.59 (0.22 to 141.8)	unclear
Sum of Injury Duration			
Actual Load	All Injuries	2.41 (1.08 to 5.36)	possibly large harmful
	Soft-Tissue	2.68 (1.17 to 6.13)	likely large harmful
	Contact	1.14 (0.21 to 6.29)	unclear
Cumulative Load	All Injuries	0.49 (0.19 to 1.27)	unclear
	Soft-Tissue	0.30 (0.11 to 0.85)	likely large beneficial
	Contact	1.95 (0.39 to 9.90)	unclear

Discussion

The rates of match- and training-related injuries in this study are higher than those reported in other studies of professional rugby[10,12,14,57] yet markedly lower than professional rugby league.[61] These differences reflect differences in match[14] and training specifics, such as the proportion of match-related tackle events. Differences in injury definition between studies of rugby union and rugby league may also contribute.

In most studies of the effects of training and match loads on injury, the authors have related training over a period of time to training injuries sustained in the same period (usually one week) or to match load and injuries in the match. For example, Gabbett and Jenkins[25] modelled weekly training load against injury in professional rugby league players over four seasons, finding a linear relationship between on-field training and the incidence of training injuries. There have been similar studies with similar outcomes in rugby league,[1,20,22-24] rugby union[6,19] and Australian Football League (AFL).[21] However, in semi-professional rugby league players Gabbett[27] showed an inverse relationship between training load and injury in some teams studied, postulating reduced active training time due to more injury stoppages to explain this effect. But the direct effect of increased training load and training injury was the more compelling result whilst match-related injuries match load also had a direct linear relationship.

Measuring weekly training loads and reporting against injury within this time period as in these previous studies is problematic; weekly training load actually measures the effects of both the actual load (on the day of injury) and cumulative load (prior to the day of the injury), failing to distinguish between these two effects. The period of cumulative load is also ill defined and does not include training prior to each weekly window. Our novel modelling approach differentiates between the effects of actual and cumulative loads, at least for their effects on training injuries. The effects we found for the actual training load are not unexpected: higher loads were associated with higher injury incidence and total days lost, and this kind of association obviously helps to account for the much higher risk of injury in a match compared with a training session. However a surprising finding was the protective effect of cumulative load on incidence of soft-tissue training injuries and total days lost, probably reflecting a positive adaptation to training of the body. The concept that fitter players have lower injury risk has been reported in match-related contact injuries.[82] This protective effect of prior training was not apparent in the analysis of match-related injuries, where we found higher prior loads increased the risk of contact injuries. This increase is presumably due to post-training physical and mental factors (muscle soreness and fatigue) and emphasizes the importance of tapering training load to allow cumulative load to decline leading into a match.

There have been few other studies properly analysing for the effect of prior load on injury risk. Studying injuries in UK Premiership rugby union, Brooks et al.[19] reported that higher quintiles of training volume the week before each match were associated with injury severity in the match itself; there was no significant effect on overall incidence, but there was an increased risk of match-related hamstring injury.[28] Monitoring 46 professional AFL players over one season, Rogalski et al.[31] analysed the effect on injuries of prior cumulative load measured in windows of one to four weeks. Their finding of the greatest risk with a two-week window of prior training is consistent with our results where associations were greatest with a 10-day time constant for cumulative training. Decaying the effect of training load, as we have done, more accurately reflects the diminishing effect that prior load will have on injury risk over a time constant. Their analysis did not distinguish between training- and match-related injuries, but to the extent that injury incidence is much higher in matches, their findings must be biased towards matches. However, even if the association relates predominantly to training injuries, their finding could be an artefact of periodisation: during periods of higher training load, the greater risk of injury could be due to the higher load on the day of injury rather than the higher load prior to the day of injury. Our analysis allowed for an adjustment for training on the day of the injury, thereby more accurately estimating the effect of prior load on training-related soft-tissue injury risk.

Several studies have suggested a curvilinear or U-shaped curve rather than a simple linear effect of training load on injury risk.[19,30, 83] These are interesting findings which propose an optimum training load range with respect to injury risk and one that we were not able to establish, with modelling for both quadratic and quintile effects of the prior cumulative load on training or match-related injuries being unclear (data not shown).

While there is no dispute that higher overall loads increase the risk of injury, our finding of a protective effect of prior training load on training-related soft-tissue injuries highlights the potential for beneficial adaptation to training. What is not clear from our research is the extent to which the rate of change of training load modifies the effects of prior cumulative load and of actual load on injury. Gradual increases in load would presumably lead to smaller increases in injury risk, although there is evidence that monotony in training is associated with higher injury risk.[21,67] More research is needed to address this issue. Future studies also need to be based on analysis of training and injury in individuals via monitoring with micro-technology (i.e. GPS, accelerometers and gyroscopes) devices[24,84]. As GPS monitoring alone does not capture the effect of high-intensity, low-volume, skills-based training drills (e.g., scrum practice) on the overall load a player is subjected to, we advocate the continued use of rating of perceived exertion in quantifying training load.

Conclusions

The novel application of modelling in this study clearly delineates the effects of actual daily and prior cumulative training load on injury risk. Higher actual training loads were associated with higher injury incidence and total days lost for training-related injuries. Higher prior cumulative load leading into matches resulted in a higher number of match-related injuries, highlighting the importance of tapering into a match. The protective effect of prior cumulative loading on training-related injuries has not been reported elsewhere and points to future research on potential reduction in injury risk with adaptation to higher training loads.

CHAPTER 4

THE EFFECT OF TRAVEL ON INJURY RISK – HOW MUCH IS THIS A FACTOR?

This chapter comprises the following paper to be submitted to be to *British Journal of Sports Medicine*.

Kara, Stephen; Hopkins, Will G.; Williams, Sean; Hume, Patria A. The effect of travel on injury risk – how much is this a factor? To be submitted to *British Journal of Sports Medicine.*

(Author contribution percentages: SK 80%, WH 10%, SW 5%, PH 5%).

Overview

Travel across time zones has well known physiological effects on the human body, commonly termed ‘jet-lag’. Travel has become an integral part of professional sport and athletes have had to employ strategies to limit the effects of ‘jet lag’ on performance. However the literature is void of studies measuring the effect of travel on injury risk. The Super Rugby competition is unique in that travel across multiple time zones is required as part of the regular season competition and potentially in the post-season play-offs. Over five Super Rugby seasons, an analysis of training- and match-related injuries against location and either long-haul travel (>5 hours duration) or short-haul travel (<5 hours duration) was performed in 73 professional rugby union players. Outcomes were expressed as a magnitude based factor effect for match- and training-related injury duration and injury counts. The limited data were not able to provide clear outcomes for injury risk as a function of location or travel duration. A trend towards an increased incidence in match-related non-contact soft tissue injuries post long-haul (>5 hours) travel was observed. The effect of travel duration and location on injury risk could not be confirmed. However further data collection and analysis may provide clearer answers regarding the impact of travel on injury risk.

Introduction

International travel is a frequent occurrence in the life of a professional athlete, with travel across more than two trans-meridian time zones causing well known physiological effects on the human body, commonly termed ‘jet-lag’. As a general rule, the resynchronization of the body to travel takes 1 – 1.5 days for each time zone crossed, with shorter periods required for westward travel compared to eastward.[85] The alteration of circadian rhythms with trans-meridian travel has led to a reversal in performance with an improvement in the mornings rather than the evenings[86] whilst the direction and duration of travel may be an influential factor in team performance.[36,38,42] Travelling teams and athletes approach this challenge in different ways with protocols around sleep, the use of medications including Melatonin[87,88] and caffeine,[89] light exposure, meal structure and training all having varying degrees of success in the literature.[3,35,90,91] With reduced task performance from 'jet lag' related to fatigue, reduced reaction times, reduced concentration and impairment in fine motor skills, scheduling and structure of training sessions are of critical importance to reduce injury risk.[25,92] The logical lowering of exercise intensity and duration in this situation seems prudent but there are no reliable studies supporting this as a prophylactic measure of injury risk reduction.[91] Moreover the impact of travel on non-contact soft tissue injury incidence is absent in the existing literature, with indirect inferences extrapolated from studies in occupational settings, where there is an increased risk of accidents from sleep deprivation and shift working.[2,4,34]

The Super Rugby competition, involving teams from New Zealand, Australia and South Africa, is unique in that travel across multiple time zones is required as part of the regular season competition and potentially in the post-season play-offs. In line with a previously published study,[93] we analyse data from one New Zealand based team to examine the association between long-haul (>5 time zones) and short-haul (<5 time zones) travel, as well as location, on injury risk.

Aim

The aim of this study is to analyse location and time zone change as independent factors of travel against injury.

Methods

This observational study is an extension of the epidemiological injury data collected over five seasons (2006 – 2010) from one professional New Zealand rugby union franchise. Daily training load and injury data were collected from all 28 full-time contracted players for each season over the five seasons studied. Injury data was divided into contact or non-contact injuries depending upon mechanism and either match or training-related. Ethical approval was granted by the Northern Y Regional Ethics Committee branch of the Health and Disability Ethics Committee of New Zealand (Appendix 5) and the Auckland University of Technology Ethics Committee (AUTEC) (Appendix 4).

Participants

Twenty eight professional rugby union players were involved in this study each year over the five rugby seasons studied (i.e. contracted full-time for the study period within each season), giving a total of 140 player seasons. The age, height, body mass and years of Super Rugby experience over the five years were 24.9 ±3.0 y, 1.86 ±0.07 m, 103 ±11 kg and 3.3 ±2.4 y respectively, with little change in between these years.

Training sessions

Weekly scheduling of training sessions was prepared one month in advance as the season progressed from pre-season to the end of competition. Each player participated in three to four on-field training sessions per week (unit specific sessions and team training sessions) and two to four strength and conditioning sessions per week (gym based weight sessions and on field conditioning sessions). Training load and injury data were collected for each session.

Measurement of loads for training and matches

The intensity of training sessions was calculated using the modified rating of perceived exertion (RPE) scale[72] with ratings elicited from a random sample of ten players at the end of each session to reflect overall team intensity. RPE is a physiologically valid method for exercise intensity estimation[73,74] with correlations of 0.89 and 0.86 with training heart rate and training blood lactate concentrations[20] and training intensity in contact sports.[75]

Training load was quantified by multiplying the RPE by the duration of the training session (which varied from 30 – 90 minutes per session) and then reported in intensity-minutes, a technique analogous to that used by Gabbett.[1] For non-zero in-season training days, actual loads ranged from 60 – 1100 intensity-minutes and session intensity from 1 – 8 depending on the year, with a mean in-season actual daily training load over the five years of 411 intensity-minutes and training session intensity of 5.4. Training loads for backs and forwards were averaged as differences between these groups were trivial. All matches were assigned an RPE of 9 (based on strength and conditioning staff opinion and individual player survey post-match) with match duration of 80 minutes, contributing 40% additional load to the average weekly training load.

Definition of injury

Injury was defined as “any injury sustained during a Super 14 campaign that prevented a player from taking full part in all training activities planned for that day and/or match play for more than one day following the day of injury”. For example, if a player had been injured in a match on Saturday and was not able to take part fully in training on Monday then this was recorded as an injury. This injury definition is consistent with the “time-loss” injury definition described by Fuller et al.[5] who in 2007, as part of the Rugby Injury Consensus Group convened by International Rugby Board (IRB), published injury definition guidelines adopted and modified from soccer. Injuries were coded to record severity (measured as duration: mild 0-7 days; moderate 8-28 days; severe >28 days), mechanisms of injury (e.g. contact (with another player or object) or non-contact) and where the injury occurred (match or training).

Statistical analyses

The original dataset consisted of an observation for each injury sustained on each training and match day over five years, with variables representing duration of the injury, duration and intensity of training or match play and number of players taking part in the training or match. Days without injury were included as a single observation with zero injury duration. To account for players not involved in training or the match, training and match loads were adjusted by a factor (squad size – number unavailable for training or match)/squad size. Players were considered unavailable for training during the first 25% of the injury duration.

Injury incidence expressed as counts of injuries, duration of injuries or sum of duration of injuries occurring on a given training or match day were analysed with the Statistical Analysis System (Version 9.2, SAS Institute, Cary NC) using a generalized mixed linear model (Proc Glimmix) procedure to specify a Poisson distribution against covariates of location or travel duration. The analyses were performed with a log link to estimate effects as factors. An over-dispersion factor was included to account for interdependence of injuries occurring on the same day.

Outcome data are expressed as an estimation of the magnitude of effect statistic (magnitude based inference) allowing the likelihood of a mechanistic effect to be qualified with a probabilistic term (possibly trivial, likely harmful, unclear etc.).[58,81] The likelihood that an effect was substantially harmful, trivial or beneficial was given in plain-language terms using the following scale: 0-0.5%, most unlikely; 0.6-5.0%, very unlikely; 5.1-25.0%, unlikely; 25.1-75.0%, possible; 75.1-95.0%, likely; 95.1-99.5%, very likely; 99.6-100%, most likely.

Results

Analysis of training load

Table 4.1 reports the difference in cumulative daily team training loads between various match locations. Travel to and from South Africa or Western Australia (long-haul flights >5 hours duration) is typically followed by light training loads whilst domestic or Eastern Australia travel (short-haul flights <5 hours duration) do not alter training load as travel occurs on the day prior to the match. The traditional tapering of training load within a season is absorbed within these training load values.

Table 4.1: Location, match-related injuries and cumulative smoothed daily team load from 2006-2010 (mean ±SD).

Match Location	No. of Matches	No. of Injuries	Sum of Injury Duration (Days)	Individual Injury Duration (Days)	Injury Count (Number)	Cumulative Daily Team Load (Intensity-Mins)
Eastern Australia	12	23	41 ±72	21 ±50	1.9 ±1.2	283 ±76
Home	32	71	46 ±74	21 ±42	2.2 ±2.0	287 ±77
New Zealand	10	28	40 ±67	14 ±30	2.8 ±1.9	277 ±45
South Africa	10	21	31 ±29	15 ±18	2.1 ±1.3	216 ±96
Western Australia	2	7	104 ±146	30 ±57	3.5 ±4.9	241 ±98

Analysis of injury by location

Over the five seasons 150 injuries occurred in matches (Table 4.1). Training-related injuries totalled 54 over this period (data not shown) but with only five training-related injuries occurring in overseas locations the sample size was too small for comparisons. Injury risk by location was therefore limited to match-related injuries only. Half of the matches were home matches (n = 32) with a near equal distribution at the other locations apart from Western Australia (n = 2). Match-related injury data appear to indicate that Western Australia was much higher risk location but the total number of injuries was small and resulted in an over-representation of this location across all injury categories. Mechanistic based inference analysis comparing differences in match-related injuries between the different locations showed unclear results (Table 4.2).

Table 4.2: Difference between locations on match-related injury data expressed as a factor effect (using a fixed time constant of 10 days for training load).

Location	Effect (90% CI)		
	Injury Counts	Injury Duration	Sum of Injury Duration
EA* - Home*	0.87 (0.54-1.40)	0.99 (0.57-1.74)	0.88 (0.36-2.14)
EA – NZ*	0.72 (0.41-1.26)	1.36 (0.68-2.72)	0.99 (0.31-3.12)
EA – SA*	0.81 (0.44-1.49)	1.56 (0.76-3.18)	1.45 (0.41-5.13)
EA – WA*	0.51 (0.21-1.20)	0.86 (0.22-3.41)	0.42 (0.10-1.73)
Home - NZ	0.83 (0.53-1.29)	1.37 (0.77-2.46)	1.12 (0.43-2.94)
Home - SA	0.93 (0.55-1.55)	1.57 (0.84-2.94)	1.64 (0.55-4.95)
Home - WA	0.58 (0.26-1.28)	0.87 (0.23-3.27)	0.48 (0.13-1.70)
NZ - SA	1.12 (0.61-2.05)	1.14 (0.54-2.44)	1.46 (0.38-5.62)
NZ - WA	0.70 (0.30-1.64)	0.63 (0.16-2.52)	0.42 (0.10-1.86)
SA - WA	0.63 (0.26-1.49)	0.55 (0.13-2.26)	0.29 (0.06-1.34)

*EA – Eastern Australia Home – NZ based home matches SA – South Africa

NZ – New Zealand based away matches WA – Western Australia

Analysis of injury by travel duration

Over the five seasons 12 matches occurred post long-haul travel (>5hrs), with 66% of these being away games (Western Australia or South Africa), the rest home games after returning from these locations. Training-related injuries were assigned to long-haul travel if they occurred within the week post travel.

Injury counts are shown in Table 4.3 with 85% of injuries post long-haul flights occurring in matches. A marked reduction in training loads was associated with significant trans-meridian travel (216 ±96 versus 287 ±77 intensity minutes) with the total numbers of training-related injuries being small (n = 5) and consisting purely of non-contact soft tissue injuries.

Table 4.3: Injury type post long-haul travel (>5 hrs.) from 2006-2010.

	Training-related	Match-related
Non-Contact	5	12
Contact	0	16

Mechanistic based inference analysis comparing differences in training-related injuries between short and long-haul flights showed unclear results (Table 4.4).

Table 4.4: Difference between duration of travel (<5 hrs. vs >5 hrs.) on training-related injuries expressed as a factor effect (using a fixed time constant of 10 days for training load).

	Effect (90% CI)	Inference
Injury Counts		
All Injuries	1.24 (0.53 – 2.90)	unclear
Non-Contact	1.15 (0.48 – 2.71)	unclear
Injury Duration		
All Injuries	0.54 (0.15 – 1.86)	unclear
Non-Contact	0.53 (0.14 – 1.98)	unclear
Sum of Injury Duration		
All Injuries	0.81 (0.20 – 3.31)	unclear
Non-Contact	0.62 (0.15 – 2.52)	unclear

Mechanistic based inference analysis comparing differences in match-related injuries between short and long-haul flights were similar to training-related injuries above with unclear effects (Table 4.5). Possible increases in the incidence of match-related non-contact soft tissue injuries post long-haul flights existed, but due to wide confidence intervals require further data to analyse the likelihood of this trend.

Table 4.5: Difference between duration of travel (<5 hrs vs >5 hrs) on match-related injuries expressed as a factor effect (using a fixed time constant of 10 days for training load).

		Effect (90% CI)	Inference
Injury Counts			
	All Injuries	0.84 (0.53 – 1.34)	unclear
	Contact	1.07 (0.60 – 1.92)	unclear
	Non-Contact	0.53 (0.25 – 1.13)	unclear
Injury Duration			
	All Injuries	1.34 (0.78 – 2.29)	unclear
	Contact	1.53 (0.79 – 2.98)	unclear
	Non-Contact	1.11 (0.60 – 2.08)	unclear
Sum of Injury Duration			
	All Injuries	1.11 (0.45 – 2.74)	unclear
	Contact	1.53 (0.49 – 4.74)	unclear
	Non-Contact	0.50 (0.16 – 1.59)	unclear

Discussion

The paucity of specific information in the literature on travel and its potential impact on injury means that team physicians and strength and conditioning staff resort to well-studied jet-lag interventions,[3,35,87,90-92] extrapolation from occupational studies[2,4,34] and historical anecdotal strategies in structuring training loads. The reduction in mean cumulative team training load associated with significant trans-meridian travel for elite rugby union players within the team studied follows logic, leading to lower exposure for players post long-haul flights.

Whilst our data fails to clearly define long-haul travel as a risk, there are trends that may serve to stimulate further research in this area. A possible increase in the number of match-related non-contact soft tissue injuries certainly warrants continued data monitoring from within this professional rugby franchise. Whilst there is a lot of uncertainty in the data due to sample size, the trends are worth considering as injury is a potentially modifiable risk factor that can be detrimental to the individual or teams' success.[19] Possible trends from the data suggest that match-related injuries in Western Australia are more severe, resulting in a greater cost to the team, but with only two matches played in this location and the large confidence intervals that the data presents, no clear conclusions can be drawn.

There are previous studies that reflect the way in which elite players can and do adapt to the rigors of necessary travel, allowing it not to impact on performance. The lack of home field advantage in the Super 12 competition[40] could represent the lack of effect travel and playing conditions have on overall performance, whilst sleep quality and match performance in Australian Football League (AFL) players are similarly unaffected by inter-state travel.[39] The disruption of circadian rhythms after long-haul eastward travel did not impact on single 'one off' sprint ability in skeleton athletes but the timing of competition here was more conducive to a stable performance.[37] In contrast Corneya and Carron[41] have shown that the longer the visiting team had to travel to get the match location, the greater the home advantage and therefore the duration of the travel may be an influential factor.

Practical applicability

Our data unfortunately does not improve upon the sparse research in the literature concerning injuries, specifically modifiable non-contact soft tissue injuries, and the effects of travel. The lack of clear trends on injury rates evident from long-haul travel (>5 hours) appear to provide some preliminary evidence that anecdotal and historical management strategies towards the effects of long-haul travel within sporting teams does not need to change and should encourage this team to continue their practice. Future analysis should continue to monitor the trend of increased match-related non-contact soft tissue injury incidence post long-haul travel, with greater sample sizes allowing for closer scrutiny of the effects of travel on injury risk.

Conclusions

The effects of travel on performance vary between individuals. However the risk of injury due to extensive long-haul travel has not been quantified for sports, with reliance on occupational settings to determine indirect evidence of risk. Unfortunately our data does not improve upon the sparse collection of studies in the literature concerning the effect of travel on injury risk. No clear effects of travel or location on injury were evident but a possible trend of an increase in the incidence of match-related non-contact soft tissue injuries after long-haul flights (>5 hours duration) warrants further monitoring.

CHAPTER 5

DISCUSSION AND CONCLUSIONS

Rugby union is the national sport of our country, with a fanaticism fuelled by our national team (*The All Blacks*) securing the Rugby World Cup in 2011 to be the current world champions. Super Rugby, the professional arm of the game inside New Zealand, supplies players to this higher level with the Super Rugby competition recognised as one of the more gruelling rugby competitions in the world.[17] Since the inception of this competition in 1996, higher demands have been placed on players through competition expansion and re-structuring, coupled with increasing match demands such as an increase in 'ball-in-play' time, more running and more contact events.

This thesis consists of a series of chapters analysing injury and injury risk against the covariates of travel and training load, using one dataset collected over five years from one professional rugby union team competing in the Super Rugby competition. The study cohort size is small compared to previous overseas studies but is comparable to the largest published study in Super Rugby, whilst the duration of data collection over five seasons is longer than any studies in the published literature. Comparing our epidemiological data with limited previous studies from Super Rugby and a larger number of studies produced in the northern hemisphere, a difference in injury rates was observed. Higher match-related injuries were attributed to the higher match demands placed on players, whilst causation for higher training-related injuries was not as well identified. The increases seen in injury rates over time were not mirrored by increases by playing position, anatomical location or severity, with injury incidence in these areas consistent with previous studies. So whilst rugby union continues to evolve, certain injury specifics do not appear to alter and therefore preventative strategies based on previous literature should continue to be followed.

The effects of training load and travel as covariates in injury risk were additionally analysed. The acute effects of training load on injury are well established in the literature with the linear relationship between acute training load and injury risk reinforced in Chapter 3. Higher prior cumulative load leading into matches resulted in an increase in match-related contact injury risk, emphasizing the importance of tapering into a match. However the protective effect that a higher prior cumulative training load has on the risk of sustaining a training-related non-contact soft tissue injury on that day was also shown. The beneficial adaptive effects to training are presumably the reason for the reduction in soft tissue injury risk. Unfortunately the effect of travel on injury risk was not able to be proven, although a trend towards an increase in match-related non-contact soft tissue injury after long-haul flights (>5 hours) should provoke interest from other researchers in this area.

Limitations

The 2007 IRB Consensus statement on epidemiological studies in rugby union[5] provides a standard for researchers. The epidemiological portion of this thesis did not consider injury risk against all of the measures outlined in this consensus statement and additional post-2007 studies. Failure to individualize playing position meant that analysis was via positional grouping. Whilst this has been done in previous studies, aggregated positional data could misrepresent the true effects of injury risk on playing position. Similarly, lack of OSIC coding of the data meant that injury type was restricted to contact or non-contact injuries and further analysis of anatomical site by injury type was precluded.

Training load measurement met the published literature norm (defining load as a product of intensity and duration) but was not individualized, with the collection of data being a group aggregate based on subjective ratings of intensity and electronic measurement of duration from a random sample of players. Therefore the interpretation and application of the data could only be applied to the group as a whole with no individualized programming. In addition the effect of training load on injury risk failed to account for any additional features that could influence load. A value for training monotony was not collected in the dataset and any effect on injury risk was not able to be analysed, although we suggest that monotony could partially reduce the training load effect and thereby reduce overall injury risk.

The effect of travel on injury risk was not determined as the data were limited, despite being collected over five seasons. This is due to the limited number of matches within one season that occur after a long-haul flight (>5 hours) and requires the data to be collected over a substantially longer time period to validate the observed trend.

Future directions

Epidemiological studies will continue to be an important source of injury surveillance with the focus firmly on player welfare via law changes and player specific preventative strategies derived from such studies. Ongoing injury surveillance studies should be encouraged within Super Rugby, either as aggregated data or from individual teams over multiple seasons. There is uniqueness to this competition, owing to the length of time over which the competition is played and the significant travel involved, and continued surveillance studies should embrace these factors. The effect of travel on injury risk is sparse in the current literature and the Super Rugby competition provides the ideal platform to study this aspect of injury risk further. Delineation of risk by long-haul and short-haul travel would be our recommendation, to ensure consistency with existing studies from Super Rugby analyses that have used travel as a covariate.

An improvement in player tracking technology has allowed individualized monitoring leading to more accurate individualized daily training load prescription. Future studies need to be based on analysis of training and injury in individuals via GPS-based monitoring. In addition, utilizing this technology to research training specifics (training load, running speed, time periods spent in zones of speed) and apply these to variables such as playing positions will ensure players' training mirrors match-demands on a positional basis. Analysing these data using similar methodologies presented in Chapter 3 would allow training- and match-related injury risk to be calculated by playing position with the aim of reducing risk further for each position. What is not clear from our research is the extent to which the rate of change of training load modifies the effects of prior cumulative load and of actual load on injury. Gradual increases in load would presumably lead to smaller increases in injury risk, although there is evidence that monotony in training is associated with higher injury.[21,67] More research is required to address this issue.

Key findings

A higher risk of match-related and training-related injuries in professional rugby union players in the Super Rugby competition is shown compared to similar studies published in the literature. Match specific demands and competition expansion provide some of the reasons for these variations but other causal factors could exist. Higher actual training loads are associated with higher risk, whilst higher prior cumulative training load increases match-related contact injury risk, supporting a tapering effect into a match. However higher prior cumulative training load over a 10 day period has a protective effect of training-related non-contact soft tissue injury risk on a given training day. The practical implications here are to allow a gradual increase in training load within a defined period of training (periodisation) to promote adaptation to higher loads over time on an individual basis.

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EPIDEMIOLOGICAL STUDIES FROM RUGBY UNION

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Table A1.1: Epidemiological studies from rugby union.

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Targett SGR (1998)	Prospective cohort injury surveillance	N = 25 Level: professional rugby union players Seasons: 1 (1997) Where: New Zealand	1. To document injury rates in professional rugby players in the Rugby Super 12 competition – pre-season and in-competition injuries included 2. Compare results with those seen in other grades of rugby	Incidence Location Severity Mechanism Medical attention and time loss injury definition: missed 2 training sessions or missing the next match or requiring 'special' medical attention (investigations or suturing) 'Significant' if the player missed the next match Re-injury was included as a new incident of injury	Overall incidence 120/1000 player hours with significant injuries 45/1000 player hours. Significant injuries occurred in the pre-season or end half of the in-competition period Forwards had a higher overall rate but no significant difference between forwards and backs 70% injuries minor with No.8 the most frequently injured position Most frequently injured body part was the face/head (26.5%) Tackle with the commonest injury event Higher injury rates when compared with 'lower' levels of rugby	Medical attention definition results in over-representation of injury incidence No differentiation of injuries into match- or training-related *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Garraway WM Lee AJ Hutton SJ Russell EBAW MacLeod DAD (2000)	Prospective cohort injury surveillance	N = 803 (773 amateur, 30 professional) Level: all rugby players registered with Scottish Rugby Union (SRU) senior clubs in the Borders Reivers district (23), including 30 professionally contracted players Seasons: 1 (1997-98) Where: Scotland	1. To measure the frequency and nature of injuries occurring in competitive matches since professionalism was introduced in rugby union 2. To compare results from a similar population performed by the authors during amateur rugby in 1993-94	Incidence Location Severity Mechanism Time-loss injury definition: only injuries directly associated with rugby (not fitness or gym sessions)	Proportion of players injured almost doubled in this study (47%) in comparison with 1993-94 data (27%) Incidence: 29.5/1000 player hours (1993-94) increasing to 60.9/1000 player hours (1997-98) Higher rate of injury amongst professional players, occurring every 59mins of competitive play compared to amateurs (1997-98) 56% of all injuries were recurrent amongst professional players (1997-98) compared to 29% in amateurs (1997-98) and 18% (1993-94) Tackle was the commonest cause for injury (48%) Lower limb was the commonest body site injured, similar between time periods compared	Linkmen completing standard closed questionnaires for data collection, rather than team medical personnel Training injuries expressed as a percentage of total injuries but training hours not quoted Location and mechanism of injuries presented for injuries sustained in matches only *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Quarrie K Alsop J Waller A Bird Y Marshall S Chalmers D (2001)	Prospective cohort study	N = 258 Level: non-professional rugby players at club or secondary school Where: New Zealand Seasons: 1 (1993)	1. To examine the association between pre-season risk factors (anthropometric, rugby specifics, lifestyle factors, psychological wellbeing, training & physical fitness) for injury and injury incidence and total time lost in-season	Injury incidence rate (self-reported) and the proportion of the season missed because of injury	Higher grade associated with higher injury risk Pre-season injury associated with higher in-season injury risk Playing position (midfield back), age (>17 yrs), previous injury experience, years of experience (<3 yrs) & lower BMI (<23) were associated with an increase in matches missed, indicating severity of injuries. Lifestyle factors not associated with injury risk in multivariate analyses Suggestion of a U-shaped curve with respect to pre-season training load and in-season injury risk, with a protective zone postulated.	Training load calculated weekly by player self-reporting with activity defined loosely as physical strenuous activity. Phone interview to collect weekly data, relying on players recall and self-reporting for injuries, with no verification of injury by trained health professional (reporting bias) Incomplete data collection with weeks missed due to phone interview ignored & not all players completing pre-season physical assessment Only reports match-loss injuries as proportion of the season *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Bathgate A Best JP Craig G Jamieson M (2002)	Prospective cohort injury surveillance	N = 82 players (91 matches) Level: national representative rugby union players (professional and amateur) Seasons: 7 (1994-2000) Where: Australia	1. To assess injury patterns and incidence in rugby union players competing at an international level 2. To compare these patterns and rates with those seen at other levels of play 3. To identify change between pre-professional (1994-5) and professional (1996+) eras	Incidence Location Severity Mechanism Match-loss injury definition: an event that forced a player to either leave the field or miss a subsequent match Severity = number of missed matches	143 injuries – 126 from matches / 17 during training 69 injuries/1000 player hours of match play - 47/1000 (prior to professional era) - 74/1000 (professional era) Lower limb highest incidence of injuries (51.7%) but head highest body site (25.1% but most minor) Severity - upper limb were disproportionately represented (hand/finger and shoulder = 31.2%) Mechanism: tackle (58.7%) Type: soft tissue highest (55%) Time: 88% match-related (most in the 3rd quarter (40%)) 12% training-related	Elevated soft tissue injury rate as haematoma were classified as non-contact injuries (incorrect classification) Unclear if the training-related injuries were included in the incidence rate calculations as these are reported in hours of game play Time-loss injuries not recorded
Junge A Cheung K Edwards T Dvorak J (2004)	Prospective cohort injury surveillance	N = 268 (123 rugby union / 145 soccer) Level: amateur male youth aged 14-18 years Season: 1 (2001) Where: NZ	1. To compare characteristics and incidence of injuries between these groups	Incidence Location Severity Mechanism Time-loss injury definition: medical attention as any physical complaint caused in training or matches (medical attention)	Rugby players older, taller and heavier 65% injuries during matches, 20% training sessions & 15% overuse Contact injuries: 66% of injuries in rugby union, 50% in soccer Rugby union players sustained 2.7x more match-related injuries but no difference with training or overuse injuries.	Large drop-out rate (23.6%) Medical attention definition results in over-representation of injury incidence *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Best JP McIntosh AS Savage TN (2005)	Prospective cohort injury surveillance	N = 600 (20 teams) Level: professional rugby union players Tournament: 1 (Rugby World Cup (RWC) - 2003) Where: Australia	1. To study match injury patterns and incidence during RWC 2003 & to compare patterns and rates with comparative rugby union data 2. To assess differences between teams playing at different levels (finalists versus non-finalists)	Incidence Location Severity Mechanism Match-loss injury definition: an event that forced a player to either leave the field or miss a subsequent match Severity = number of missed matches	Incidence 97.9/1000 player match hours (84.7 – 111.2 CI) Location: head/neck/face injuries highest incidence but most minor (lacerations) Mechanism: tackle (41%) and contact (80%) of all injuries Timing: 38% 3rd quarter (mostly minor) with 43% of severe injuries occurring in the 2nd quarter Significant rate ratio increase for non-finalist teams (1.35) compared to finals teams	No anthropometric data available No differentiation into forwards or backs No report on training-related injuries *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Brooks JHM Fuller CW Kemp SPT Reddin DB (2005)	Prospective cohort injury surveillance	N = 546 Level: professional rugby union players Where: English Premiership (12 of 13 clubs) Seasons: 2 (2002 – 2004)	1. To provide a detailed analysis of match-related injuries in professional rugby union	Incidence Location Severity Mechanism Time-loss & match-loss injury definition	Incidence = 91/1000 player match hours and average duration of 18 days with no significant differences between forwards or backs Recurrent injuries had a longer duration (↑ severity) Location: lower limb higher incidence but severity similar between the limbs 6% of match injuries due to foul play 72% match-related injuries due to contact Lower incidence of injuries from pre-season matches & highest incidence in the 4th quarter of the match 18% squad or 7 players unavailable each week due to match-related injuries Using missed match definition, rates comparable to those reported in other contact sports.	Long term or season-ending injuries: unclear how these were recorded as part of the dataset Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Brooks, JHM Fuller, CW Kemp, SPT Reddin, DB (2005)	Prospective cohort injury surveillance	N = 502 Level: professional rugby union players Where: English Premiership (11 of 13 clubs) Seasons: 2 (2002 – 2004)	1. Provide a detailed analysis of training-related injuries in professional rugby union	Incidence Location Severity Mechanism Time-loss injury definition	Incidence = 2/1000 player training hours & average 24 days duration with no significant difference between backs and forwards Recurrent injuries had a longer duration (↑ severity) Location: lower limb higher incidence but severity similar between the limbs 57% training-related injuries due to non-contact ↑training volume mirrored an ↑injury incidence - 5% squad or 1.8 players unavailable each week	Long term or season-ending injuries: unclear how these were recorded as part of the dataset Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) Training exposure measured in number of sessions per week and duration (hrs) which varied between pre- and in-season Training volume only measured but not training load
Brooks JHM Fuller CW Kemp SPT (2005)	Prospective cohort injury surveillance	N = 53 Level: professional rugby union players Seasons: 1 Where: England	1. To assess the aetiology, incidence, severity, and causes of injuries to England rugby union players during preparation for and participation in RWC 2003	Incidence Location Severity Mechanism Time-loss injury definition Significant injury definition also adopted (=loss of at least one match) to compare with previous studies	Incidence: 218/1000 player hours (match) and 6.1/1000 player hours (training) with no significant difference between backs and forwards Severity: average 12 days for new injuries, 28 days for recurrent injuries Lower limb represented the area injured the most (60%) Tackle was the event causing the highest number of injuries	Markedly higher incidence for match- (2x) and training-related (2x) injuries than has been seen elsewhere in the literature with limited explanation for these differences

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Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Holtzhausen LJ Schwellnus MP Jakoet I Pretorius AL (2006)	Prospective cohort injury surveillance	N = 75 Level: professional rugby union players (3 Super 12 teams) Seasons: 1 (1999) Where: South Africa	1. To document the incidence, nature and risk associated with injuries during a Super 12 rugby competition	Incidence Location Severity Mechanism Medical attention and time loss injury definition: prevented a player from playing or training or that required special medical attention (radiology, medication or suturing)	Match-related injury rate 55.4/1000 player game hours Training-related injury rate 4.3/1000 training hours Overall rate (above combined) is 84/1000 player game hours Mechanism: contact (64.5%) with the tackle (40% of all injuries) Location: lower limb highest incidence Time: lowest incidence in the 1st quarter / 2nd & 3rd quarters the highest incidence	Medical attention definition results in over-representation of injury incidence Severity definition results in over-representation of severe injuries *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Studies employing 2007 IRB consensus statement[5] on epidemiological studies in Rugby Union						
Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Fuller CW Brooks JHM Cancea RJ Hall J Kemp SPT (2007)	Prospective cohort injury surveillance	N = 645 Level: professional rugby union players Seasons: 2 (2003-2005) Where: UK	1. To determine the incidence of contact events in professional rugby union matches and to assess their propensity to cause injury	IRB Consensus injury definition of time loss for match-related contact injuries Injury diagnosis recorded using OSICS coding IRB Consensus definition for severity	Average number of contact events per game = 456.8 High incidence of contact events due to the tackle (221 events/game – 33.9/1000 player hrs) and the ruck (142 events/game – 7/1000 player hrs) Player-player collision events had a greater propensity to cause injury Lineout injuries were the most severe The tackle and the scrum presented the greatest risk of injury	Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) Positional grouping of players may over-represent injuries as unequal numbers in each positional group
Headey J Brooks JHM Kemp SPT (2007)	Descriptive epidemiology study	N = 546 Level: professional rugby union players Where: English Premiership (12 of 13 clubs) Seasons: 2 (2002 – 2004)	1. To describe the incidence, severity and risk factors associated with shoulder injuries in professional rugby union.	IRB Consensus injury definition of time loss for all injuries Injury diagnosis recorded using OSICS coding IRB Consensus definition for severity	Incidence of shoulder injury lower in training (0.10/1000 player-training hours) compared to matches (8.9/1000 player-match hours) AC joint was the most common match injury Instability and dislocation were the most severe injuries, with the greatest proportion of absence (42%) and the highest recurrence rate (62%) Tackle was the commonest event in matches resulting in shoulder injury Midfield backs had the highest incidence of injury in matches but outside backs & midfield backs were most likely to sustain an injury from tackling Training-related injuries were less severe with defensive training sessions carrying the highest risk.	Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) Positional grouping of players may over-represent injuries as unequal numbers in each positional group

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Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Kaplan KM Goodwillie A Strauss EJ Rosen JE (2008)	Review article Search criteria: PubMed search for prospective epidemiological studies in professional rugby union since 1995	N = 4 studies (Targett 1998) (Noakes & Jakoet 1998) (Bathgate 2002) (Brooks 2003)	1. To review the international literature as the USA prepares for an increase in rugby-related injuries	Time-loss & match-loss injury definition	Wide range of incidence depending on the study (32-218/1000 player hours of exposure) 3 of the 4 studies showed an increase in match-related injuries compared to training Mechanism: most injuries occur in the tackle (36%-56%) No conclusive evidence for playing position and injury risk Soft tissue injuries account for >50% of all injuries Location: lower limb predominant (42%-55%)	Non-standardized definitions of injury between studies account for wide variations in results Change in match demands and laws can influence injury incidence over the individual study periods
Fuller CW Laborde F Leather RJ Molloy MG (2008)	Prospective cohort injury surveillance	N = 626 (20 teams) Level: professional rugby union players Tournament: 1 (Rugby World Cup (RWC) - 2007) Where: France	1. To determine the incidence, nature and causes of match and training injuries sustained during the IRB RWC 2007	IRB Consensus injury definition of time loss for all injuries Injury diagnosis recorded using OSICS coding IRB Consensus definition for severity	Injury incidence: 83.9/1000 player-match hours and 3.5/1000 player-training hours) Severity: average of 14.7 days for match-related injuries and 17.8 days for training-related injuries Tackle was the highest risk event with a higher proportion from being tackled rather than tackling 55.2% of injuries were assessed using single or multiple imaging techniques.	Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) Positional grouping of players may over-represent injuries as unequal numbers in each positional group

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Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Fuller CW Raftery M Redhead C Targett SGR Molloy MG (2009)	Prospective cohort injury surveillance	N = 813 (27 teams) Level: rugby union players both professional and amateur (14 teams Super Rugby / 13 teams national provincial competition in South Africa Vodacom Cup) Seasons: 1 (2008) Where: Southern Hemisphere (South Africa, New Zealand, Australia)	1. To identify the incidence, nature and causes of match injury 2. To evaluate the impact of the Experimental Law Variations (ELV's) on match injuries in these competitions	IRB Consensus injury definition of time loss for all injuries Injury diagnosis recorded using OSICS coding IRB Consensus definition for severity	493 time loss injuries &179 matches missed 96.3 injuries per 1000 playing hours (86.9 – 106.7 CI) in Super Rugby - significantly higher than Vodacom Cup - no difference when compared to RWC 2007 & UK Premiership injury rates Increase injury severity in Vodacom Cup compared to Super Rugby (median 12 days, mean 21.4 days) No significant difference in the nature or the mechanism of injury between Super Rugby and Vodacom Cup Less ruck/maul injuries & higher tackle related injury in this study compared to UK Premiership ELV's had no impact on the measures of injury.	Different level of competition comparing Super Rugby with Vodacom Cup could account for higher risk seen Higher severity at the lower level of competition could be mixture of professional and amateur players at this level (mismatch) Lack of evidence for the impact of ELV's on injury risk could be due to underpowered study
Haseler CM Carmont MR England M (2010)	Prospective cohort injury surveillance	N = 210 players Level: amateur male youth rugby players from U9-U17 grade community rugby Seasons: 1 (2008-9) Where: UK	1. To determine the match injury rates occurring in community youth rugby union, identifying incidence, severity & anatomical location	IRB Consensus injury definition of time loss for all injuries IRB Consensus definition for severity	Incidence overall 24/1000 player hours (lower than professional player based studies) Injury rates and severity increased with increasing age Mechanism: tackle highest (59%) Location: no statistical difference between areas (due to lower rate in lower limb).	Type I errors in statistical analyses due to under-powering in the study Match observation to record injury and phase of play – data collection errors

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Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Fuller CW Ashton T Brooks JHM Cancea RJ Hall J Kemp SPT (2010)	Prospective cohort injury surveillance	N = 645 Level: professional rugby union players Where: English Premiership (13 clubs) Seasons: 2 (2004 – 2006)	1. To examine factors associated with tackles in rugby union matches and to assess their impact on injury risk	RR calculated by comparing the frequency of occurrence of risk factors in players injured in tackles with their frequency of occurrence in tackles not resulting in injury Risk factors measured: - playing position - impact data - tackle specifics - type of tackle IRB Consensus injury definition of time loss for injuries Injury diagnosis recorded using OSICS coding	Significant risk factors identified: - high speed going into the tackle - high impact force - contact or collision with players head/neck - midfield backs	Low inter-rater reliability tests achieved in 10/12 tackle variables
Brooks JHM Kemp SPT (2011)	Prospective cohort injury surveillance	N = 899 Level: professional rugby union players Where: English Premiership (13 clubs) Seasons: 4	1. To present match injury profile data as a function of days absence and playing position	IRB Consensus injury definition of time loss for all injuries Injury diagnosis recorded using OSICS coding IRB Consensus definition for severity	Match injuries 1307 (forwards) & 1177 (backs) Number of injuries and absence due to injuries did not differ between forwards & backs Significant differences in injury profile between different playing positions were reported although three common body locations caused a high proportion of days of absence in forwards and backs	Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection)

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Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Fuller CW Molloy MG (2011)	Prospective cohort injury surveillance	N = 941 (35 teams) Level: Under 20 international rugby union players (amateur) Competitions: 4 (2008 & 2010 U20 Junior World Cup: 2008 & 2010 Junior World Rugby Trophies) Where: Chile & Wales (2008); Argentina & Russia (2010)	1. To determine the incidence, nature and causes of match-related injuries in international U20 rugby	IRB Consensus injury definition of time loss for all injuries Injury diagnosis recorded using OSICS coding IRB Consensus definition for severity	Incidence 57.2/1000 player match hours Severity: mean 22.4 days, median 6 days Tackle caused the highest number of injuries (45.1%) Lower limb the commonest body site injured No significant differences in injuries sustained between forwards and backs Overall risk lower than reported in higher levels of play but the type and mechanism of injury were similar	Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) No reporting of training-related injuries
Fuller CW Sheerin K Targett S (2012)	Prospective cohort injury surveillance	N = 615 (20 teams) Level: professional rugby union players Tournament: 1 (Rugby World Cup (RWC) - 2011) Where: New Zealand	1. To determine the frequency & nature of training and match injuries sustained during the IRB 2011 Rugby World Cup. 2. To report on anthropometric characteristics of the players. 3. To compare results with those obtained at RWC 2007.	IRB Consensus injury definition of time loss for all injuries Injury diagnosis recorded using OSICS coding IRB Consensus definition for severity	Results from IRB RWC 2011 were similar to those reported for RWC 2007 Injury incidence: 89.1/1000 player-match hours and 2.2/1000 player-training hours (lower for backs though compared to RWC 2007) Severity: mean higher than RWC 2007 due to a small number of knee and shoulder injuries but the median severities were similar. Severity distribution unchanged Inside backs and back row forwards were highest risk positions 49.3% of injuries were assessed using single or multiple imaging techniques No statistically significant difference in anthropometric measurements between 2007 & 2011 RWC.	Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) *Continued next page*

Table A1.1: Epidemiological studies from rugby union (*continued*).

Authors	Design	Results	Limitations
Brooks JHM Kemp SPT (2008)	Review article Search criteria: not specified	1. Professionalism has resulted in an increase in ball in play time (↑19%), increase in the number of tackles (↑51%) and rucks (↑63%) per match. 2. Match injuries contribute 80-90% of rugby-related injuries, with higher incidence as age and competitive level of play rise. Lower limb is the most common injury location (41-55%) whilst upper limb injuries appear to be disproportionately severe esp. shoulder injuries. Larger cohort studies show no difference in incidence between backs and forwards, whilst individual playing position varies depending on study. Contact or collision events account for the majority of injuries with the tackle the most prominent mechanism (50%). 3. Training injuries contribute 10-20% of rugby-related injuries and are more severe, resulting in greater time loss. The lower limb is still the highest injury location with a greater proportion than matches (strains, sprains) presumably due to the increased running in training sessions. The type of training activity dictates the injury risk, location and severity.	Non-standardized definitions of injury measure account for wide variations in results between studies
Holtzhausen LJ (2001)	Review article Search criteria: the only 3 studies of injury in professional rugby union to date (Targett 1998) (Garraway et al. 2000) (Holtzhausen et al. – unpublished at that time)	1. Mean incidence of all recorded injuries in professional rugby is 86.4/1000 player game hours (range 67.8 – 150). 2. The highest injury rates were in the lower limb, particularly to the knee and the ankle, and these were mainly ligament sprains (25.8%) and musculo-tendinous tears (24.2%). 3. The tackle was the most frequent cause of injury. 4. There were no significant trends in the proportion of injury episodes according to player position.	Differences in study design, method of data collection and study population between the three studies reviewed so direct comparisons incompatible
Kemp SPT Brooks JHM Fuller CW	Seasonal Report 2009-10 English Rugby Premiership Injury Report and Training Audit	1. Average of 1.6 injuries per club per match. 2. Match Injury: 80/1000 hours. Training Injury: 2.1/1000 hours. Since the beginning of the study in 2002 the likelihood of sustaining a match injury varies between 75 - 100 injuries per 1000 hours. 3. Training soft tissue injuries remain high and unchanged over the study period - due to conditioning non weights sessions / strength and conditioning sessions / rugby skills training. 4. Greatest proportion of match injuries still sustained in the 3rd quarter. 5. Injury distribution in season remains relatively constant throughout the whole season.	Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection)

APPENDIX 2

SUMMARY OF STUDIES ASSESSING INJURY RISK AS A FUNCTION OF LOAD IN CONTACT RUNNING TEAM SPORTS

Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports.

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Brooks, John HM Fuller, Colin W Kemp, Simon PT Reddin, DB (2008)	Prospective cohort injury surveillance	N = 502 Level: professional rugby union players Seasons: 2 (2002 – 2004) Where: English Premiership (11 of 13 clubs)	1. Higher training volumes lead to a higher incidence in match injuries. 2. Players undertaking higher volumes of training would lead to a higher incidence of non-contact injuries in the 2nd half of matches. 3. Teams that finished the season in a higher league table position achieved this by exposing players' to higher volumes of training.	IRB Consensus injury definition of time loss for all match- and training-related injuries Weekly quintiles of training volume (measured in hours) Match exposure data	3 hypotheses not supported Incidence and severity of training-related injuries did not vary significantly according to weekly volume Higher training volume (>9.1 hrs) per week resulted in: A. higher average severity of match-related injuries B. higher average severity of match-related injuries in 2nd half of matches Intermediate training volumes (6.2-9.1hrs) produced lowest number and severity of match-related injuries	Intensity not measured in this study (RPE) so no calculation of training load Reasons for these results not well supported with evidence (e.g. fatigue)
Brooks, JHM Fuller, CW Kemp, SPT Reddin, DB (2006)	Prospective cohort injury surveillance	N = 546 Level: professional rugby union players Seasons: 2 (2002 – 2004) Where: English Premiership (12 of 13 clubs)	1. Define incidence, severity and risk factors associated with hamstring injuries. 2. Determine if stretching or strengthening altered risk of hamstring injury.	IRB Consensus injury definition of time loss for all match-related hamstring injuries Location, severity and mechanism of injury Weekly quintiles of training volume (measured in hours)	Increase in training volume in the preceding week increased likelihood of sustaining minor hamstring injury in a match Very high volumes (>12.5hrs) of training in the preceding week significantly increased risk of major hamstring injury in a match Risk lower in stretching, strengthening and Nordic drops group	No randomization to intervention with preventative strategies & unclear numbers in each intervention Intensity not measured in this study (RPE) so no calculation of training load High hamstring injury rates could be due to other factors not considered here No reasons given for the proposed association between higher load and hamstring injury risk in matches

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Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Brooks, JHM Fuller, CW Kemp, SPT Reddin, DB (2005)	Prospective cohort injury surveillance	N = 502 Level: professional rugby union players Seasons: 2 (2002 – 2004) Where: English Premiership (11 of 13 clubs)	1. Provide a detailed analysis of training-related injuries in professional rugby union.	Incidence Location Severity Mechanism Time-loss injury definition	Incidence = 2/1000 player training hours & average 24d duration with no significant difference between backs and forwards Recurrent injuries had a longer duration (↑ severity) Location: lower limb higher incidence but severity distributed between the limbs (knee / shoulder / wrist) 57% training-related injuries due to non-contact ↑training volume mirrored an ↑injury incidence - 5% squad or 1.8 players unavailable each week due to training-related injuries	Long term or season-ending injuries: unclear how these were recorded as part of the dataset Relies on accurate and complete reporting of all injuries from team medical personnel (independent data collection) Training exposure measured in number of sessions per week and duration (hrs) which varied between pre- and in-season Training volume only measured but not training load
Gabbett T (2004)	Prospective cohort injury surveillance	N = 79 Level: semi-professional rugby league players Seasons: 1 (2001) Where: Brisbane, Australia	1. To examine the influence of weekly training and match intensity, duration and load on the incidence of injury. Duration = time Intensity = RPE Load = Duration x Intensity.	Medical attention injury definition	Injury rates: training = 105.9/1000 training hrs / match = 971.3/1000 playing hrs Seasonal variation with greater training-related injuries in the 1st half and vice versa for match-related injuries. Match-related injuries increased with load and level of play. But training-related injuries were higher in 1st Grade where there was a lower training load. As intensity increased in training or matches, there was a corresponding increase in injuries.	Not all participants exposed to the same training conditions as players spread across 3 semi-professional teams (N=57) with the remainder in an affiliated amateur 'feeder' team (N=22). Match load varied between teams; 'non-training' load that could have contributed to load on the day not considered. Training-related injuries increased with a reduction in training load unexplained. Medical attention injury definition over-represents injury incidence.

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Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Gabbett, Tim J Jenkins, David G (2011)	Prospective cohort injury surveillance	N = 79 Level: professional rugby-league players Seasons: 4 (2007-10) Where: Brisbane, Australia	1. To investigate the relationship between weekly training load and injury Duration = time Intensity = RPE Load = Duration x Intensity	Medical attention and time loss (training and matches) injury definition Training load measured weekly with average weekly intensity	Rate of training-related injuries 10.5 / 1000 training hrs (non-contact > contact > S&C sessions) - time loss training: non-contact 9.6 / 1000 hrs > contact 3.6 > S&C 1.5 - time loss match: similar trends: non-contact 2.6 > contact 1.0 > S&C A significant relationship between training load and on-field non-contact & contact injuries, with similar findings for S&C sessions. Strength and conditioning training is an indirect risk factor for on-field training related injuries Higher weekly training load, higher chance of a training-related injury	Weekly training load measurements is a combination of acute loads (on the day of the injury) and cumulative load (prior to the day of the injury) Random allocation of training load to only the week prior to the match but does not include the prior match
Quarrie K Alsop J Waller A Bird Y Marshall S Chalmers D (2001)	Prospective cohort injury surveillance	N = 258 Level: non-professional rugby players at club or secondary school Seasons: 1 (1993) Where: New Zealand	1. To examine the association between pre-season risk factors (anthropometric, rugby specifics, lifestyle factors, psychological wellbeing, training & physical fitness) for injury and injury incidence and total time lost in-season.	Injury incidence rate (self-reported) and the proportion of the season missed because of injury	Higher grade associated with higher injury risk; Pre-season injury associated with higher in-season injury risk. Playing position (midfield back), age (>17yrs), previous injury experience, years of experience (<3yrs) & lower BMI (<23) were associated with an increase in matches missed, indicating severity of injuries. Lifestyle factors not associated with injury risk in multivariate analyses. Suggestion of a U-shaped curve with respect to pre-season training load and in-season injury risk, with a protective zone postulated.	Training load calculated weekly by player self-reporting with activity defined loosely as physical strenuous activity; Phone interview to collect weekly data. Players self-reported injuries with no verification of injury by trained health professional (reporting bias). Incomplete data collection with weeks missed & not all players completing pre-season physical assessment. Only reports match-loss injuries as proportion of the season

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Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Lee AJ Garraway WM Arneil DW (2001)	Prospective cohort injury surveillance	N = 803 Level: mixture of professional (4%) and non-professional (96%) rugby union players Seasons: 1 (1997-98) Where: Scotland, senior rugby union clubs in the Borders Reivers district	1. To examine the influence of pre-season training, fitness and existing injury on injury risk. 2. To measure injury against pre-season fitness variables by multivariate analyses.	Time-loss injury definition for training- and match-related injuries	180% relative increase in risk of injury for contracted players Players who attended more pre-season training sessions were at greater risk of in-season injury (reason for this not known) Players carrying injuries into the pre-season period or injured in the pre-season period were more at risk of an in-season injury	Survey questionnaire or phone interview to obtain pre-season training information, previous injuries and current status (reporting and data collection bias) No verification of injuries by health professional Small numbers of professional players so comparisons between groups unreliable
Gabbett TJ Domrow N (2007)	Prospective cohort injury surveillance	N = 183 Level: semi-professional rugby league players Seasons: 2 Where: Gold Coast, Australia	1. To develop statistical predictive models that estimate the influence of training load on training injury and physical fitness.	Training load measured weekly & well defined as RPE x Duration of session, with structured sessions delivered by trained S&C staff (robust) Medical attention injury definition	Injury incidence higher in the pre-season (137.7/1000 hrs.) compared to early competition (76/1000) and late competition (62.6/1000) periods Two models: 1. For the individual - injury odds risk increases with increase in training load per week 2. For the team – training injuries increase two-fold with increase in training load in pre-season but not evident in early or late competition, suggesting that the pre-season injuries are unavoidable	Discrepancy between individual risk increase with increasing load not seen in team model (Model 2) but this is not well explained. Semi-professional athletes who entered pre-season in poorer condition and therefore could be an additional reason for higher pre-season injury rates Training only 2x per week and is not reflective of elite athletes Injury definition results in over-representation of injury incidence

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Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Piggott Ben Newton Michael J McGuigan Michael R (2009)	Longitudinal research design cohort	N = 16 Level: professional Australian Football League (AFL) players Seasons: 1 (2007) Where: Australia	1. To investigate the relationship between pre-season training load and the incidence of injury and illness.	Weekly Training Load = Intensity (RPE) x Duration + training monotony & training strain Injury and illness defined as time-loss occurrences	Injury and illness associated with preceding spike (>10%) increase in training load, but not immediate load Low monotony = high degree of variation in training load is associated with a lower risk of injury	Small study in only 16 players limited to 15 weeks pre-season Only 5 GPS Units were available for measuring distance across 16 players Study bias in that players found to be 'at risk' of soft tissue injury via daily screening had altered training during the study period Tenuous explanations for additional training spikes not causing reported outcome effects
Killen Natasha M Gabbett Tim J Jenkins David G (2010)	Prospective experimental design	N = 36 Level: professional rugby league players Seasons: 1 Where: Australia	1. To examine the relationship between training load, monotony and strain, physical status, psychological parameters and injury incidence in a 14 week pre-season period.	Weekly Training Load = Intensity (RPE) x Duration Medical attention injury definition Physical and psychological well-being: aggregated team data collated 2 x per week	Total of 20 injuries in the pre-season (6.9/1000 training hrs), with 60% being minor and not resulting in time loss No significant relationship between overall pre-season weekly training load, strain, monotony or psychological data and injury rate 1st half pre-season training load was higher and associated with higher injury rate compared to the 2nd half of the pre-season	Sessions varied in duration as did the numbers of players attending (range from 11 – 36) with the actual not stated Lower than expected pre-season training loads compared to other studies (2800 Units) subjecting players to less risk Short duration and low number of subjects may have contributed to the failure of this study to prove their hypotheses Wide confidence intervals limits conclusive outcomes

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Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Buttifant D Berry J Ullah S Finch CF (2011)	Prospective cohort injury surveillance	N = 64 1st yrs 58 3+ yrs. Level: professional Australian Football League (AFL) players from 9 of 16 clubs Seasons: 1 (2009) Where: Australia	1. To measure the training and match loads in 1st year AFL football players to determine the relationship between load & injury risk. To compare these to mature 3+ years AFL football players.	Abstract only so specifics not available	1st yr players had a significantly higher injury incidence and prevalence compared to 3+ yr players (4.3x missed matches & 2.6x missed training sessions) 1st yr players were 14.3x more likely to be unavailable for matches compared to other available players	Abstract only so specifics not available
Gabbett Tim J (2010)	Prospective cohort comparative injury surveillance	N = 91 (154 player seasons) Level: professional rugby-league players Seasons: 4 (2006-9) Where: Australia	1. To develop an injury prediction model for non-contact soft tissue injuries in elite collision sport athletes. 2 phases: 1st – prospective training load and injury data over 2 seasons modeled to determine relationship 2nd – as above for next 2 seasons with development of injury prediction model based on planned and actual training loads	Weekly Training Load = Intensity (RPE) x Duration Time-loss injury definition for non-contact soft tissue injuries sustained in training or matches	Phase 1: training load and injury risk determined, with these levels used in planning loads for the next 2 seasons Phase 2: players were at higher risk of non-contact soft tissue injury if actual training loads exceeded planned loads. Injury prediction model developed with threshold reference ranges for ‘safe’ training loads depending on time of the season (pre-season, early or late competition) - sensitivity 87% - specificity 98% - PPV 62%	Players training was modified if thought to be at risk so only those with actual training loads > planned loads contributed to injury prevalence(outcome bias) More suitable to non-contact running sports Training load is not the only risk factor for non-contact soft tissue injury and these covariates are not addressed in the statistical analyses (age, past history of injury)

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Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Gabbett TJ (2004)	Prospective observational study	N = 220 Level: semi-professional rugby league players Seasons: 3 (2001-3) Where: Australia	1. To examine whether reductions in pre-season training loads reduced the incidence of training injuries, without compromising physical fitness. Over 3 pre-seasons with load altering in 2nd and 3rd seasons through alteration in training duration or intensity.	Weekly Training Load = Intensity (RPE) x Duration Medical attention injury definition	Reduction in training load either by a reduction in duration or intensity resulted in significantly lower injury risks in the pre-season period 156.7/1000hrs 2001 94.4/1000hrs 2002 78.4/1000hrs 2003 No detrimental effects on physical fitness with load reductions, with high probability of improvement in the 2002/3 pre-seasons	Injury incidence over-stated due to the injury definition Training twice per week & not reflective of elite athletes training Applicability of this study in elite athletes limited as overtraining and inadequate recovery were contributing factors in this cohort Not able to control for additional load outside of this environment caused by player's work or extra training etc. Covariates to injury risk not controlled for with regards to age, playing experience or previous injury (NB – older group in 2001)
Gabbett Tim J UllahShahid (2012)	Prospective cohort injury surveillance	N = 34 Level: professional rugby league players Seasons: 1 Where: Australia	1. To determine the running loads in elite team sport players & to explore the relationship between low intensity vs. high intensity activities on non-contact soft tissue injury risk.	GPS tracking systems validated to record speed, duration and distance covered Medical attention injury definition for only non-contact soft tissue injuries - separate into time loss from training or match or no time loss injuries	Injury rates: - no time loss 37.4/1000 hrs - time loss 42.1/1000 hrs - match loss 13.1/1000hrs Higher injury rates with the following: - increasing speed (sprinting) - high speed running >9m Lower injury rates with the following: - distances covered in low, very low or moderate intensity	Data limited to one season No session intensity measurement for contact sports (tackles, collisions) which is important for energy utilization and fatigue causing non-contact soft tissue injuries

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Table A2.1: Summary of studies assessing injury risk as a function of load in contact running team sports (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Rogalski B Dawson B Heasman J Gabbett TJ (2013)	Prospective cohort injury surveillance	N = 46 Level: professional Australian Football League (AFL) players from one club Seasons: 1 Where: Australia	1. To examine the relationship between training and game loads and injury risk across an entire season, in particular cumulative prior weekly loads and change between weekly loads.	Weekly individual load = training + game load (sum) Load calculated as duration x intensity (RPE) for each individual Time-loss injury definition from training sessions or games, or modified training Injury analysed against prior accumulation of load over 1 – 4 weeks & against a large increment in load between weeks	Higher weekly loads (odds ratio 2.44 increasing to 3.38 as load increased) and higher cumulative load over 2 weeks increased risk of injury (odds ratio 1.00 increasing to 4.74 as load increased) Change in the weekly load (>1250AU = 6x greater than the reference group) resulted in a higher injury risk (odds ratio = 2.58) Lower risk in players with 2-3 years or 4-6 years' experience	Prior load not decayed with the effect of the prior load assumed to exert the same influence on the injury risk regardless of time Confounding factors on outcomes: 1. not reporting injuries as either contact or non-contact soft-tissue injuries may hide effects 2. prior load reflects actual load in that the higher the actual load the higher the prior load

APPENDIX 3

SUMMARY OF STUDIES ASSESSING THE EFFECT OF AIRLINE TRAVEL AND SLEEP DEPRIVATION ON PERFORMANCE

Table A3.1: Summary of studies assessing the effects of airline travel and sleep deprivation on performance.

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Manfredini R Manfredini F Conconi F (2000)	Prospective cohort clinical trial	N = 12 Level: elite bi-athletes (8 men, 4 women)	1. To measure body temperature in establishing the effectiveness of standard dose Melatonin in rhythm resynchronization after trans-meridian travel in eastward direction.	Body temperature measured 8 times daily on 1st day (Day 1) and last day (Day 6) Subjective questionnaire daily on sleep quality & undesired effects Dosage: 5mg in men, 3mg in women daily post flight (Melatonin)	Melatonin administration had varying effects depending on gender - in males this facilitated a phase shift of peak body temperature to the afternoon - in females there was no resynchronization effect of body temperature	Control for additional factors that could aid resynchronization not stated e.g. light exposure, training regimen on arrival Results could be a function of dosing differences
Philbert I (2005)	Meta-analysis Selection Criteria: 1. assessed the effect of sleep loss on cognitive function, memory, vigilance or clinical performance 2. adults >19yrs 3. provided the number of hours participants went without sleep 4. reported data that could be transformed to measure the size of effect	N = 60 studies - 959 resident physicians (20 studies) - 1028 non-physicians (40 studies)	1. The measure the effect of sleep loss on cognitive performance.	Cognitive performance and performance on clinical tasks under acute and partial chronic sleep deprivation (<5-6 hrs of sleep for a period of several nights)	Acute and partial chronic sleep loss had largest effect on vigilance and clinical performance Sleep loss of 24 - <30 hrs had the 2nd largest effect (loss reflective of 'real world') Sleep loss >54 hrs had the largest effect Non-physician participants had a larger reduction in performance	Meta-analyses by definition are not able to include all studies because of exclusion factors (data, technical, reporting) Small number of non-published studies included and therefore a bias towards studies showing significant findings *Continued next page*

Table A3.1: Summary of studies assessing the effects of airline travel and sleep deprivation on performance (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Morton H (2006)	Retrospective analysis	N = 375 Level: professional rugby union Seasons:5 (2000-4) Where: full-time scores by both sides in all the Super 12 (345) and Tri-nations (30) matches	1. To present evidence & estimates of a home team advantage for professional rugby union in the southern hemisphere.	Points difference (measured as home team score - away team score) Modelled using multiple linear regression	The ability rating of a team is a far more potent indicator of performance outcome rather than 'home team advantage' in this model. Fickle nature of home-team advantage from year to year is non-significant and does not carry over from year to year. The only team with a constant home-team advantage played at altitude and this could have been the main factor in their advantage.	Not a balanced model in that not all teams play each other home and away; introduces bias in that stronger or weaker teams could have contributed to any home advantage (or lack of it). The formulae for statistical analyses is complex making it difficult for the reader to verify interpretations
Richmond LK Dawson B Stewart G Cormack S Hillman DR Eastwood PR (2007)	Prospective cohort surveillance	N = 19 Level: professional Australian Football League (AFL) players from one team Seasons: 1 (2004) Where: Australia	Sleep quality and quantity would be poorer (following interstate travel) prior to away games, compared to home games Poor sleep would correlate with poorer performance.	Sleep was measured via actigraphy, measuring sleep duration (SLD), efficiency (SLE), wake time (WT) and number of wakings (NW) & subjective sleep ratings Baseline measured for 4 consecutive non-game nights Performance measured by coach rating & impact rating scale as well as official AFL statistics	Relative to baseline sleep duration increased prior to home and away games, with no changes in other sleep variables Performance measures and subjective sleep ratings improved with home games Correlations between sleep parameters and performance were small and insignificant; No effect of interstate travel	Interstate travel is a maximum of 1.5 – 2hrs and therefore not long enough to effect 'jet lag' changes which occur >3 time zones crossed Limited sample size and limited to one season only

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Table A3.1: Summary of studies assessing the effects of airline travel and sleep deprivation on performance (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Jehue R Street D Huizenga R (1993)	Retrospective analysis	N = 27 teams Level: professional National Football League (NFL) teams Seasons: 10 (1978-1987) Where: USA	1. To determine the home field advantage within respective time zones & to assess the impact of travel and timing of games on results.	Win-loss percentages when playing against teams from the same or different time zones (home or away) - performance - travel factor	If playing a team within your time zone, a home team advantage was evident Teams travelling eastward had a performance decrement	Sample size small for the teams travelling eastwards for games
Bullock N Martin DT Ross A Rosemond D Marino FE (2007)	Prospective cohort surveillance	N = 12 (5 Australian athletes who undertook travel and 7 Canadian 'control' athletes) Level: elite skeleton athletes Where: Canada	1. To quantify the impact of long-haul eastward travel on cortisol, wellness and physical performance.	Morning salivary cortisol Liverpool John Moores University subjective jet lag questionnaire Maximal 30m sprint times	Reduction in salivary cortisol in the travel group for 48 hours compared to baseline Post-travel sprint times did not significantly alter compared to baseline Post-travel jet lag symptoms remained for 4 days based on questionnaires.	Small sample size Short duration of exercise may not 'pick up' jet lag effects Time of the one-off exercise may have correlated with optimum nadir for performance in the new time zone
Bishop D (2004)	Retrospective analysis	N = 171 (pairs of games) Level: national competition netball players Seasons: 6 (1997-2002) Where: Australia	1. To assess the influence of travel within and across time zones on netball team performance.	Pairs of games assessed so that each game acted as its own control; Analyses for points difference in home or away games, with travel as a covariate Effect size measured using a pooled standard deviation (small 0.2-0.5 / moderate 0.5 – 0.8 / large > 0.8	Large effect size on points difference for East-West travel >2hrs Moderate size effect when East-West travel >2hrs compared to East-West travel <2hrs & North-South travel Travel across time zones >2hrs had an effect on team performance	Circadian dysrythmia hypothesis not well supported with the effects of fatigue more likely due to duration of travel

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Table A3.1: Summary of studies assessing the effects of airline travel and sleep deprivation on performance (*continued*).

Author	Design	Participants	Aims / Hypotheses	Outcome Measures	Results	Limitations
Du Preez M Lambert MI (2007)	Retrospective data analysis	N = 1320 matches (12 teams) Level: Professional rugby teams Seasons: 10 (1996-2005) Where: Super 12 competition (South Africa subgroup 440 matches from 4 teams)	1. To determine whether home performances of the South African teams were different prior to or after travel in this competition.	Points margin (points for – points against) were used to measure performance Analysis of variance (ANOVA) modelling applied to determine differences between teams and performances pre and post touring	All teams showed a home advantage with improved performances as measured by positive points differences No difference between the mean home points difference for all 4 South African teams either before or after touring	Whilst the results suggest that a home team advantage exists, the direction of travel is not taken into account as travelling back to SA is in a westward direction from Australia or NZ and therefore ‘easier’ for the body to cope with a phase advance
Samuel A Weggmann HM Vejvoda M (1995)	Abstract only available	Long-haul aircrew	Abstract only available	Abstract only available	Jet lag and sleepiness were identified causes of accidents	Abstract only available

Continued next page

Table A3.1: Summary of studies assessing the effects of airline travel and sleep deprivation on performance (*continued*).

Author	Design	Results	Limitations
Samuels C (2012)	Review article	1. Pre-flight adjustments to minimize the time shift, although this may be impractical due to schedule restrictions. Advise that sleep 'banking' prior to travel to cope with sleep debt, training time modifications to the time zone you are going to if practical. 2. In-flight components: adjust watch to the destination time zone, essentials for sleep comfort, scheduling of meals to destination time zone, hydration & use of pharmacological agents to achieve sleep at destination times. 3. Post-flight components: stretches from days 2-4 and involves scheduled light therapy, light avoidance and use of Melatonin with training modifications.	
Reilly T (2009)	Review article	1. Peak performance does follow circadian rhythms and core body temperature changes, improving in the evening compared to the morning. 2. Endurance exercise though may be improved in the morning, again linking this to critical core body temperature - this is because the core temp may start lower and therefore a slower rise. 3. Age >47yrs pushes the circadian rhythm more towards the morning and although differences can be seen between morning and evening still, the gap difference is less. 4. Body is resistant to sleep deprivation, at least for brief effects in muscular performance, but not so tolerant towards tasks involving more cognitive input. But the circadian rhythm performance variations are still maintained in these instances.	Studies are limited in number Performance measures are varied between studies Lab studies may not reflect 'real world' scenarios
Reilly T Waterhouse J Edwards B (2005)	Review article	1. Health consequences of airline travel due to DVT & impairment of the immune function 2. Strategies to cope with jet-lag: behavioural strategies, pharmacological strategies & light cycle interventions	
Akerstedt T (2007)	Article review	1. Lack of sleep shown as a reduction in simple performance measures, similar to having an elevated blood alcohol level, in laboratory studies as well as night shift workers and other occupations exposed to extended working hours or those that simulate shift-work (pilots, overnight drivers, on call physicians). This reduction in performance corresponds to the circadian temperature low. Studies report work errors in the medical fraternity with night shift, an increase in accidents from the transport industry at night or from fatigue, a moderate increase in risk of accidents at night from the manufacturing industry.	Studies do not measure the individual variability in a person's response to night shift. Nor do they take into account the aspect of the job itself that may lead to 'boredom' and error.
Leatherwood WE Dragoo JL (2013)	Systematic literature review 106 studies met the inclusion criteria (initial search found 1602 records identified + 109 records from other sources)	1. Performance and jet lag: airline travel has a detrimental effect on neuromuscular control and jump performance in the first 1-2 days post travel / a decline in team performance after travel crossing multiple time zones from MLB and Australian national netball data. 2. Direction of air travel and performance: eastward bound travel produces longer and more marked jet lag symptoms as the body finds it easier to adjust to a phase delay. But the timing of the game can impact on the result despite the direction of travel. 3. Phase shifting circadian rhythms: to ensure the event falls in the peak performance hours. Strategies include blue light where a natural source is better than a commercial one, pharmacological agents & Melatonin. 4. Air travel and nutrition: particular foods/diet to enhance circadian re-adjustment.	Variation in study designs does not allow for control of confounding variables when comparing studies

APPENDIX 4

AUT ETHICS COMMITTEE APPROVAL – OCTOBER 2011

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To:Patria Hume

From:**Dr Rosemary Godbold** Executive Secretary, AUTEC

Date:11 October 2011

Subject: Ethics Application Number 11/283 **The incidence of rugby unioninjuries in a professional environment: Are we able to predict risk?**

Dear Patria

I am pleased to advise that the Chair of the Auckland University of Technology Ethics Committee (AUTEC) and I have approved your ethics application. This approval is for this case only and does not in any way constitute a precedent for future research. This delegated approval is made in accordance with section 5.3.3. of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 31 October 2011.

Your ethics application is approved for a period of three years until 10 October 2014.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 10 October 2014;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/research/research-ethics/ethics. This report is to be submitted either when the approval expires on 10 October 2014 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact me by email at ethics@aut.ac.nz or by telephone on 921 9999 at extension 6902.

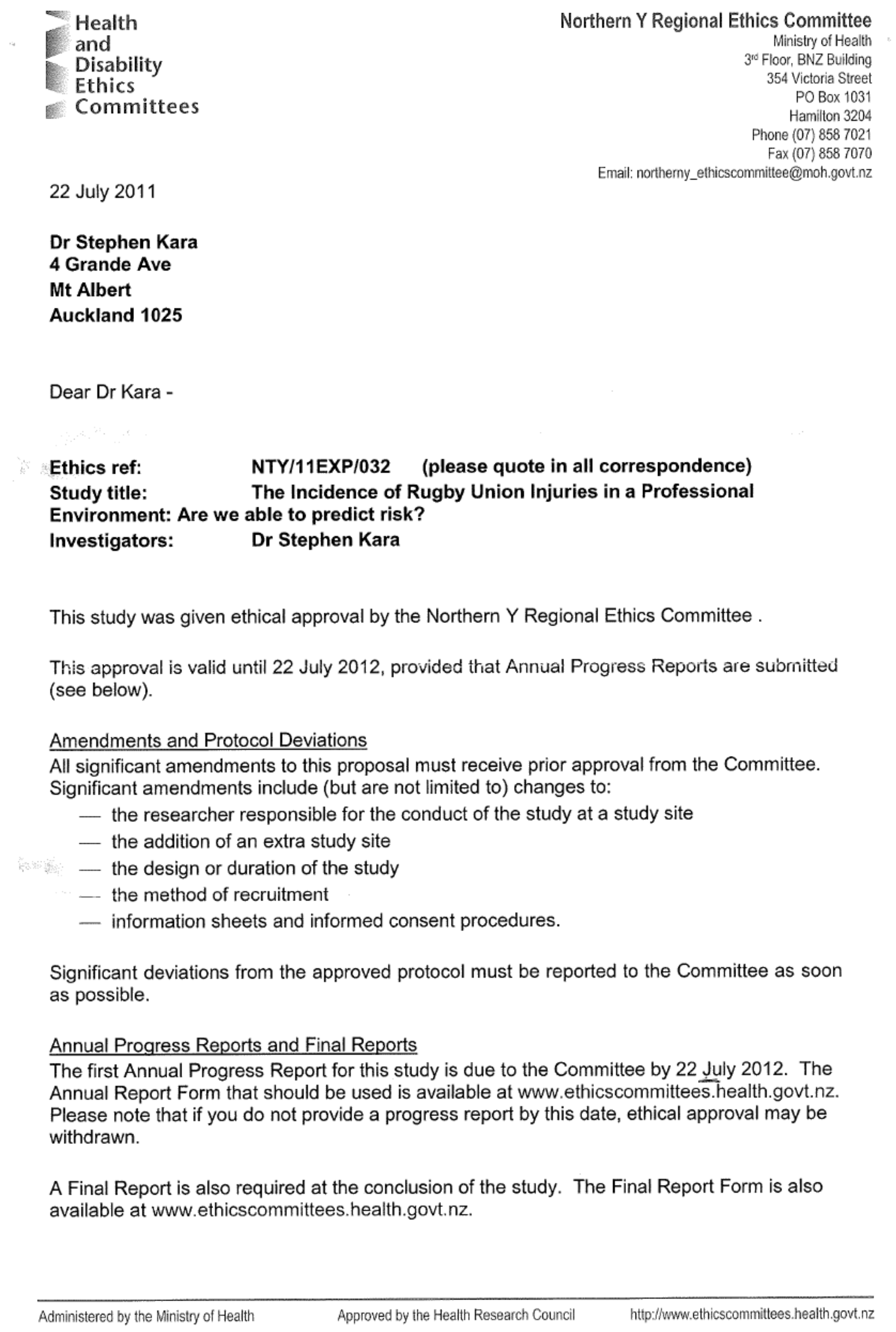
On behalf of AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Dr Rosemary Godbold
Executive Secretary
Auckland University of Technology Ethics Committee
Cc:Stephen Kara stephen.kara@theblues.co.nz

APPENDIX 5

HEALTH AND DISABILITY ETHICS COMMITTEE APPROVAL – 22 JULY 2011



Health
and
Disability
Ethics
Committees

Northern Y Regional Ethics Committee
Ministry of Health
3rd Floor, BNZ Building
354 Victoria Street
PO Box 1031
Hamilton 3204
Phone (07) 858 7021
Fax (07) 858 7070
Email: northerny_ethicscommittee@moh.govt.nz

22 July 2011

Dr Stephen Kara
4 Grande Ave
Mt Albert
Auckland 1025

Dear Dr Kara -

Ethics ref: **NTY/11EXP/032** **(please quote in all correspondence)**
Study title: **The Incidence of Rugby Union Injuries in a Professional Environment: Are we able to predict risk?**
Investigators: **Dr Stephen Kara**

This study was given ethical approval by the Northern Y Regional Ethics Committee .

This approval is valid until 22 July 2012, provided that Annual Progress Reports are submitted (see below).

Amendments and Protocol Deviations

All significant amendments to this proposal must receive prior approval from the Committee. Significant amendments include (but are not limited to) changes to:

- the researcher responsible for the conduct of the study at a study site
- the addition of an extra study site
- the design or duration of the study
- the method of recruitment
- information sheets and informed consent procedures.

Significant deviations from the approved protocol must be reported to the Committee as soon as possible.

Annual Progress Reports and Final Reports

The first Annual Progress Report for this study is due to the Committee by 22 July 2012. The Annual Report Form that should be used is available at www.ethicscommittees.health.govt.nz. Please note that if you do not provide a progress report by this date, ethical approval may be withdrawn.

A Final Report is also required at the conclusion of the study. The Final Report Form is also available at www.ethicscommittees.health.govt.nz.

Administered by the Ministry of Health Approved by the Health Research Council http://www.ethicscommittees.health.govt.nz

Statement of compliance
The committee is constituted in accordance with its Terms of Reference. It complies with the *Operational Standard for Ethics Committees* and the principles of international good clinical practice.

The committee is approved by the Health Research Council's Ethics Committee for the purposes of section 25(1)(c) of the Health Research Council Act 1990.

We wish you all the best with your study.

Yours sincerely

Amrita Kuruvilla
Administrator
Northern Y Regional Ethics Committee
Email: amrita_kuruvilla@moh.govt.nz