INJURY EPIDEMIOLOGY OF ELITE NEW ZEALAND CRICKETERS: A 2009-2015 UPDATE

Timofei Alekseevich Dovbysh

BPhty, PGDipHSc

A thesis submitted to Auckland University of Technology in partial fulfilment of the requirements for the degree of Master of Health Science

2019

Primary supervisor: Duncan Reid

Secondary supervisor: Dayle Shackel

Faculty of Health and Environmental Sciences

Table of Contents

LIST OF FIGURES .... **iv**
LIST OF TABLES .... **v**
CERTIFICATE OF AUTHORSHIP .... **vi**
ACKNOWLEDGEMENTS .... **vii**
ABSTRACT .... **ix**
Chapter 1 – Introduction **1**
1.1 Statement of the problem 1
1.2 Purpose of the study 3
1.3 Significance of the problem 4
Chapter 2 - Review of Literature **6**
Introduction 6
2.1 Injury prevention and surveillance models 6
2.1.2 Summary 12
2.2 Definitions and methods in injury surveillance 12
Introduction 12
2.2.1 Definition of injury 13
2.2.2 Broad injury definition 13
2.2.3 Narrow injury definition 18
2.2.4 Definitions of injury recovery 21
2.2.5 Definitions of recurrent injury 22
2.2.6 Injury severity 22
2.2.7 Injury diagnosis and coding 23
2.2.8 Study design 24
2.2.9 Injury rates 24
2.2.10 Injury surveillance methods in cricket 25
2.2.11 Injury surveillance in New Zealand Cricket 26
2.2.12 Summary 27
2.3 Injury epidemiology in cricket 28
2.3.1 Injury incidence in cricket 30
2.3.2 Study characteristics 31
2.3.3 Injury incidence 37
2.3.4 Injury prevalence rates 39
2.3.5 Injury prevalence per player position 39
2.3.6 Injuries per body region 40
2.3.7 Summary 40

2.4.1 Injury definitions......42
2.4.2 Body regions......43
2.4.3 Playing levels......43
2.4.4 Participant ages......44
2.4.5 Countries represented......45
2.4.6 Playing positions......45
2.4.7 Risk factors......46
2.4.8 Workload......46
2.4.9 Summary......56
Chapter 3 - Methods......57
Introduction......57
3.1 Study design......57
3.2 Participants......57
3.3 Surveillance method......58
3.4 Definitions and methods......59
3.4.1 Injury definition......59
3.4.2 Injury recovery definition......59
3.4.3 Definition of injury recurrence......60
3.4.4 Definition of surveillance cohort......60
3.4.5 Calculations of exposure rates with a time-based denominator......60
3.4.6 Calculation of match incidence with a time based denominator......61
3.4.7 Seasonal injury incidence......62
3.4.8 Annual injury incidence......63
3.4.9 Match injury prevalence......63
3.4.10 Injury incidents and match days lost......64
3.4.11 Relationship between workload and injury......64
3.4.12 Data analysis......64
Chapter 4 – Results......66
Introduction......66
4.1 Participants......66
4.2 Exposure rates......68
4.3 Match injury incidence of new and recurrent injuries per 10,000 player hours......70
4.4 Match injury incidence of new versus recurrent injuries per 10,000 player hours......71
4.5 Match injury incidence per 1,000 player days......73
4.6 Seasonal injury incidence per squad per season......75
4.7 Annual injury incidence per 100 players per year......76
4.8 Match injury prevalence rates by season......78
4.9 Match injury prevalence rates by body site......79

4.10 Injury incidents and severity by body site 81
4.11 Injury incidents and severity by body region 84
4.12 Injury incidents and severity by player position 86
4.13 Comparing injury status between domestic and international players from 2009-2015 88
4.14 Comparing injury status between player positions from 2009-2015 88
4.15 Relationship between match exposure hours and the number of injuries 89
Chapter 5 – Discussion 92
Introduction 92
5.1 Participants 92
5.2 Injury incidence 93
5.2.1 Match injury incidence rates 93
5.2.2 Seasonal injury incidence rates 98
5.2.3 Annual injury incidence rates 99
5.3 Match injury prevalence 103
5.4 Injury incidents and severity 106
5.5 Injury and playing position 108
5.6 Relationship between load and injury frequency 110
5.7 Limitations 111
5.8 Conclusion 114
5.9 Future directions 116
References 119
Appendices 126
Appendix A 126
Appendix B 128
Appendix C 129
Appendix D 135
Appendix E 136
Appendix F 137
Appendix G 139

LIST OF FIGURES

Figure 2.1 “Sequence of prevention” of sports injuries, adapted from van Mechelen et al. (1992). 7
Figure 2.2 Translating Research into Injury Prevention Practice (TRIPP) model, adapted from Finch (2006). 10
Figure 2.3 The interaction of injury definitions, adapted from Clarsen and Bahr (2014), not to scale. 15
Figure 2.4 Flow diagram of literature search for studies of injury epidemiology in cricket. 31
Figure 2.5 Flow diagram of literature search for studies of injury risk in cricket. 42
Figure 4.1 Match days played between 2009-2015. 69
Figure 4.2 Team exposure hours per match format per season. 69
Figure 4.3 Match injury incidence of new and recurrent match injuries per 10,000 player hours per format per season. 71
Figure 4.4 Match injury incidence of new (excluding recurrent) injuries per 10,000 player hours per format per season. 72
Figure 4.5 Match injury incidence of recurrent injuries per 10,000 player hours per season. 73
Figure 4.6 Match injury incidence of new and recurrent match injuries per 1,000 player days. 74
Figure 4.7 Seasonal injury incidence per squad per season. 75
Figure 4.8 Injury prevalence rates (%) by season. 78
Figure 4.9 Number of new match injuries, recurring injuries, and training injuries from 2009 to 2015 by body site in domestic and international cricket. 82
Figure 4.10 Match days lost due to new match injuries, recurring injuries, and training injures from 2009 to 2015 by body site in domestic and international cricket. 83
Figure 4.11 Number of new match injuries, recurring injuries, and training injuries by player position. 87
Figure 4.12 Number of match days lost to new match injuries, recurring injuries, and training injuries by player position. 87
Figure 4.13 Graph of domestic competition match exposure hours with number of injuries from 2009-2015. 89
Figure 4.14 Graph of international competition match exposure hours with number of injuries from 2009-2015. 90
Figure 5.1 Comparing match injury incidence per 1,000 players days between New Zealand and Australia from 2009-2015. 97
Figure 5.2 Comparing highest annual injury incidence rates per 100 players per year by body site between New Zealand (total) and Australia (average) from 2009-2015. 101

LIST OF TABLES

Table 2.1 Possible surveillance system injury definitions, adapted from Orchard, Ranson, et al. (2016) ... 21
Table 2.2 Comparison of 2016 and 2005 injury rate reporting standards in cricket ... 29
Table 2.3 Summary of epidemiological studies retrieved from literature search ... 33
Table 2.4 Summary of studies investigating workload as a risk factor for injury in cricket ... 48
Table 3.1 Exposure rates for cricket match formats ... 61
Table 4.1 Participant characteristics ... 67
Table 4.2 Annual incidence of new and recurrent injuries per 100 players ... 77
Table 4.3 Injury prevalence rates (%) by body site and season ... 80
Table 4.4 Number of new match injuries, recurring injuries, and training injuries (% total) by body region ... 85
Table 4.5 Number of match days lost to new match injuries, recurring injuries, and training injuries (% total) by body region ... 85
Table 4.6 Injury status of players by playing level ... 88
Table 4.7 Injury status of players by playing position ... 88

CERTIFICATE 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 (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning."

Student: Timofei Dovbysh

Signature:

ACKNOWLEDGEMENTS

I would like to thank my wife Stephanie who has given me endless patience, encouragement, and freedom to complete this project. Without your support I would not be able to work in the environments that I do. I am looking forward to repaying all the lost family time and even have a holiday without bringing my laptop.

Thank you to all my friends and colleagues who have had to endure my erratic work hours and deadline extensions.

I would like to acknowledge the AUT Scholarship Office for their financial support, awarding a Postgraduate Fees Scholarship (Health and Environmental Sciences) for this project.

Thank you to Sandra Kingi for collating the New Zealand Cricket injury surveillance system into a format I could use, and to Priya Parmar for help and insight with the statistical analysis.

A final thanks to my supervisors Duncan Reid and Dayle Shackel, who started this project and continued to support it through its challenges. Your guidance and insight were instrumental in completing this project. It was a privilege to work with leaders of our profession.

The Auckland University of Technology Ethics Committee (AUTEC) granted ethical approval for this research on 27 April 2016. Ethics Application Number 16/121 (see Appendix A).

ABSTRACT

Introduction: Cricket played in New Zealand at international and domestic level has increased in recent time as well as growth of the new Twenty20 match format. Increasing and variable workloads are known to influence the risk of injury in sport. Understanding the impact of injury is necessary to develop appropriate injury prevention measures. An update of the injury incidence and prevalence rates in New Zealand cricketers is required to establish the current impact of injury and direct future interventions.

Purpose: To determine the injury incidence and prevalence rates of elite New Zealand cricketers from 2009-2015 and investigate the relationship between injury and the level of cricket played, playing position, and workload.

Methods: New Zealand Cricket maintains an injury surveillance system to prospectively record injury status in domestic and international cricketers. The injury status of 873 domestic cricketers (mean age 28.2, SD = 4.6), and 216 international level cricketers (mean age 28.9, SD = 4.0) between 2009-2015 was retrospectively analysed.

Results: The overall new match injury incidence rates between 2009-2015 were 37.0 injuries per 10,000 player hours in domestic cricket, and 58.0 injuries per 10,000 player hours in international cricket. Total injury prevalence rates from 2009-2015 were 7.6% in domestic cricket, and 10.0% in international cricket. The most injured body site in domestic cricket was the hamstring (8.2%), and the groin (13.5%) in international cricket. Most match days were lost to lumbar spine injuries in domestic cricket (417 days), and groin injuries in international cricket (152 days). There was a statistically significant difference in injury status between domestic and international level cricketers ($\chi^2 = 4.39$, $p = 0.036$), and playing position ($\chi^2 = 42.29$, $p < 0.0001$). The number of match exposure hours was associated with increased number of injuries ($p < 0.0001$).

Conclusion: Total injury incidence rates have increased in elite New Zealand cricket between 2009-2015 compared to 2002-2008, most likely due to the increase in Twenty20 matches domestically and internationally. International level players and fast-medium pace bowlers were the most injured player types, with increasing match hours of exposure related to the number of injuries. It is suggested that workload interventions may positively influence injury incidence rates in the future.

Chapter 1 – Introduction

1.1 Statement of the problem

Cricket is a team sport, popular in most countries of the former British Empire (Annear, Chakera, Foster, & Hardcastle, 1992). Teams are comprised of 11 players whose roles are specialised to bowling, batting, or wicket keeping (Bartlett, 2003). Different forms of game are played, requiring various physical workloads and demands (Petersen, Pyne, Dawson, Portus, & Kellett, 2010; Petersen, Pyne, Portus, & Dawson, 2011). The traditional game consists of a Test match played over five days in international cricket, and as a four-day variant in domestic First-Class competition. Balls are delivered to batters in groups of six, referred to as “overs” (Orchard et al., 2015a). There are an unlimited number of overs in the Test and First-Class format, leading to workload variations that in some instances require bowlers to bowl more than 50 overs during the course of the match. The modern game includes a style of play with limited overs. These are the One Day format that is limited to 50 overs, and the Twenty20 format which is limited to 20 overs per side. In these limited overs matches, bowlers are allowed to bowl a maximum of ten and four overs each, respectively (Orchard et al., 2015a).

Over recent years the popularity and commercial nature of the sport has grown, particularly in the Twenty20 format of the game (Orchard, James, Kountouris, & Portus, 2010). This rise in popularity has brought about competitive international Twenty20 leagues in major cricketing nations such as Australia, England, and India. This presents players with an increased physical demand to contend with, which can increase their risk of injury (Gabbett, 2004).

The New Zealand Cricket domestic competition is made up of six provincial teams that play all formats of the game. From this pool of cricketers, New Zealand Cricket will contract players to play for the New Zealand international representative team.

Although cricket is a non-contact sport, the roles of batting, bowling, wicket keeping, and fielding all expose players to physical loads (Petersen et al., 2010; Petersen et al., 2011). Therefore, the non-contact nature of cricket does not exempt players from injury. Overuse injuries are the most common in elite competitive cricket due to repetitive movements with high or varied workloads (Finch, Elliott, & McGrath, 1999; Hulin et al., 2014; Orchard et al., 2015a). Fast bowlers typically represent the majority of injury occurrences and days lost to injury (Orchard, James, Alcott, Carter, & Farhart, 2002; Orchard, James, & Portus, 2006; Orchard, Kountouris, & Sims, 2016) as they are most impacted by fluctuations in match format and subsequent workload demands. There is also potential for players to be inadvertently impacted by ball, bat, collide with other players, or with the ground surrounds. However, these injury mechanisms are less common (Finch et al., 1999).

Injury can have negative consequences on both health and future sporting aspirations (van Mechelen, Hlobil, & Kemper, 1992). This is of particular concern regarding athletes, whose chosen vocation is competitive sport. There is also evidence that the more an athlete can train unrestricted, the more likely they are to achieve sporting success (Raysmith & Drew, 2016). Injury itself has also been shown to be a risk for future injury (Fulton et al., 2014). Given this impact of injury, preventative strategies should be considered. One such framework has been described by van Mechelen et al. (1992). This framework outlines that robust epidemiological investigation of the at-risk population is initially required. Injury surveillance systems can be used to track and register injuries, and are commonly used in sports (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Ranson, et al., 2016; Pluim et al., 2009; Timpka, Alonso, et al., 2014). Findings from these investigations can be used to identify key injury problems to then target with interventions. The effectiveness of the intervention can then be assessed by observing changes in injury incidence rates through repeated epidemiological analysis.

New Zealand Cricket implemented an injury surveillance system in the 2002-2003 season. An epidemiological study of elite New Zealand cricketers from this surveillance system has been previously conducted for the 2002-2008 period (Frost & Chalmers, 2014). Subsequent years have not been investigated; thus, the ongoing burden of injury is not known. Other international studies have suggested that injury rates have been increasing due to the emergence of Twenty20 cricket (Orchard, James, et al., 2010; Orchard, Kountouris, et al., 2016), the effects of which on a New Zealand cricketing population are also not known.

1.2 Purpose of the study

This study will have two major aims. The initial purpose of this study will be to provide an update of the injury epidemiology in elite New Zealand cricket from 2009-2015 using internationally recommended methods of injury surveillance and reporting for cricket (Orchard et al., 2005). This study will also expand on the previous work by Frost and Chalmers (2014) by further describing injury incidence rates in line with the updated consensus guidelines on injury surveillance and reporting in cricket (Orchard, Ranson, et al., 2016). The secondary purpose of this study will be to undertake analysis of the epidemiological data to describe the relationship between injury and the level of cricket played, playing position, and exposure to playing load which was not investigated in the earlier study by Frost and Chalmers (2014).

1.3 Significance of the problem

Injuries can have negative effects on the health and performance of athletes (van Mechelen et al., 1992). Injury surveillance is the primary step in being able to identify the extent of the issue. These epidemiological findings provide a comparative baseline on which the efficacy of interventions to reduce injury rates and their impact can be evaluated (van Mechelen et al., 1992). New Zealand cricket have maintained an injury surveillance system from 2002, but injury epidemiology has only been described for the 2002-2008 period (Frost & Chalmers, 2014). An update is required as the emergence of Twenty20 cricket as a mainstream form of the game has been demonstrated to increase injury rates in other international cricketing populations (Orchard, Rae, et al., 2010; Orchard, Kountouris, et al., 2016).

The internationally recommended cricket injury surveillance and reporting standard has also been updated by Orchard, Ranson, et al. (2016) since publication of the 2002-2008 injury report in New Zealand cricketers by Frost and Chalmers (2014). It is critical that for injury rates to be comparable between studies, they must be collected, prepared, and presented in a consistent manner (van Mechelen et al., 1992). Therefore, New Zealand Cricket’s injury rates must be updated and presented to the current international standard. To date, only one other study has been published with the updated recommendations (Orchard, Kountouris, et al., 2016) so this study will play a key role in expanding the international knowledge base on injury epidemiology in cricket.

The relationship between workload and injury is also emerging as a risk factor injury in sport (Gabbett, 2016). This is of particular interest in cricket, which is a non-contact sport with variable workloads due to the different match formats and player roles. Identifying relationships between workload and injury in a New Zealand cricketing population is therefore of interest.

By completing an epidemiological analysis of the New Zealand Cricket injury surveillance system, a baseline set of data will be produced that will describe the impact of injury on that population. Assessing which variables have a statistically significant relationship with injury will provide a greater understanding and direction for which measures could be targeted to reduce the impact of injury. Having these epidemiological baselines will also allow the efficacy of any future interventions to be evaluated against them.

Chapter 2 - Review of Literature

Introduction

This chapter will be divided into four main sections. The first will present on common sports injury surveillance models and their role in injury prevention. The second section will present the definitions and methods of injury surveillance and reporting systems. The next section will present existing epidemiological findings on cricket injury, including data on elite New Zealand cricketers. The final section will present literature investigating which factors contribute to the risk of injury in cricket.

2.1 Injury prevention and surveillance models

There have been several models of injury prevention described in scientific literature. These have all built on the original injury prevention model described by van Mechelen et al. (1992). The authors reported that while sport has many health benefits, there is an accompanied risk of injury which can have negative implications on health or future sporting aspirations. The same authors subsequently recognised that a preventative approach to injury reduction should be considered in sport, so presented the "sequence of prevention" as a framework on which injury prevention programmes could be developed. The model is presented below in figure 2.1:

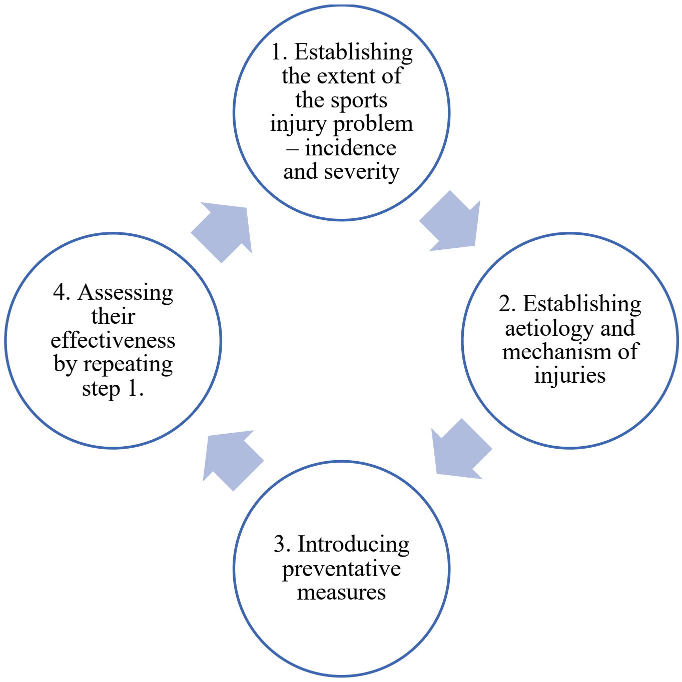

Figure 2.1 "Sequence of prevention" of sports injuries, adapted from van Mechelen et al. (1992).

The first step of the van Mechelen et al. (1992) model is to identify and describe sports injury problems in terms of injury incidence and severity. The second step is to establish what factors and mechanisms contribute to the occurrence of injury in sport. The third step is to introduce preventative measures that are likely to reduce the risk and severity of injury, based on the aetiological factors and mechanisms identified in the previous step. The final step is to assess the effectiveness of the preventative measures by repeating the first step to compare post-intervention injury incidence and severity with those initial findings.

A complete understanding of injury causation is needed to address the multi-factorial nature of injury risk factors (Bahr & Krosshaug, 2005). Meeuwisse (1994) proposed a model for assessing the risk factors involved with injury. This model acknowledges that although injury may appear to occur from a single event, there are a background of interacting internal and external risk factors that precede it.

Bahr and Krosshaug (2005), using an example of a study by Olsen, Myklebust, Engebretsen, Holme, and Bahr (2003) which showed an increased risk for anterior cruciate ligament injury in female handball athletes on high friction floors, discussed that complex interactions may exist between internal and external risk factors. They reported that this interaction of factors contributes to injury risk, rather than those factors that exist in isolation. Bahr and Krosshaug (2005) further reported that the mechanical properties of tissues must be also be considered when describing an inciting event to injury, as internal and external factors will be important determinants of how that tissue responds to a biomechanical load. In addition to considering epidemiological and biomechanical models to describe the interaction between factors, Bahr and Krosshaug (2005) further promoted precise descriptions of the injury mechanism to further differentiate causative factors for injury. This included describing the situation in the context of the sport at the time (e.g. preparing to shoot in handball), behaviour of the athlete and opponent (e.g. opponent making contact with player), description of whole-body biomechanics (e.g. rotation on a fixed foot), and description of joint/tissue biomechanics (e.g. rotation of the tibia relative to the femur). The considerations around the interaction between internal and external factors, their influence on load, and specific circumstances leading to injury are comprehensive and complex. However, Bahr and Krosshaug (2005) proposed that a deeper understanding of injury causation would improve the design of specific prevention programme models, and presented their injury causation model to build on the work by van Mechelen et al. (1992).

Gissane, White, Kerr, and Jennings (2001) described the model by Meeuwisse (1994) as “linear” as it considers injury incident as the end-point upon which an athlete exits the model. Gissane et al. (2001) instead describe a “cyclical” model that the authors proposed would additionally capture the effect of treatment and rehabilitation as factors of injury, explaining that they are factors in injury prevalence. They consider that a cyclical model appropriately reflects that injury and added experience of continuous play over an athletes career from season to season will have an influencing factor on intrinsic and extrinsic factors thus needs to be considered (Gissane et al., 2001). This model is considered cyclical as there is no exit point for an injured athlete, but rather a shift into a rehabilitative period before reintroduction back into play and a cohort under surveillance.

Meeuwisse, Tyreman, Hagel, and Emery (2007) acknowledged the limitations of the previous linear model (Meeuwisse, 1994) where individuals who are either exposed or not exposed to a risk factor are followed in time, up to an end point of injury. The reality of sport is that exposure is a combination of participation while possessing a risk factor for injury (Meeuwisse et al., 2007). Throughout the course of participation a player may be variably exposed to one or more factors for various times under different or similar conditions (Meeuwisse et al., 2007). The event of injury may also not permanently remove the player from ongoing participation so therefore does not reflect a true end point (Meeuwisse et al., 2007). These authors thus proposed a “dynamic” model which acknowledged that players could adapt to risk factors in sport with or without presence of injury which would further affect aetiology.

Finch (2006) commented that although the van Mechelen et al. (1992) model has been valuable in guiding injury prevention and research, it does not adequately describe the required direction for research leading to direct injury prevention. Finch (2006) considers that players, coaches, and sporting organisations also need to understand and adopt research for it to be effective at preventing sports injury – a consideration lacking in the van Mechelen et al. (1992) model. Finch (2006) developed the Translating Research into Injury Prevention

Practice (TRIPP) model (figure 2.2) that reflected these proposed additions, building on the van Mechelen et al. (1992) model. The initial four steps of the TRIPP model overlap with the van Mechelen et al. (1992) model where the first step is injury surveillance, the second is understand injury aetiology, the third is developing preventative measures, and the fourth is assessing their efficacy. The fifth step introduces the notion to focus research attention into how these the outcomes of efficacy assessment can then be incorporated in a "real world" sporting context that considers policy making, environmental or equipment modifications, as examples to drive change. The sixth step involves evaluating the measure identified in step 4 implemented with the context identified in step 5. Finch (2006) believes that the TRIPP model will result in injury prevention measures that better reflect real-world sporting conditions through collaboration with key stake holders to ensure better compliance of the proposed injury prevention interventions.

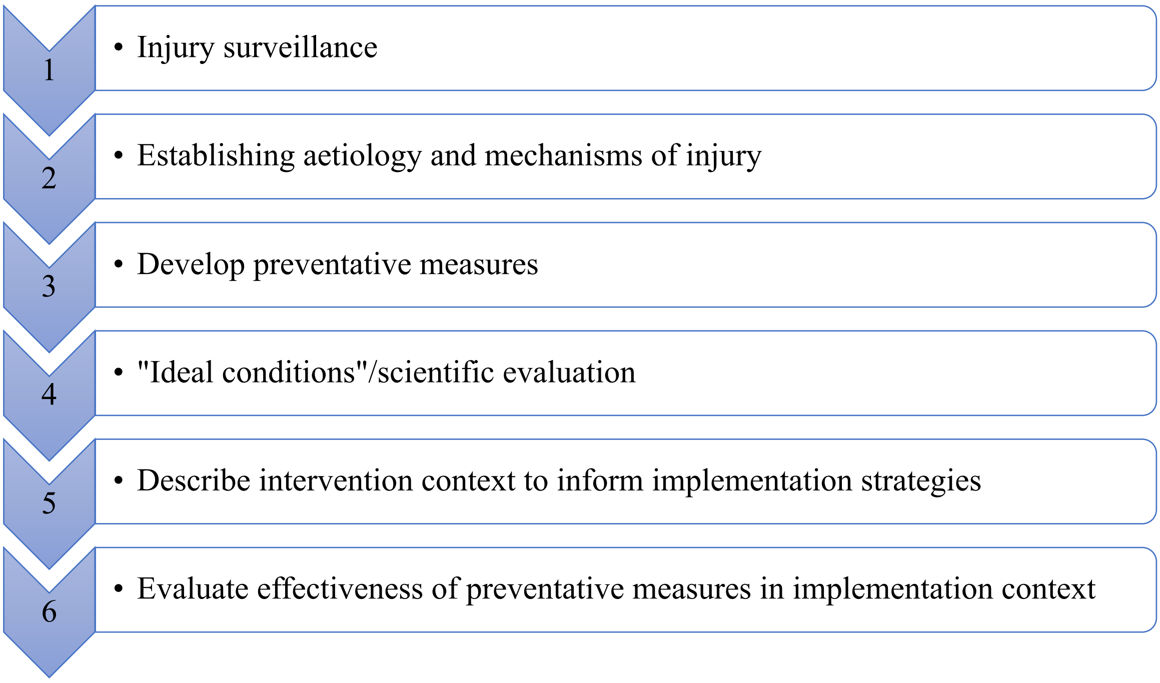

Figure 2.2 Translating Research into Injury Prevention Practice (TRIPP) model, adapted from Finch (2006).

Fuller, Bahr, Dick, and Meeuwisse (2007) reported that studies were beginning to demonstrate that previous injury could increase the risk of sustaining a similar injury. They reported that although consistent methodologies exist for reporting and recording initial and recurrent injuries in sports such as football (Fuller et al., 2006) and rugby union (Fuller, Molloy, et al., 2007), these guidelines needed to further consider the nature and clinical status of the first injury at the time of the subsequent injury. Fuller, Bahr, et al. (2007) recommended for injury prevention and surveillance models to differentiate similar injuries to the same player as either a reinjury or an exacerbation depending on whether a player had returned to full participation. They hypothesised this would result in fewer reported recurrent injuries as this term would exclude exacerbations but would increase the reported severity of the initial injury as the days of play lost to exacerbation would be reflected as days lost to initial injury.

Finch and Cook (2014) reported that terms such as repeat, recurrent, and multiple were still used in literature to describe injury where more than one occurrence of an injury was studied. This has statistical implications in either over-reporting or underestimating the incidence of new or recurrent injury. Additionally, the poor consistency of definitions does not provide a platform on which the impact of one injury on the development of another can be appropriately identified and studied by researchers. To address the inconsistency in definitions of recurrent injury, Finch and Cook (2014) presented the Subsequent Injury Categorisation (SIC) model. This model presents ten classification categories for injuries subsequent to the initial event and the relationship with it. In this model a subsequent injury is categorised as either a) the exact same injury in terms of body site and nature, b) injury to the same body site but different nature, or c) injury to a different body part irrespective of nature. This injury is then sub-classified based on how this occurrence was related to the index injury. To further explain the relevance of subsequent injury coding, Finch and Cook (2014) showed that of 469 injuries in a cohort of 282 Australian football players over a single season, 15.6% of those injuries were directly related to a previous index injury. Studies have since shown that previous injury can indeed be a risk factor for future injury (Fulton et al., 2014), which will be explored later in this chapter.

2.1.2 Summary

While van Mechelen et al. (1992) described an early model for injury prevention, several authors have expanded it with subsequent publications (Bahr & Krosshaug, 2005; Finch, 2006; Gissane et al., 2001; Meeuwisse, 1994; Meeuwisse et al., 2007). Although more recent models have added steps and further considerations to build on the original van Mechelen et al. (1992) model, they all retain the need to gather epidemiological data, understand the aetiology of injury, implement an injury prevention measure, then reassess the effect of that intervention. The next section will describe definitions of the methodology of injury surveillance systems for the purpose of reporting injury incidence rates.

2.2 Definitions and methods in injury surveillance

Introduction

Examining sports injury data can ascertain how injury risk varies between sports, which injuries are common for given sports, the player roles or positions most at risk, and how much participation time is lost due to specific injury (Phillips, 2000). Quality studies are needed because methodological factors influence the analysis and interpretation of incidence rates gathered from them (Phillips, 2000). The following section will explore the definitions and concepts in sports epidemiology research.

2.2.1 Definition of injury

To ensure that sports injury surveillance systems can be comparable in research, a consistent definition of sports injury is a prerequisite (van Mechelen et al., 1992). Cricket was the first sport to publish recommended injury surveillance methods (Orchard et al., 2005). The consensus injury definition by Orchard et al. (2005) is as follows:

> *Any injury or other medical condition that either:*
>
> *a) prevents a player from being fully available for selection for a major match or*
>
> *b) during a major match, causes a player to be unable to bat, bowl, or keep wicket when required by either the rules or the team's captain.*

This definition is considered to be a "match time-loss" definition whereby a scheduled match has to be missed for the injury to be included in surveillance. Once a player has been able to return to at least one match regardless of format or level, they are considered to have recovered from that injury (Orchard et al., 2005).

2.2.2 Broad injury definition

Despite the consensus statement for injury surveillance and reporting by Orchard et al. (2005), some cricket studies have used broader terms to define injury. Saw, Dennis, Bentley, and Farhart (2011) investigated the relationship between throwing workload and injury by defining injury as a condition that caused a player to present to the team physiotherapist. Kountouris, Portus, and Cook (2012) investigated whether quadratus lumborum asymmetry was associated with lumbar spine injury defined as the athlete needing to present to a sports physician. Olivier, Stewart, Olorunju, and McKinon (2015) investigated whether a preseason musculoskeletal examination could be associated with injury in fast bowlers defined as a musculoskeletal condition that resulted in the loss of at least one day of sporting activity or an event that occurred during a sporting activity that required medical attention which forced the bowler to quit the activity.

Other sports including football (Fuller et al., 2006), rugby union (Fuller, Molloy, et al., 2007), tennis (Pluim et al., 2009), athletics (Timpka, Alonso, et al., 2014) and aquatics (Mountjoy et al., 2016) have established their own consensus papers on injury definition and data collection procedures which define injury broadly, as any physical complaint sustained by a player that results from a match or training in their respective sport, irrespective of the need for medical attention or time-loss from that sports' activity. Those authors included a subsequent category of "medical attention" injury defined as a player needing to receive medical attention, and a "time-loss" category if an injury resulted in a player being unable to take a full part in future training or match play. Mitchell and Hayen (2005) and Timpka, Jacobsson, et al. (2014) have also proposed that tissue pathology or trauma are an important precursor to injury, so tissue status may have a role in defining injury as well. Clarsen and Bahr (2014) provide a useful visualisation of the relationship between these various definitions and what proportion of all complaints they capture (figure 2.3).

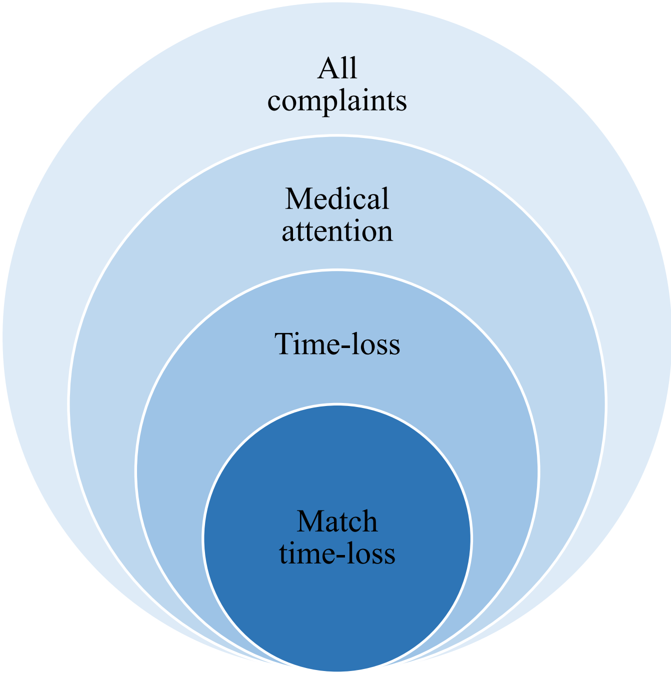

Figure 2.3 The interaction of injury definitions, adapted from Clarsen and Bahr (2014), not to scale.

In published injury surveillance literature, there is debate in whether the definition of injury should be narrowed to only focus on missed matches or whether recording all injuries is more appropriate. Several limitations to the narrower time-loss injury definition have been reported. Hodgson, Gissane, Gabbett, and King (2007) argue that reporting only injuries that result in missed matches will underreport the true incidence of injury, and that recording all injuries will better answer research questions of injury risk. Athletes may continue to train or compete despite presence of injury (Clarsen & Bahr, 2014). The use of analgesic treatment modalities or modification of training intensity or structure may also lead to a number of injuries going unreported (Clarsen & Bahr, 2014) thus underreporting the extent of injury (Hodgson et al., 2007). Failing to record missed training sessions may limit understanding the full extent of injuries as missing training can affect team performance, increase risk of sustaining injury, or play with suboptimal fitness (Hodgson, Standen, & Batt, 2006). This concept of "tip of the iceberg" reporting is noted by van Mechelen et al. (1992). This analogy suggests that only a small proportion of the whole is easily seen from the surface, but the bigger proportion and potentially the full extent of injury burden may be missed (Orchard & Hoskins, 2007).

The concept of being unable to fully participate in training or competition in a time-loss definition is also difficult to apply to individual sports (Clarsen & Bahr, 2014). Individual athletes have greater scope to modify their training requirements in response to injury or illness such as the frequency, intensity, or volume of training thus challenging the notion whether a "normal" training load has been maintained, compared to team sports (Clarsen & Bahr, 2014). Additionally in individual sports, competition occurs less frequently so a time-loss from competition definition may not be particularly useful to establish the impact of that injury (Orchard & Hoskins, 2007).

Match scheduling will also create a bias with a time-loss injury definition. Should matches deviate from a standard schedule (e.g. one match per week), comparing sports that play fewer or greater competitions becomes less reliable (Orchard & Hoskins, 2007). Another scheduling bias with a time-loss definition may occur towards the end of a sporting season (Orchard & Hoskins, 2007). For example, a significant injury that occurs on the last match of a season will only count towards one lost match rather than if it had occurred at the beginning of the season and potentially resulted in multiple games missed. This implicates the accuracy of reporting the severity of the injury and can under-estimate its true effect, incorrectly identifying it as a less burdensome injury.

Healthcare resourcing may also be influenced by the broad injury definition. If non time-loss injuries are regularly reported and perceived as burdensome, an organisation may resource health care costs towards injuries that may not necessarily cause missed playing time. It is possible that the effort placed into quality treatment that prevents match time-loss injuries or results in efficient rehabilitation may in fact allow a player to participate in a situation that would otherwise have resulted in a missed match (Orchard & Hoskins, 2007).

While the match time-loss injury definition is able to capture acute injuries, it may not provide an appropriate impact of injury severity of less serious injury and may overlook overuse injury (van Mechelen et al., 1992). Bahr (2009) highlighted that assessment of injury severity should additionally include measures based on functional level, and that prevalence of pain and overuse-type injuries may otherwise not be recorded thus their burden not truly represented. In acknowledgement that true injury burden of overuse injuries may be underestimated based on the time-loss injury definition, Clarsen, Myklebust, and Bahr (2013) developed the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. Rather than focusing on whether the athlete is able to participate or not (time-loss definition), this questionnaire enquires about the athlete's level of function or performance (Clarsen et al., 2013). To validate the OSTRC questionnaire as a method of registering overuse injuries in sport, Clarsen et al. (2013) compared their proposed methods of detecting overuse injuries with those described by Fuller et al. (2006) which have been widely adopted by other sports. In the injury registration methods described by Fuller et al. (2006), an injury is first defined as a physical complaint, resulting from a match or training, referred to as either needing medical attention or resulting in inability to train or play. The recorder then categorises this injury as either the result of overuse or trauma. In a 3-month prospective study of 313 athletes from cross-country skiing, floorball, handball, road cycling and volleyball, Clarsen et al. (2013) demonstrated that the OSTRC questionnaire (modified to enquire about knee, lower back and shoulder complaints) was able to detect 419 overuse injuries compared to 40 overuse injuries with methods described by Fuller et al. (2006). This showed that injury definitions that focus on time loss from training or competition capture a smaller percentage of all injuries, including those considered overuse (Clarsen et al., 2013).

Different sports place different physical demands on athletes. Contact sports for example, will expose athletes to different injury risks compared to non-contact sports. For reasons like this, if researchers wish to investigate and compare injury rates between sports, narrow injury definitions, such as those adopted within specific sports (Orchard et al., 2005) may not be appropriate (Junge et al., 2008). In recognition of this, a surveillance system to record injury in a multi-sport setting was developed for use by the International Olympic Committee (Junge et al., 2008), and later expanded further to capture illness (Engebretsen et al., 2010). The injury definition in this surveillance system remained broad, based on data collection procedures in football by Fuller et al. (2006) of any new musculoskeletal complaint injured as a result of competition and/or training that received medical attention regardless of consequence on absence from competition or training. This definition was chosen by Junge et al. (2008) as they believed it had the advantage of capturing the full spectrum of injuries incurred in competition.

2.2.3 Narrow injury definition

It was described earlier in this chapter that match time-loss represents the narrowest definition of injury (Clarsen & Bahr, 2014). Despite advantages of a broader definition of injury, there are also advantages of using a time-loss definition.

While the previous section presented evidence that a broad injury definition can be promoted to capture and avoid missing injuries, conversely this definition can be argued to risk overreporting. Orchard and Hoskins (2007) presented an epidemiological study from the Australian Football League (Orchard & Seward, 2002) where a broad definition was used in the 1995 season (*"any injury that caused a player to miss playing time during a match or be unable to be selected in a match or participate in a training session"*) and a narrower definition in the 1997 season (*"any physical or medical condition that prevents a player from playing in a regular season match"*). The broader definition in 1995 resulted in 1,813 injuries reported, averaging 120.9 (SD = 122.2) per team compared to the narrower definition in 1997 where 852 injuries were reported, averaging 53.2 (SD = 17.3) injuries per team. Teams in the 1995 season reported a skewed injury distribution compared to a roughly normal distribution with smaller standard deviations which Orchard and Hoskins (2007) concluded was marker of poorer reliability. Orchard and Hoskins (2007) believe this was strengthened further as the teams in the study were reported to have had similar training, playing, and injury management conditions . Research like this can demonstrate why it is not appropriate to compare epidemiological data where results are gathered from studies with varied injury definitions.

Orchard and Hoskins (2007) further debated that surveillance systems with broad definitions, such as those stated by Fuller et al. (2006), may not account well for common real-world scenarios. If for example a player with a chronic injury such as early knee osteoarthritis misses one weekly training session for the duration of the season as part of their management plan, the first instance would be recorded as the primary injury, and the remaining weeks would be recurrences. Orchard and Hoskins (2007) consider that in a common situation like this, surveillance recorders are unlikely to register weekly recurrence into their data set for the duration of a full season resulting in an unreliable system. In the TRIPP injury prevention model by Finch (2006) mentioned earlier in this chapter, consideration of how to integrate interventions into real-world situations is a key concept. Orchard and Hoskins (2007) consider that implementation of a narrower injury definition into surveillance systems better reflects such real-world scenarios and so more likely to be accepted by investigators.

For an injury definition to be considered reliable, surveillance recorders would need to independently determine the same outcome from the criteria that constitute injury for a given surveillance system (Orchard & Hoskins, 2007). For example, injuries that require detection of radiological abnormality will differ based on the interpretation of the reviewer therefore and there introduces risk of poor reliability between recorders (Orchard & Hoskins, 2007). Orchard, Ranson, et al. (2016) discussed how well these various definitions capture injury rates and their reliability (table 2.1). An advantage of a time-loss definition is that recognition of a player's inability to partake fully in their scheduled training or competition is relatively simple (Clarsen & Bahr, 2014). For this reason, time-loss definitions are considered relatively reliable and can be administered by anyone taught to recognise this criteria, therefore allowing the comparison of injury data between different teams and time periods (Clarsen & Bahr, 2014).

Table 2.1 *Possible surveillance system injury definitions, adapted from Orchard, Ranson, et al. (2016)*

Definition type	Scope	Reproducibility	Injury rates
All tissue pathology	Most broad	Least reliable	Highest
All symptoms	Broader	Less reliable	Higher
All medical presentations	Moderate	Moderate	Moderate
Time-loss injuries	Narrower	More reliable	Lower
Match time-loss injuries	Most narrow	Most reliable	Lowest

A further limitation to the reliability of the broad injury definition is that differences in availability of staff will influence surveillance system completeness leading to bias between player groups (Clarsen & Bahr, 2014; Orchard et al., 2005). It is likely that those who have medical staff present at all trainings will report a higher injury rate than in the teams where players have to travel for medical consultation (Orchard et al., 2005).

2.2.4 Definitions of injury recovery

As the definition of injury can vary between studies, the definition of injury recovery also changes. Some consider that for an injury to be considered recovered, a player must return to unrestricted participation in at least one match (Orchard et al., 2005). This is particularly relevant to injuries that have been defined match time-loss. Timpka, Alonso, et al. (2014) consider full recovery in a 'return to play' sense where recovery is defined as the return to full training and availability for competition. For injury definitions that are broader than match time-loss, various definitions of recovery are required. A general time-loss injury, that considers a player unavailable for match-play regardless of a match or training being actually scheduled, is considered recovered if medical staff determine the player is appropriate to return to play regardless if a match was scheduled for that particular day (Orchard, Ranson, et al., 2016). A broad injury definition, such as one requiring medical attention, is considered recovered when the injury no longer requires ongoing medical monitoring or management (Orchard, Ranson, et al., 2016). Defining recovery in the context of sport can be challenging as athletes may return to participation while still undergoing treatment, or while experiencing symptoms or adverse effects (Timpka, Alonso, et al., 2014). Hammond, Lilley, and Ribbans (2013) considered that a clear definition of injury recovery is crucial, given its impact on establishing injury severity and recurrence.

2.2.5 Definitions of recurrent injury

Early published consensus statements considered an injury of the same type and at the same site as the initial injury, but which occurred after the player's full return to participation, to be a recurrent injury (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Orchard et al., 2005; Pluim et al., 2009). When discussing recurrent injury, the initial injury is often described as the "index" injury (Fuller, Bahr, et al., 2007). Finch and Cook (2014) have described their SIC model for categorising injures subsequent to the index injury to standardise reporting definitions, improve consistency in studies of recurring or subsequent injury, and to minimise under-reporting or overestimation of injury incidence or severity. This model, described earlier in this chapter, classifies a recurrent injury in one of ten categories depending on its relationship to the index injury.

2.2.6 Injury severity

Injury severity is typically based on the number of days of absence from sport participation from the day of onset to the day of the athlete's ability to return to competition (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Hammond et al., 2013; Orchard et al., 2005; Orchard, Ranson, et al., 2016). Reporting days of absence relies on a robust definition of injury recovery which is subject to the definition of injury itself. As variability in these definitions exists in literature, researchers must be aware of this limitation when comparing studies.

2.2.7 Injury diagnosis and coding

Phillips (2000) recommended that the coding and recording of injuries needs to be consistent with clear definitions to limit subjectivity in data collection. The Orchard Sports Injury Classification System (OSICS) developed by Dr John Orchard is one such injury diagnostic coding system, and is one of the most used injury coding systems in the world (Orchard, Rae, et al., 2010). This coding system describes pathologies within each anatomical region to express sports injury diagnoses, but also allow the option for greater detail and diagnostic accuracy (Hammond, Lilley, & Ribbans, 2009). The OSICS system has been shown to have moderate inter-rater reliability (Hammond et al., 2009) and high levels of agreement (Finch et al., 2012).

To promote completeness of injury data sets, numerous methods have been proposed such as individual athlete reporting through text messaging or smartphone applications, or health staff monitoring through daily or weekly questionnaires such as the OSTRC questionnaire by Clarsen and Bahr (2014). Despite the options available for athlete injury monitoring and their various eases of applying the time-loss definition (Clarsen & Bahr, 2014), surveillance studies can remain prone to incompletion and inaccuracy. Bjørneboe, Flørenes, Bahr, and Andersen (2011) for example, demonstrated that a prospective injury surveillance system used by medical staff in Norwegian male professional football underestimated time-loss injury incidence by at least one-fifth of total injuries recorded. Phillips (2000) reported that a single individual who records injury information will achieve the greatest intra-rater reliability in surveillance studies. However, such scenarios may not be realistic when injury data from multiple teams is gathered for study.

2.2.8 Study design

Cohort studies monitor an injured and non-injured population so therefore can report on the effect of participation, ideally in a prospective nature (Phillips, 2000). Case-control studies only monitor those with injury and are typically retrospective (Phillips, 2000). Prospective, cohort design studies are favoured as they minimise errors associated with recall which can be an issue with retrospective study designs such as a case-control study (Fuller et al., 2006).

2.2.9 Injury rates

Rate is the basic unit of measurement used to describe injury (Phillips, 2000). Calculating injury rate requires identifying the total number of injuries as a numerator, divided by a denominator of the athlete's exposure time in their sport (Phillips, 2000). Time-based denominators are the most common, but other units of expression can be used such as balls bowled or faced, depending on the purpose of data interpretation. Injury incidence rate in sport is typically expressed as a rate per 1,000 hours of player exposure. Maintaining this approach in surveillance systems and reports improves comparability of incidence rates between sports. Ideally both training and competition time exposure is included to accurately reflect the true exposure time athletes are exposed to (Phillips, 2000). Calculations for exposure time will be detailed in the methods chapter.

Incidence rates are used to express risk. They are concerned with the number of new injuries occurring in a defined population over a given timeframe divided by the total exposure of the players participating in that sport (Phillips, 2000). Incidence rates must consider exposure reliably to produce a valid description of the problem, and to allow comparison with other studies. Phillips (2000) recommends that attention needs to be paid to the recording of all injuries whether they result in lost participation or not, whether injures occur in training or match play, specific injury diagnosis, along with a consistent definition of injury. However, the definitions and processes of data collection vary across sports and studies.

2.2.10 Injury surveillance methods in cricket

Outside of the primary author of the consensus statement on injury surveillance in cricket (Orchard et al., 2005), few studies have complied with these surveillance methods. This is potentially due to the limitations that exclusion of the non-time loss injury definition creates. It has been noted that the choice of injury definition will be dependent on the purpose and context of a surveillance system or research (Clarsen & Bahr, 2014). In recognition that encouraging all research to comply with the same injury definition may not be appropriate, an updated consensus statement on cricket injury surveillance was published by Orchard, Ranson, et al. (2016). This updated consensus retains the match time-loss definition from Orchard et al. (2005), but no longer as the only recommended definition. The Orchard, Ranson, et al. (2016) updated cricket injury surveillance consensus statement now allows for inclusion of the following additional injury definitions:

- General time-loss injures: *"any injury or illness that results in a player being considered unavailable for match-play, irrespective of whether a match or training was actually scheduled"*.
- Medical attention injuries: *"any health-related condition that required medical (or medical staff) attention and had the potential to affect cricket training or playing"*.
- Player reported injuries: *"any condition which was considered to represent an injury by the player (or parent/teacher on the player's behalf, with respect to junior players in teams without medical staff"*).
- Imaging abnormality injuries: *"any condition which gives rise to abnormal findings on specific medical imaging"*.

Due to the subjective nature and reliance on individual player reporting, the player reported injury definition is recommended to be exclusive for the study of community level cricket where medical staff are likely absent (Orchard, Ranson, et al., 2016). Imaging abnormality definitions are also not recommended for general surveillance, rather for studies examining specific body areas or injuries, and the high prevalence of abnormal imaging findings in clinically asymptomatic athletes must be recognised (Orchard, Ranson, et al., 2016).

2.2.11 Injury surveillance in New Zealand Cricket

New Zealand cricket implemented a surveillance system in the 2002-2003 season. Prior to the start of each season, each of the six domestic teams contract players to make up their squad. Players selected to represent New Zealand at an international level are chosen from those six teams. These players form the surveillance cohort for a given season. Domestic cricket matches include First-Class, One Day, and Twenty20 matches. International cricket matches include Test, One Day, and Twenty20 matches. Before the start of the season each cricketer is classified according to their primary role of bowler (fast-medium pace or slow-spin), batter, or wicket keeper. The player's match participation is recorded for all matches in a season by their team physiotherapist. The player's participation is recorded for each match whether they were played, rested, unavailable, not selected, injured, or play cancelled due to poor weather (Appendix B). Injuries are sub-categorised into those incurred at training, a match, recurrent injury, or illness. The injured body-part is recorded and encouraged to be classified with the OSICS injury coding system (Orchard, Rae, et al., 2010). An epidemiological study of elite New Zealand cricketers between 2002-2008 by Frost and Chalmers (2014) of this surveillance system was consistent with the Orchard et al. (2005) guidelines that were current to their time of publication. This work by Frost and Chalmers (2014) is of particular interest to this study as these authors published injury surveillance data that this thesis will be providing an update and comparison with.

2.2.12 Summary

Key concepts of sports epidemiology studies have been presented. Despite the presence of sports injury surveillance consensus statements, various definitions and interpretations of these concepts exist which influences the comparability of injury rates between studies. An understanding of a surveillance system or study method is therefore required prior to appropriate interpretation or comparison. Cricket has previously recommended a narrow time-loss definition for injury surveillance studies (Orchard et al., 2005). Therefore, this thesis will retain consistent definitions and methods to be able to make meaningful comparison to the previous findings by Frost and Chalmers (2014) as recommended in the van Mechelen et al. (1992) model. The limitations of the narrow time-loss definition have been explored and is it acknowledged that the purpose and context of surveillance should be reflected by the chosen definitions (Clarsen & Bahr, 2014). Expanding the recommended consensus definitions offers researchers greater flexibility to apply appropriate methods for the purpose of their study (Orchard, Ranson, et al., 2016), permitting this study to appropriately retain definitions used by Frost and Chalmers (2014) and complying with current recommendations. This study will expand on the previous work by Frost and Chalmers (2014) by additionally presenting injury incidence rates consistent with the updated guidelines.

2.3 Injury epidemiology in cricket

The previous section described injury surveillance system considerations and methods. The data gathered from such injury surveillance models can be used to establish the extent of injury problems in sport by describing them in terms of their incidence and severity (van Mechelen et al., 1992). Injury incidence assesses the number of injuries (new or recurrent) over a given time period and match injury incidence particularly refers only to injuries incurred during a match (Orchard et al., 2006). Injury prevalence considers the number of players from a cohort unavailable for selection through injury, expressed as a percentage, to represent the percentage of players missing as a result of injury (Orchard et al., 2006).

The current consensus paper on injury reporting in cricket (Orchard, Ranson, et al., 2016) recommends where possible to calculate injury incidence occurring over a defined time period in all major formats of the game for match injury incidence, training injury incidence, and annual injury incidence. The consensus statement also recommends calculating match injury prevalence, annual injury prevalence, and general injury prevalence. Match and training injuries should be expressed as injuries per 1,000 player days, and annual injuries as 100 players per year. Injury prevalence should be expressed as annual injury prevalence. The consensus statement by Orchard et al. (2005) recommended reporting match injury incidence rates per 10,000 player hours as opposed to the traditional 1,000 player hours (Phillips, 2000). This was recommended at a time when Twenty20 cricket was considered a novel match format. Now however, it is the most popular form of the game and due to the short match duration will report a high injury incidence when expressed per 10,000 player hours (Orchard, James, et al., 2010). To compare injury incidence between match formats better, match injury incidence rates are now recommended to be expressed as per 1,000 player days (Orchard, Ranson, et al., 2016). The differences in reporting injury rates between consensus paper versions can be seen in table 2.2.

Table 2.2 *Comparison of 2016 and 2005 injury rate reporting standards in cricket*

	Orchard, Ranson, et al. (2016)	**Orchard et al. (2005)**
Match injury	per 1,000 player days	per 10,000 player hours
Bowling injury	per 1,000 deliveries bowled or per 1,000 overs	per 1,000 overs bowled
Batting injury	per 10,000 deliveries faced	per 10,000 deliveries faced
Seasonal injury	N/A	per squad per season
Annual injury	per 100 players per year	N/A

Note: N/A = not applicable.

For major teams the international cricket window has evolved into a 9-12 month schedule (Orchard, Ranson, et al., 2016). In 2005 a season was defined as 60-days of scheduled match play and a squad as 25 players, but could be adjusted to reflect a more accurate scenario (Orchard et al., 2005). The current consensus by Orchard, Ranson, et al. (2016) considers that exposure of 365 days is better reflective of modern international season scheduling. For mathematical simplicity it is also recommended to consider a squad size as 100 players. Rather than expressing seasonal injury per squad per person, the recommended unit is annual injuries per 100 players per year (Orchard, Ranson, et al., 2016).

2.3.1 Injury incidence in cricket

A literature search was conducted to examine previously published cricket injury surveillance studies (figure 2.4). CINAHL, MEDLINE, PubMed, and SPORTDiscus databases were searched with the key words *cricket AND injur**. Only full text studies in English were included. Studies had to have reported injury incidence for an international and/or domestic cricket team season(s). Reference lists of studies were screened for any additional studies not identified in the original search. Ten studies were identified. Three were excluded as they did not report on injury incidence, and one was not included because findings in the same study period were reported in a more current study by the same author, resulting in a final total of six studies.

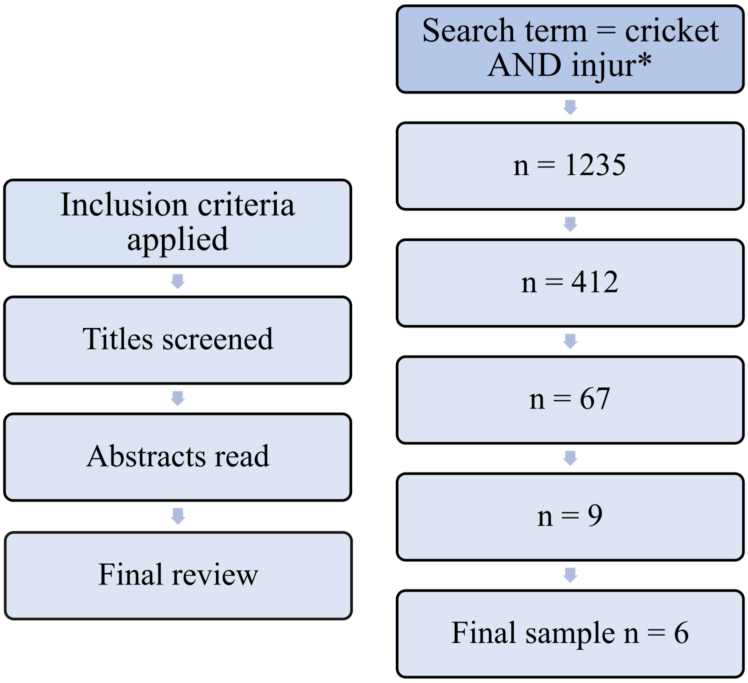

Figure 2.4 Flow diagram of literature search for studies of injury epidemiology in cricket.

2.3.2 Study characteristics

The main characteristics of the studies are presented in table 2.3. Four of the six studies evaluated both domestic and international cricketers (Frost & Chalmers, 2014; Mansingh, Harper, Headley, King-Mowatt, & Mansingh, 2006; Orchard et al., 2006; Orchard, Kountouris, et al., 2016). The remaining two studies reviewed domestic (Stretch, Raffan, & Allan, 2009) and international (Stretch & Raffan, 2011) cricketers independently.

The studies were from wide cohort of international cricket playing nations that included Australia (Orchard et al., 2006; Orchard, Kountouris, et al., 2016), New Zealand (Frost & Chalmers, 2014), South Africa (Stretch & Raffan, 2011; Stretch et al., 2009), and the West Indies (Mansingh et al., 2006). All six studies included only male participants. Only Mansingh et al. (2006) reported on the age range of their participants (18–37 years).

All six studies reported findings using the injury definitions and methods recommended by Orchard et al. (2005). Despite the study by Orchard, Kountouris, et al. (2016) being conducted after the publication of the updated consensus (Orchard, Ranson, et al., 2016), these authors elected to follow the match time-loss injury definition described in the earlier version of the cricket injury surveillance consensus paper. The authors did this as records for the alternative injury definitions, as described in the latest injury surveillance consensus paper, were not utilised over the 10 season study period from which their study's data was gathered.

Table 2.3 *Summary of epidemiological studies retrieved from literature search*

Study	Participants	Injury definition	Outcome measured	Key findings
Frost and Chalmers (2014)	Elite male international and domestic New Zealand cricketers N = 248 Age range = not reported Study period = 2002-2003 to 2007-2008	As defined by Orchard et al. (2005)	Match injury incidence per 10,000 player hours Seasonal injury incidence per squad per season Injury prevalence Circumstance of injury Injury incidents per body region, body part, specific diagnosis, and match days lost	Overall international match injury incidence rate = 51.6 injuries per 10,000 player hours (95% CI: 40.1-65.3) Overall domestic match injury incidence rate = 27.2 (95% CI: 23.5-31.4) International prevalence rate = 12% (95% CI: 11.3-12.8) Domestic prevalence rate = 9.7% (95% CI: 9.4-10.1) 79.5% of injuries occurred in matches 48.7% of all injuries sustained while bowling Most commonly injured body region was the lower limb (43.5%) Most common specific diagnosis was hamstring strains/tears (11.1%) Lower back stress fractures contributed highest proportion of match days lost (22%)
Mansingh et al. (2006)	Elite male international and domestic West Indian cricketers N = 33 Age range: 18 – 37 years Study period = 2003 – 2004	As defined by Orchard et al. (2005)	Match injury incidence per 10,000 player hours Injury prevalence Circumstances of injury	Mean match injury incidence in Test cricket = 48.7 per 10,000 player hours Mean injury prevalence in Test cricket = 11.3% Mean match injury incidence in One Day international cricket = 40.6 per 10,000 player hours

			Injury incidents per body part	Mean injury prevalence in One Day international cricket = 8.1% Match injury incidence in domestic First-Class cricket = 13.9 per 10,000 player hours Match injury incidence in domestic One Day cricket = 25.4 per 10,000 player hours Batsmen and fast bowlers sustained 80% of injuries Most injured areas were phalanges (22%) fielding, and the lumbar spine (20%) while fast bowling
Orchard et al. (2006)	Elite male international and domestic Australian cricketers N = not reported Age range = not reported Study period = 1995–1996 to 2004–2005	As defined by Orchard et al. (2005)	Match injury incidence per 10,000 player hours Seasonal injury incidence per squad per season Injury prevalence	Injury incidence remained fairly constant level over the 1995–1996 to 2004–2005 study period Injury prevalence gradually increased over the 1995–1996 to 2003-2004 period, but fell in 2004–2005 Fast bowlers have the highest injury prevalence (16%)
Orchard, Kountouris, et al. (2016)	Elite male international and domestic Australian cricketers N = not reported Age range = not reported Study period = 2006–2007 2015–2016	As defined by Orchard et al. (2005)	Match injury incidence per 1,000 days of play Annual injury incidence per 100 players per year Injury prevalence	Mean match injury incidence over past 10 seasons = 155 per 1,000 days of play Highest daily injury rate in 50-over cricket, then 20-over cricket, then First-Class matches Annual injury incidence = 64 per 100 players per season Mean annual injury prevalence over past 10 seasons = 12.5%

				Most common injury was the hamstring strain (seasonal incidence 8.7 per 100 players per season) Most prevalent injury were lumbar spine stress fractures (1.9% of players unavailable at all times, representing 15% of all missed playing time)
Stretch et al. (2009)	Domestic male South African cricketers N = not reported Age range = not reported Study period = 2004-2005 to 2005-2006	As defined by Orchard et al. (2005)	Match injury incidence per 10,000 player hours Injury prevalence Circumstances of injury	Match and training injury incidence = 30 per 10,000 player hours Match injury incidence = 74 per 10,000 player hours Training incidence = 15 per 10,000 player hours Injury prevalence = 8% per match Bowling (29%), fielding and wicket-keeping (27%), and batting (19%) accounted for the majority of injuries The lower limb was the most injured body region in 2004-2005 (45%) and 2005-2006 (42%) Most injures occurred in First-Class matches (39%) Most common diagnoses in 2004-2005 were haematomas (19%), muscle strains (17%) and other trauma (14%) Most common diagnoses in 2005-2006 were muscle strains (16%), other trauma (20%), tendinopathy (16%) and acute sprains (15%)

				Most common injury mechanism was the delivery stride when bowling (19%)
Stretch and Raffan (2011)	International male South African cricketers N = 36 Age range = not reported Study period = 2004-2005 to 2005-2006	As defined by Orchard et al. (2005)	Match injury incidence Injury prevalence Circumstances of injury	Match injury incidence = 90 per 10,000 player hours Injury prevalence = 4% per match Injuries occurred mostly to the lower limbs, back and trunk, upper limbs and head and neck. Injuries occurred predominantly during test matches (43%) Most common diagnoses in 2004-2005 were haematomas (20 %), muscle strains (14%), and other trauma (20%) Most common diagnoses in 2005-2006 were muscle strains (16%), other trauma (32%), tendinopathy (10%) and acute sprains (12%) Most common injury mechanism was bowling (67%)

Note: CI = confidence interval

2.3.3 Injury incidence

Five studies reported injury incidence per 10,000 hours (Frost & Chalmers, 2014; Mansingh et al., 2006; Orchard et al., 2006; Stretch & Raffan, 2011; Stretch et al., 2009) which is consistent with the recommended cricket injury reporting methods by Orchard et al. (2005). The study by Orchard, Kountouris, et al. (2016) reported injury incidence per 1,000 days of play and annual incidence as per 100 players per year. This is in line with the updated cricket injury surveillance consensus by Orchard, Ranson, et al. (2016), but limits the ability to make comparison with the five other studies.

The overall (Twenty20, One Day, and Test match) international match injury incidence rate for New Zealand between 2002-2008 of 51.6 injuries per 10,000 player hours (Frost & Chalmers, 2014) was slightly higher than the 2002-2005 period (27.3–49.4 per 10,000 player hours) in Australian international cricket (Orchard et al., 2006). The rate was much lower than in South African international cricket from 2004-2006 of 90 injuries per 10,000 player hours (Stretch & Raffan, 2011). The West Indian cricket study did not calculate overall international match injury rates (Mansingh et al., 2006). A limitation of this comparison is that the New Zealand overall incidence total calculation includes Twenty20 matches, which are known to express higher incidence rates (Orchard, James, et al., 2010), as opposed to the Australian and South African studies which did not include Twenty20 matches in their overall calculation. The total New Zealand international test cricket incidence rate between 2002-2008 of 30.1 injuries per 10,000 player hours (Frost & Chalmers, 2014) was lower than the West Indies incidence rate of 48.7 injuries per 10,000 player hours in their 2003-2004 season (Mansingh et al., 2006).

The overall (Twenty20, One Day, First-Class) domestic competition match injury incidence in New Zealand between 2002-2008 of 27.2 injuries per 10,000 player hours (Frost & Chalmers, 2014) was similar to the Australian overall domestic One Day and First-Class competition of 27.3-33 injuries per 10,000 player hours from 2002-2005 (Orchard et al., 2006), and the South African competition of 30 injuries per 10,000 player hours from 2004–2006 (Stretch et al., 2009). The West Indian study did not calculate an overall domestic competition incidence rate (Mansingh et al., 2006).

In New Zealand cricket between 2002-2008 the overall international match injury incidence rate of 51.6 injuries per 10,000 player hours was almost double the domestic competition rate of 27.2 injuries per 10,000 player hours (Frost & Chalmers, 2014). Frost and Chalmers (2014) propose that this was influenced by the incidence rate for international one day matches of 73.1 injuries per 10,000 player hours being double the domestic One Day rate of 36.2 injuries per 10,000 player hours, and that similar findings are observed in Australian (Orchard et al., 2006), South African (Stretch & Raffan, 2011), and West Indies cricket (Mansingh et al., 2006).

International One Day match injury incidence rates in New Zealand cricket between 2002-2008 of 73.1 injuries per 10,000 player hours were more than double for Test matches of 30.1 injuries per 10,000 player hours (Frost & Chalmers, 2014). Orchard et al. (2006) reported a similar observation in Australian international One Day cricket between 2002-2005 (57.7-72.2 per 10,000 player hours) and Test cricket (8.8-44.6 per 10,000 player hours). By contrast, the match injury incidence of international One Day matches was lower than Test match injury incidence in South Africa (79 vs 95 per 10,000 player hours) and the West Indies (40.6 vs 48.7 per 10,000 player hours) (Mansingh et al., 2006; Stretch & Raffan, 2011).

2.3.4 Injury prevalence rates

The overall injury prevalence rate from 2002-2008 in New Zealand international players was higher (12%) compared to domestic players (9.7%) (Frost & Chalmers, 2014). The opposite findings was seen in South African cricket where domestic players had a higher injury prevalence (8%) than international players (3.8%) (Stretch & Raffan, 2011; Stretch et al., 2009). The Australian (Orchard et al., 2006) and West Indian (Mansingh et al., 2006) studies did not report overall domestic and international injury prevalence rates.

2.3.5 Injury prevalence per player position

Pace bowlers reported the highest overall injury prevalence (18.7%) of all player positions in New Zealand cricketers between 2002-2008 with international pace bowlers reporting a higher prevalence (21.1%) compared to domestic pace bowlers (18.1%) (Frost & Chalmers, 2014). Australian pace bowlers also reported the highest injury prevalence (9.3-19.5%) of all playing positions between seasons 1995-1996 to 2004-2005 (Orchard et al., 2006). The average injury prevalence rate for Australian pace bowlers increased to 20.6% from seasons 2006-2007 to 2015-2016 (Orchard, Kountouris, et al., 2016). The West Indian (Mansingh et al., 2006) two South African studies (Stretch & Raffan, 2011; Stretch et al., 2009) did not report injury prevalence rates by player position.

2.3.6 Injuries per body region

The lower limb was the most commonly injured body region injured in New Zealand cricketers between 2002-2008 making up 46.3% of all injuries (Frost & Chalmers, 2014). This finding was similar in South African international (40%) and domestic cricketers (42%) between seasons 2004-2005 to 2005-2006. The most common injury New Zealand cricket between 2002-2008 was to the thigh (17.1%), with 11.1% specifically diagnosed as a hamstring tear (Frost & Chalmers, 2014). However, injuries to the lower back contributed to the most match days lost (27.1%) with stress fracture of the pars interarticularis contributing the most days lost at 22.1%. In the Australian study between seasons 1995-1996 to 2004-2005 (Orchard et al., 2006) the groin/buttock/thigh region recorded the highest seasonal injury incidence in nine of the ten observed seasons, whereas body region injury prevalence varied between seasons. In the Australian study between seasons 2006-2007 to 2015-2016 (Orchard, Kountouris, et al., 2016), hamstring strains recorded the highest average annual injury incidence at 8.7% whereas lumbar spine stress fractures reported the highest body area injury prevalence at 1.9%. Lumbar spine injuries were the second most common injury (20%) behind phalanx injuries (22%) in West Indian cricketers (Mansingh et al., 2006).

2.3.7 Summary

This section presented published epidemiological findings on cricket injury. Injury epidemiology studies have been published in Australia, New Zealand, South Africa, and the West Indies for both international and domestic level players. These studies have mostly retained consistent methodologies and reporting standards, allowing for reliable comparison. Understanding the impact of injury is the first step in the van Mechelen et al. (1992) model. The next section will review published literature on the known risk factors for cricket injury as per the second step in the van Mechelen et al. (1992) model.

2.4 Risk factors for injury in cricket

Understanding the aetiology of injury risk factors is the second step of injury prevention in the van Mechelen et al. (1992) model. To understand which factors are known to be associated with injury risk in cricket, a literature review was undertaken (figure 2.5). Studies were identified from CINAHL, MEDLINE, PubMed, and SPORTDiscus databases. The specific search term was “cricket AND injur*”. There was no limitation to the earliest publication date and studies up to January 2019 were identified. Only English language full text studies from academic journals were included. Once identified by the search term, study titles then their abstracts were read. Studies were included in this review if there was a clear investigation of an intrinsic or extrinsic factor that had an association with risk injury in a cricketing population. A risk factor was defined as a variable or condition that influenced or had the potential to influence injury outcome. Overall there were 26 studies that reported on risk factors for injury in cricket. All study participants were male.

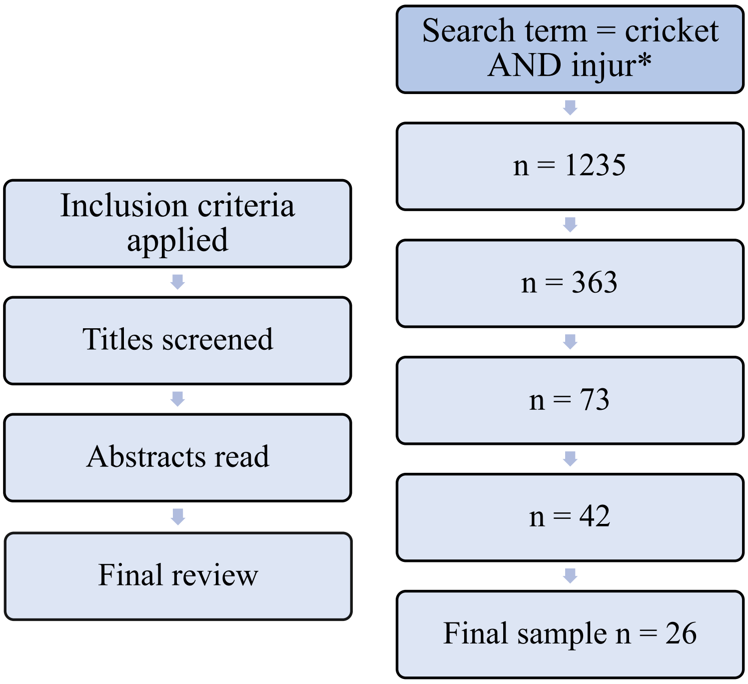

Figure 2.5 Flow diagram of literature search for studies of injury risk in cricket.

2.4.1 Injury definitions

There was variability to the definition of injury among the 26 studies. The most commonly cited definition of injury was from the cricket injury consensus document by Orchard et al. (2005) and was the injury definition in five studies (Bayne, Elliott, Campbell, & Alderson, 2016; Orchard, 2010; Orchard et al., 2015a, 2015b; Orchard, James, Portus, Kountouris, & Dennis, 2009). Three studies (Dennis, Farhart, Clements, & Ledwidge, 2004; Dennis, Farhart, Goumas, & Orchard, 2003; Dennis, Finch, & Farhart, 2005) used the definition provided by Orchard et al. (2002). Another three studies used a consistent time-loss definition they defined between them (Olivier, Gillion, Stewart, & McKinon, 2017; Olivier, Stewart, & McKinon, 2014; Olivier et al., 2015). Two studies used a consistent definition that included either time-loss or requiring medical attention (Martin, Olivier, & Benjamin, 2017a; Martin, Olivier, & Benjamin, 2017b). Two studies determined injury on the basis of a sports physician clinical and radiological assessment (Kountouris et al., 2012). The remaining 11 studies had their own individual definitions of injury that included time-loss, non-time-loss, radiological assessment, and when players required medical attention.

2.4.2 Body regions

There was variation among which body regions were investigated throughout the 26 studies. Seven studies exclusively investigated injury risk to the lower back (Bayne et al., 2016; Gray, Aginsky, Derman, Vaughan, & Hodges, 2016; Kountouris et al., 2012; Kountouris, Portus, & Cook, 2013; Kountouris et al., 2018; Portus, Mason, Elliott, Pfitzner, & Done, 2004a; Ranson, Burnett, & Kerslake, 2010). Six studies investigated injury risk factors to any region injured as a result of bowling (Dennis et al., 2004; Dennis et al., 2005; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Warren, Williams, McCaig, & Trewartha, 2018). Five studies investigated injury risk factors to any region regardless of injury mechanism (Ahmun, McCaig, Tallent, Williams, & Gabbett, 2019; Dennis et al., 2003; Martin et al., 2017a; Martin et al., 2017b; Orchard, 2010). Three studies investigated injury risk of non-contact lower back and lower limb injuries (Dennis, Finch, McIntosh, & Elliott, 2008b; Olivier et al., 2017; Olivier & Gray, 2018). The remaining studies investigated injury risk for any region with a non-contact mechanism (Hulin et al., 2014), lower back injury as a result of bowling (Olivier et al., 2014), hamstring injury (Orchard, Kountouris, & Sims, 2017), and shoulder or elbow injury (Saw et al., 2011).

2.4.3 Playing levels

Domestic cricketers were the most commonly studied population, investigated by 14 studies (Bayne et al., 2016; Dennis et al., 2004; Dennis et al., 2003; Gray et al., 2016;

Hulin et al., 2014; Olivier et al., 2017; Olivier & Gray, 2018; Olivier et al., 2014; Olivier et al., 2015; Orchard, 2010; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Saw et al., 2011). Junior and adolescent cricketers were the next most investigated population by seven studies (Ahmun et al., 2019; Dennis et al., 2005; Kountouris et al., 2012; Kountouris et al., 2018; Martin et al., 2017a; Martin et al., 2017b; Warren et al., 2018). Elite international cricketers were represented in three studies (Kountouris et al., 2013; Orchard et al., 2017; Ranson et al., 2010). High performance cricketers of various age groups were investigated in two studies (Dennis et al., 2008b; Portus et al., 2004a).

2.4.4 Participant ages

The studies recruited participants from a variety of age groups. Nine studies researched risk factors in junior and adolescent cricketers whose age range and means were between 12 to 19 years (Ahmun et al., 2019; Bayne et al., 2016; Dennis et al., 2005; Gray et al., 2016; Kountouris et al., 2012; Kountouris et al., 2018; Martin et al., 2017a; Martin et al., 2017b; Warren et al., 2018). Ten studies included older cricketers with ages and means ranging from 18 to 38 years (Dennis et al., 2004; Dennis et al., 2003; Hulin et al., 2014; Kountouris et al., 2013; Olivier et al., 2017; Olivier & Gray, 2018; Olivier et al., 2014; Olivier et al., 2015; Orchard, 2010; Saw et al., 2011). Two studies included a wide range of ages from 12-33 years (Dennis et al., 2008b; Ranson et al., 2010). Five studies did not report the ages of their participants (Orchard et al., 2015b; Orchard et al., 2009; Orchard et al., 2017)

2.4.5 Countries represented

Sixteen studies were conducted with an Australian cricketing population (Bayne et al., 2016; Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Dennis et al., 2008b; Hulin et al., 2014; Kountouris et al., 2012, 2013; Kountouris et al., 2018; Orchard, 2010; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Orchard et al., 2017; Portus et al., 2004a; Saw et al., 2011). Seven studies were conducted with South African cricketers (Gray et al., 2016; Martin et al., 2017a; Martin et al., 2017b; Olivier et al., 2017; Olivier & Gray, 2018; Olivier et al., 2014; Olivier et al., 2015). Three studies were conducted on English and Welsh cricketers (Ahmun et al., 2019; Ranson et al., 2010; Warren et al., 2018)

2.4.6 Playing positions

Twenty-one studies exclusively investigated risk factors in fast and fast-medium bowlers (Bayne et al., 2016; Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Dennis et al., 2008b; Gray et al., 2016; Hulin et al., 2014; Kountouris et al., 2012, 2013; Kountouris et al., 2018; Martin et al., 2017a; Martin et al., 2017b; Olivier et al., 2015; Orchard, 2010; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Portus et al., 2004a; Ranson et al., 2010; Warren et al., 2018). The remaining five studies examined risk factors in all player types (Ahmun et al., 2019; Olivier & Gray, 2018; Olivier et al., 2014; Orchard et al., 2017; Saw et al., 2011).

2.4.7 Risk factors

In total there were 12 risk factors reported across those studies. Workload was the most commonly cited risk factor for injury in cricket and was reported in 11 studies (Ahmun et al., 2019; Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Hulin et al., 2014; Kountouris et al., 2018; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Saw et al., 2011; Warren et al., 2018). Five studies identified lumbopelvic control and balance as a risk factor (Bayne et al., 2016; Martin et al., 2017b; Olivier & Gray, 2018; Olivier et al., 2014; Olivier et al., 2015). Five studies identified muscle morphology as a risk factor (Gray et al., 2016; Kountouris et al., 2012, 2013; Martin et al., 2017a; Olivier et al., 2017). Four studies identified previous injury as a risk factor (Olivier & Gray, 2018; Orchard, 2010; Orchard et al., 2015a; Orchard et al., 2017). Four studies identified lower limb mechanics as an injury risk factor (Dennis et al., 2008b; Martin et al., 2017a; Martin et al., 2017b; Olivier & Gray, 2018). Other risk factors were reported, but identified by fewer studies. Two studies reported bowling kinematics (Bayne et al., 2016; Portus et al., 2004a) and radiological findings (Kountouris et al., 2018; Ranson et al., 2010) as risk factors. Only single studies reported the following risk factors: upper limb mechanics (Olivier & Gray, 2018), player type (Orchard et al., 2017), match location (Orchard et al., 2017), playing season (Orchard et al., 2017), and wellness (Ahmun et al., 2019).

2.4.8 Workload

The literature review identified workload as the most studied risk factor for cricket-related injury. A systematic review by Drew and Finch (2016) across a variety sports identified moderate level evidence of a relationship between training loads and increased risk of injury or illness. Load can be broadly categorised as internal or external. Internal workload is defined as a perceived individual effort and is typically expressed as a rate of perceived exertion on a 10-point Likert scale (Foster et al., 2001). External workload is quantified objectively as a measure of exposure whether that being distance covered, number of balls bowled, or duration of activity. Internal and external workloads can be multiplied together to produce an "arbitrary unit" (Gabbett, 2016). Gabbett (2016) describes that by using this arbitrary unit, calculation of acute workload (seven-day sum) and chronic workload (28-day sum) to produce an acute:chronic ratio can express increases or decreases in load. Using this concept, Gabbett (2016) demonstrated that rapid and excessive increases in load are responsible for a large proportion of non-contact soft tissue injuries. This is particularly relevant for cricket which is a non-contact sport. The findings by Gabbett (2016) that changes in load are associated with injury risk are reflected in all 11 studies of workload identified in the literature review (table 2.4).

Table 2.4 *Summary of studies investigating workload as a risk factor for injury in cricket*

Study	Population	Injury definition and type	Study results
Ahmun et al. (2019)	39 male adolescent international age group cricketers (mean = 17.5, SD = 0.8 years)	As defined by Orchard, Ranson, et al. (2016)	High (>0.35) 3-day workload associated with increased risk of injury (RR = 2.51; CI: 1.70–3.70; $p < 0.01$) High (>0.67) 14-day workload associated with an increased risk of injury (RR = 1.48; CI: 1.01–2.70; $p = 0.01$)
Dennis et al. (2004)	Australian New South Wales state squad male fast or medium-fast bowlers N = 12 Age = 21-34 (mean = 25.2 years)	A condition that affected availability for team selection Injuries were a mechanism of gradual bowling	Injured bowlers bowl more frequently than uninjured bowlers, mean = 1.9 (SD = 1.5) vs 3.2 (SD = 3.3) days between sessions ($p < 0.01$) Bowling ≥5 sessions in 7-day period may increase injury risk x4.5 (95% CI: 1.0-20.1) Increased deliveries per session 8-21 days prior to observed in injured bowlers (mean = 77) compared to rest of season (mean = 60), $p < 0.02$ Injured bowlers (mean = 235, SD = 30) bowl more than uninjured bowlers (mean = 165, SD = 23) per week ($p < 0.01$) Bowlers with >203 deliveries per week increased injury risk (RR = 6.0, 95% CI: 1.00-35.91) Bowling over mean average (>522 match deliveries) in a 30-day period increased injury risk ($p < 0.01$)

Dennis et al. (2003)	Male Australian fast and fast-medium state squad bowlers Age = 18-38 (mean = 27 years) 2000-2001 and/or 2001-2002 N = 90	As defined by Orchard et al. (2002)	Bowlers with average of <2 days (95% CI: 1.6-3.5) or ≥5 days (95% CI: 1.1-2.9) between bowling sessions were at increased risk of injury 2000-2001: bowling average <6 days between training sessions x1.8 injury risk vs bowling ≥6 days between training sessions (95% CI: 1.1-3.0) 2001-2002: bowling with <6 days between training sessions x2 injury risk vs bowling ≥6 days between training sessions (95% CI: 1.5-2.7) Bowling <40 deliveries per session increased injury risk (RR = 1.2, 95% CI: 0.8-1.9) vs bowling average >40 deliveries per session Bowling average <123 deliveries per week (RR = 1.4, 95% CI: 1.0-2.0) or >188 deliveries per week (RR = 1.4, 95% CI: 0.9-1.6) increased risk of injury vs bowling average of 123-188 deliveries per week
Dennis et al. (2005)	Male Australian junior fast bowlers 2002–2003 season N = 44 Age = 14.7 (SD = 1.4 years)	As defined by Orchard et al. (2002) Injuries were overuse type injuries as a result of bowling.	Injured bowlers bowled with greater frequency than uninjured bowlers (median 3.2 v 3.9 days between bowling days, *M* rank: 171.0 and 819.0, respectively, Mann-Whitney $U = 105.0$, $p = 0.038$) No association found between the average number of deliveries bowled per week and injury Compared with bowlers with an average of >3.5 rest days between bowling, bowlers averaging ≥3.5 rest

			days between bowling were at increased risk of injury (RR = 3.1, 95% CI: 1.1-8.9)
Hulin et al. (2014)	Australian New South Wales and Victoria state cricket squad fast bowlers N = 28 Mean age = 26 (SD = 5 years)	An injury was defined as any non- contact injury that resulted in a loss of either match-time or greater than one training session over a one-week period.	Higher external workloads in the current week associated with a lower injury risk ($p = 0.0001$) Higher chronic external workloads in the current week ($p = 0.002$) and subsequent week ($p = 0.017$) associated with lower injury likelihood Acute > chronic workload associated with increased injury risk week following exposure for internal workload (RR = 2.2, CI: 1.91-2.53, $p = 0.009$) and external workload (RR = 2.1, CI: 1.81-2.44, $p = 0.01$) Internal workload training-stress balance >200% had injury relative risk of 4.5 (CI: 3.43-5.90, $p = 0.009$) vs internal training-stress balance of 50%-99%, and 3.4 (CI: 1.56 to 7.43, $p = 0.032$) vs training-stress balance 0–49%. Internal workload training-stress balance of 150%-199% injury RR = 2.1 (CI: 1.25-3.53, $p = 0.035$) vs training-stress balance of 50%-99% External workload training-stress balance >200% injury relative risk of 3.3 (CI: 1.50-7.25, $p = 0.033$) vs external training-stress balance of 50%-99%, and 2.9 (CI: 1.14 to 7.40, $p = 0.044$) vs training-stress balance <49%
Kountouris et al. (2018)	Australian junior elite fast bowlers N = 65	The participant was unable to bowl for a period in the season	When BMO detected 2 weeks prior to the National Championships (period of high load), risk of BSI RR = 18.9 (95% CI: 2.7-134.3), OR = 44.8 (95% CI: 5.1–390.3)

	Age range 14.7–18.8 (mean = 17.3 years)		Percentage of days bowled in training higher in-season in those who sustained a BSI vs those who did not – preseason: 39% (SD = 23) vs 26% (SD = 10), p = 0.002; in-season: 41% (SD = 20) vs 29% (SD = 9), p = 0.002; full-season: 26% (SD = 6) vs 21% (SD = 5), p = 0.001) Percentage of days bowled in training higher in-season in those who had BMO vs those who did not during the pre-season: 32% (SD = 17) vs 23% (SD = 8), p = 0.013; and over the full season: 23% (SD = 6) vs 19% (SD = 6), p = 0.010 Fewer days between training sessions in those who sustained a BSI vs those who did not: 10 days (SD = 6) vs 19 days (SD = 8), $p < 0.001$ Increased days between sessions strong negative predictor of BMO detected in the next 4–12 weeks, OR = 0.98 (95% CI: 0.96-1.00, $p \leq 0.010$) Days bowled per week trivially higher on average for those who sustained a BSI of 2.1 days (SD = 0.4) vs 1.8 days (SD = 0.4) for no injury (p = 0.051), and most likely trivially higher for participants who had BMO during the study of 2.0 days (SD = 0.4) vs 1.8 days (SD = 0.4) for no BMO (p = 0.015) Days bowled per week in preceding 12 weeks (OR = 2.8, 1.2–6.5, p = 0.021) and 8 weeks (OR = 2.4, 1.3–4.2, p = 0.004) was a positive predictor of BSI. Days

			bowled per week in preceding 4 weeks were a positive predictor of BMO (OR = 1.2, 1.0–1.5, $p = 0.036$) Days between bowling sessions likely lower on average for those who sustained a BSI (1.7 days, SD = 0.5) vs 2.4 days (SD = 0.8) for no injury, $p = 0.004$; and likely lower for those who had BMO during the study of 2.0 days (SD = 0.6) vs 2.6 days (SD = 0.9) for no BMO, $p = 0.007$ Days between sessions in the preceding 12 weeks (OR = 0.4, 0.2–0.8, $p = 0.005$) and 8 weeks (OR = 0.5, 0.3–0.8, $p = 0.009$) a strong negative predictor of BSI
Orchard et al. (2015b)	Australian First-Class fast bowlers N = 235	As defined by Orchard et al. (2005) Acute non-contact bowling mechanism or a gradual onset bowling mechanism	Fast bowlers bowling >50 match overs in a 5-day period vs <50 match overs, increased injury risk over the next month (RR = 1.54, 95% CI: 1.04-2.29, $p < 0.05$)
Orchard et al. (2015a)	Australian First-Class fast bowlers N = 235	As defined by Orchard et al. (2005) Acute non-contact bowling mechanism or a gradual onset bowling mechanism	Tendon injury risk in next 21 days increased in bowlers with acute match workload ≥50 overs (OR = 3.69, 95% CI: 1.82-8.24, $p < 0.01$), a career workload ≥1200 overs (OR = 2.38, CI: 1.65-3.42, $p < 0.01$), previous season workload ≥400 overs (OR = 2.01, CI: 1.38-2.94, $p < 0.01$), a previous injury of any type during the season (OR = 1.85, CI: 1.33-2.55, $p < 0.01$), playing a limited overs match of ≤10 overs (OR = 1.67, CI: 1.15-2.42, $p < 0.01$)

			Protective effect on tendon injury in next 21 days in those bowling ≥150 overs in previous 3 months (OR = 0.29, CI: 0.17-0.50, $p < 0.01$), and having ≥3000 career overs (OR = 0.24, CI: 0.11-0.52, $p < 0.01$) Bone stress injury in next 28 days increased in fast bowlers who bowled ≥150 overs in previous 3 months (OR = 2.10, CI: 1.48-2.99, $p < 0.01$), or had previous injury the same season (OR = 1.71, CI: 1.25-2.34, $p < 0.01$) Protective effect on bone stress injury in next 28 days increased in fast bowlers ≥1200 career overs (OR = 0.31, CI: 0.21-0.45, $p < 0.01$) Muscle injury in next 21 days increased in fast bowlers playing a limited overs match of ≤10 overs (OR = 1.34, CI: 1.08-1.67, $p < 0.01$) Protective effect on muscle injury in next 21 days increased in fast bowlers with ≥400 overs in previous season (OR = 0.71, CI: 0.53-0.95, $p = 0.02$) Joint injury in next 28 days increased in fast bowlers with ≥450 previous season overs (OR = 1.96, CI: 1.14-3.37, $p = 0.02$), ≥3000 career overs (OR = 1.84, CI: 1.02-3.31, $p = 0.04$)
Orchard et al. (2009)	Australian First-Class fast bowlers N = 129 fast bowlers	As defined by Orchard et al. (2005)	Bowling >50 vs ≤50 match overs increased risk of injury per 1000 overs over next 21 days (OR = 1.77; 95% CI: 1.05-2.98), and next 28 days (OR = 1.62, CI: 1.02-2.57) after event

		Injuries incurred in fast bowling only, including either acute non-contact bowling mechanism or gradual-onset bowling mechanism injuries	Bowling >30 match overs in 2^{nd} innings increases injury risk over next 28 days (RR = 2.42, CI: 1.38-4.26) following event
Saw et al. (2011)	Australian, New South Wales elite male cricketers N = 28 Age range = 18-32 years Mean age = 24.4 (SD = 3.9 years)	A condition that caused a player to present to the state team physiotherapist complaining of shoulder or elbow pain that was associated with throwing	Injured players threw approximately >40 throws (p = 0.04) than uninjured players per week Injury risk increased in players throwing >75 throws per week (RR = 1.73, 95% CI: 1.03-2.92) In the week prior to injury, injured players increased mean number days throwing per week by approximately 2 days (4.14 vs 2.37, $p < 0.01$), mean throws per week by approximately 39 throws (146.14 vs 107.23, $p < 0.05$), and had fewer mean rest days (0.73 vs 2.92, $p < 0.01$) compared to all other weeks preceding injury
Warren et al. (2018)	English and Welsh National level male fast bowlers N = 23 Age range = 15-18 Mean age = 16.7 (SD = 1.2 years)	All non-contact injuries considered to be fast bowling related that resulted in a loss of either match or training time	Injury risk increased over the subsequent 4 weeks with 2 standard deviation acute workload of 130 balls (RR = 4.16, 90% CI: 2.55-6.78, $p < 0.01$) Injury risk increased over the subsequent 4 weeks with 2 standard deviation chronic workload of 96 balls (RR = 5.19, 90% CI: 3.05-8.82, $p < 0.01$) Acute:chronic workload of ≥142% increased injury risk in the subsequent 4 weeks (RR = 1.66, 90% CI: 1.06–2.59, p = 0.06) compared to <87% workload

	High chronic workload (>83 balls) reduced the influence of a high (>108%) acute:chronic workload ratio on injury risk in the subsequent 4 weeks (RR = 0.35, 90% CI: 0.17–0.74)

Note: RR = relative risk; CI = confidence interval; SD = standard deviation; BSI = bony stress injury; BMO = bone marrow oedema; OR = odds ratio

2.4.9 Summary

This literature review identified 26 studies that investigated risk factors for injury in cricket. The identified studies however, applied various methodologies including definition of injury, body regions under investigation, level of participation, age range, country of origin, and playing position. Therefore the identified risk factors cannot be broadly applied to all cricketing contexts. Workload was the most studied risk factor in cricket and has been explored in other sports. Identifying risk factors for injury is the second step for injury prevention in the van Mechelen et al. (1992) model so the relationship between workload, exposure, and injury is therefore of interest in this study. These findings may influence recommendations regarding targeting risk factors with interventions that reduce injury risk as per the third step in the van Mechelen et al. (1992) injury prevention model.

Chapter 3 - Methods

Introduction

The participants under investigation in this study were elite New Zealand domestic and international cricketers from seasons 2009-2010 to 2014-2015. Injury surveillance and match data for these players was prospectively captured using New Zealand Cricket's injury surveillance system. Those seasons of interest were then retrospectively analysed for this study. The following section will describe this process.

3.1 Study design

A retrospective descriptive epidemiological study. This study was approved by the Auckland University of Technology Ethics Committee (AUTEC), Ethics Application Number 16/121.

3.2 Participants

The participants in this study were contracted male New Zealand cricketers from each of the six domestic teams from seasons 2009-2010 to 2014-2015 inclusive. Players who were selected to represent New Zealand at the international level were drawn from this domestic cohort and could therefore be counted as domestic or international players through various times of the season.

Players were classified as fast-medium bowlers, slow-spin bowlers, batters, or wicket keepers according to their primary role as determined by New Zealand Cricket. Domestic cricket matches included First-Class matches, One Day matches, and Twenty20 matches. International cricket matches were Test matches, One Day matches and Twenty20 matches.

3.3 Surveillance method

The physiotherapist for each of the six New Zealand domestic cricket teams and the New Zealand international representative team was tasked with prospectively providing data for the New Zealand Cricket injury surveillance system. The domestic cricket seasons were played over seven consecutive months from October to April. The international cricket seasons were defined from July to June. The injury surveillance system recorded all match exposure and injury data over the six seasons from 2009-2010 to 2014-2015. Training exposure was not collected. To accurately capture player participation status, collected data included:

a. Game days and match format played by each player.
b. Absence due to new or recurrent injury or illness, and whether this occurred during a training or match.
c. Injury type and body region.
d. If a player was not selected or rested from play.
e. If a match was not played due to poor weather.
f. If a player was unavailable due to suspension or other commitments.

The coding template for reporting player status can be seen in Appendix B. The captured data was cross-checked by the New Zealand Cricket injury surveillance coordinator then collated into a Microsoft Excel database. This database was given to the primary researcher with player's assigned an identification number rather than their name to maintain anonymity. This database was prepared into a SPSS Statistics dataset, from which descriptive statistical analysis, injury incidence, and prevalence rates could be calculated.

3.4 Definitions and methods

The definitions and methods presented below are consistent with the consensus statements of Orchard et al. (2005) and Orchard, Ranson, et al. (2016).

3.4.1 Injury definition

Injury was defined in the surveillance method as any injury or other medical condition that prevented a player from participating in a normal season match. This time-loss definition is consistent with recommendations by Orchard et al. (2005) which was the current consensus statement for cricket injury surveillance during seasons 2009-2010 to 2014-2015. Injuries were classified as either a new training injury, a new match injury, a recurring injury, or illness.

3.4.2 Injury recovery definition

In the surveillance method an injury was considered to have recovered once a player returned to full participation in at least one match of any type (Orchard et al., 2005).

3.4.3 Definition of injury recurrence

A recurrent injury was defined as an injury that occurred to the same side, body part, and injury type, as an injury earlier in the same season that had recovered (Orchard et al., 2005).

3.4.4 Definition of surveillance cohort

For comparative purposes, a squad is standardised to 25 players (Orchard et al., 2005). Each of the six seasons were analysed as separate cohorts. Warm up and preseason matches, or injuries incurred in these matches, were not included in the surveillance data.

3.4.5 Calculations of exposure rates with a time-based denominator

Player hours of exposure per team is an important calculation to understand as it is required to calculate incidence. It is further complicated when factoring in various match formats of cricket. Player hours of exposure per team is calculated by multiplying the number of players per team by the designated hours of play for a match. During play there are 13 players on the field (two batting from one team, and eleven from the bowling and fielding team) and as each team will bat and bowl in the course of a match it is therefore considered that 6.5 players per team are exposed to injury at any given time. It is assumed and standardised that matches are played at a rate of 15 overs per hour. Therefore calculating designated hours of play requires dividing total scheduled overs for a match format by 15 (Orchard et al., 2005). Table 3.1 lists the exposures for the match formats observed in this cohort using unrounded figures as per guidelines, and the equations to calculate exposure are presented below:

Table 3.1 *Exposure rates for cricket match formats*

Match type	**Players per team**	**Total scheduled overs**	**Total designated hours of play**	**Total player hours of exposure per team**
Twenty20	6.5	40	$2.6\dot{6}$	$17.3\dot{3}$
One Day	6.5	100	$6.6\dot{6}$	$43.3\dot{3}$
Domestic First-Class (4 days, 90 overs per day)	6.5	360	24	156
Test match (5 days, 90 overs per day)	6.5	450	30	195

$$\textit{Player hours of exposure per team} = \textit{Players per team} \times \textit{Designated hours of play}$$

$$\textit{Designated hours of play} = \frac{\textit{Total overs scheduled}}{15}$$

3.4.6 Calculation of match incidence with a time based denominator

Match injury incidence is the number of new or recurrent match injuries that occur in a population over a specified time period. In this equation the numerator is number of injuries incurred in a match and the denominator is player exposure. To be consistent with the international cricket reporting standards of Orchard et al. (2005) the value is expressed as 10,000 player hours of exposure. The updated consensus by Orchard, Ranson, et al. (2016) recommends expressing incidence per 1,000 player days. These equations can be seen below:

$$\textit{Match injury incidence rates per 10,000 player hours} = \frac{\textit{Number of match (new and recurrent) injuries}}{\textit{Hours of exposure}} \times 10{,}000$$

$$\textit{Match injury incidence rates per 1,000 player days} = \frac{\textit{Number of match (new and recurrent) injuries}}{\textit{Player match days}} \times 1{,}000$$

3.4.7 Seasonal injury incidence

Orchard et al. (2005) reports that seasonal injury incidence considers the number of injuries occurring per squad per season. In this calculation the numerator is the total number of match and training injuries (new and recurring) multiplied by the squad season. A squad season standardised as 1500 player days (25 players multiplied by 60 days). The denominator is the total number of days actually played (excluding washed out games) multiplied by the number of players in the squad. This equation is presented below:

$$\textit{Seasonal injury incidence rates per squad per season} = \frac{\textit{Number of total injuries} \times (\textit{season length} \times \textit{squad size})}{\textit{Days played} \times \textit{squad size}}$$

3.4.8 Annual injury incidence

Orchard, Ranson, et al. (2016) in the updated consensus on injury surveillance in cricket recommended using annual injury incidence per 100 players per year, rather than seasonal injury incidence. To be consistent with this recent consensus and recent publications (Orchard, Kountouris, et al., 2016) this will be expressed by body site in this study. This equation is below:

$$\textit{Annual injuries per 100 players per year} = \frac{\textit{Match injuries (new and recurrent)}}{\textit{Match days played}} \times 100$$

3.4.9 Match injury prevalence

Match injury prevalence considers the proportion of squad members unavailable for selection due to injury. It is expressed as a percentage to represent the average percentage of players unavailable through injury for a given cohort for a given exposure period. Match injury prevalence considers the numerator as the number of missed match days and the denominator to be the number of total match days for a given period (excluding training days) multiplied by squad members exposed. Match injury prevalence can be expressed as a total of all injuries per season or per body site. The equation for match injury prevalence presented below considers the average squad size to be 25 players (Orchard et al., 2005):

$$\textit{Match injury prevalence} = \frac{\textit{Missed match days}}{\textit{Number of match days} \times \textit{squad members exposed}}$$

3.4.10 Injury incidents and match days lost

To capture the total number of injuries incurred, and their impact, the number of new and recurring injuries from matches and trainings were drawn from the dataset. These injuries will be expressed by body site, body region, and by player type. If a recorded injury was missing a code for a body site or a body region it was labelled in the dataset as unconfirmed. The number of match days lost per injury were also drawn from the dataset to describe the impact of injury in terms of lost match playing time.

3.4.11 Relationship between workload and injury

To observe the relationship between workload and injury, match exposure hours (workload) is plotted with the number of injuries against the combined monthly totals for domestic and international teams from seasons 2009-2015.

3.4.12 Data analysis

The purpose of the data analysis was to describe epidemiological findings from 2009-2015, to be able to compare to previous reports from 2002-2008 (Frost & Chalmers, 2014). Statistical analysis would then assess for relationships between variables to further build on the work by Frost and Chalmers (2014).

All data was initially analysed descriptively to ensure there were no extreme outliers. Continuous data was assessed for normal distribution. Means and standard deviations were calculated. Frequencies were calculated for categorical data. Descriptive analysis was performed to determine injury frequency and match days lost, injury incidence rates, and injury prevalence rates. These were sub-divided by season, playing level, match format, playing position, body site, and body region where appropriate.

To compare demographic differences between domestic and international level playing groups *t*-tests were used. Chi-squared analysis was used to assess for differences of injury status between domestic and international level playing groups, and for differences of injury status between playing positions. A linear regression model was constructed to assess for any relationship between match hour exposure and injury frequency while accounting for playing level and the time of the season.

The statistical analysis was conducted using IBM SPSS Statistics for Mac, version 25 (IBM Corp., Armonk, N.Y., USA), with alpha levels set at 0.05 (95% confidence level).

Chapter 4 – Results

Introduction

This chapter will first present the characteristics of the participants in this study. Exposure rates will be presented in terms of match days played and match hours. Incidence and prevalence rates are described in formats consistent with the cricket injury surveillance consensus statements by both Orchard et al. (2005) and Orchard, Ranson, et al. (2016) to compare to previous epidemiological data by Frost and Chalmers (2014), and to be consistent with current reporting standards. Figures of incidence and prevalence rates will be presented in this chapter with source data included in Appendix C. The final section will explore the relationship between injury status and playing level, playing position, and the relationship between match exposure and injury with statistical analysis.

4.1 Participants

Data was retrospectively analysed from the New Zealand Cricket injury surveillance system. This system included six New Zealand domestic cricket teams and the New Zealand international representative cricket team across six seasons between 2009-2015. A total of 873 domestic level athletes made up the cohort under surveillance. From this cohort 216 athletes represented New Zealand internationally. Therefore, a total of 1,089 participants were reported on in the injury surveillance dataset. Each recurring injury was recorded in the injury surveillance dataset, capturing injury status in 991 domestic competition cricketers and 281 international level cricketers, analysing 1,272 final dataset entries.

The participants ranged in age from 17 to 40 years with a mean age of 28.2 years (SD = 4.6 years) for domestic level players, and mean age of 28.9 years (SD = 4.0) for international level players. Analysis of participant ages demonstrated a normal distribution. Body mass index (BMI) of the participants ranged from 20.9 to 34.7kg/m^2 with a mean BMI of 25.8kg/m^2 (SD = 2.2) for domestic level players, and mean BMI of 25.9 kg/m^2 (SD = 2.4) for international level players. Analysis of BMI demonstrated a normal distribution. All athletes under surveillance were male. Further demographic information of participant characteristics can be seen in table 4.1.

Table 4.1 *Participant characteristics*

	Domestic	**International**
Number of participants (n)	873	216
Age range (years)	17 – 40 years (mean = 28.2, SD = 4.6)	18 – 38 years (mean = 28.9, SD = 4.0)
BMI mean (kg/m^2)	25.8 (SD = 2.2)	25.9 (SD = 2.4)
Player type (n)		
Bowler (fast-medium)	361 (41.4%)	90 (41.7%)
Bowler (slow-spin)	111 (12.7%)	30 (13.9%)
Batter	338 (38.7%)	76 (35.2%)
Wicket keeper	63 (7.2%)	20 (9.3%)

Note. BMI = body mass index, SD = standard deviation

An independent samples *t*-test was conducted to first compare mean age, then BMI for domestic and international cricketers. There was no significant difference in age (p = 0.07) or BMI (p = 0.08) between domestic and international cricketers.

While performing the independent samples *t*-tests, it was acknowledged that international level players were selected from the domestic competition playing group. However, analysis was conducted assuming these players were from different cohorts.

4.2 Exposure rates

Figure 4.1 displays the number of match days played per match format for seasons between 2009-2015. Figure 4.2 displays the team player hours of exposure for each match format per season. Exposure hours are calculated by multiplying the number of players per team by the designated hours of play for each format (table 3.1). In the domestic cricket competition First-Class matches contribute to the most exposure hours followed by One Day then Twenty20 formats for all seasons. In the international competition, players were most exposed to the Test cricket format followed by One Day then Twenty20 formats in three seasons. Seasons 2010-2011 and 2014-2015 coincided with the International Cricket Council World Cup, played in One Day format hence greater exposure hours for One Day matches in those seasons.

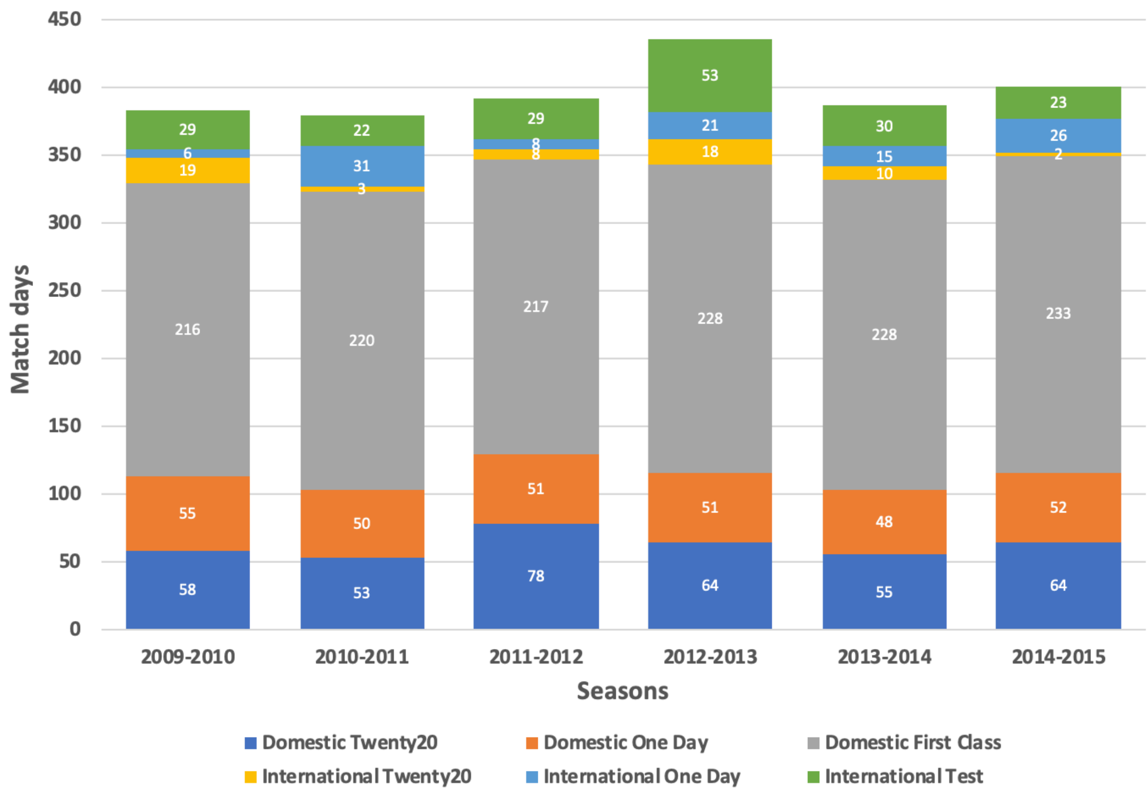

Figure 4.1 Match days played between 2009-2015.

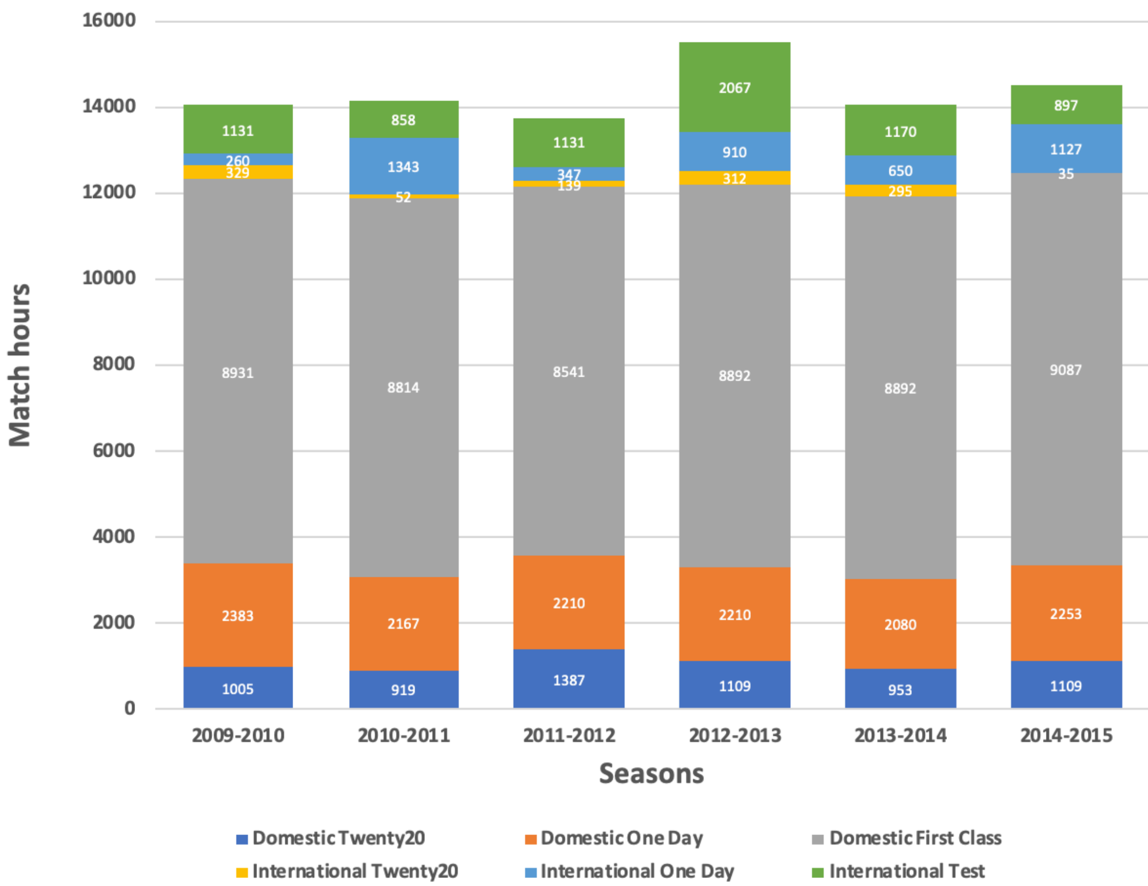

Figure 4.2 Team exposure hours per match format per season.

4.3 Match injury incidence of new and recurrent injuries per 10,000 player hours

Match injury incidence of new and recurrent injuries per 10,000 player hours (figure 4.3) was calculated by dividing the number of new and recurrent match injuries by the total exposure hours. In the domestic cricket competition, Twenty20 matches recorded the highest injury incidence of all match formats across all seasons. Domestic Twenty20 match incidence per 10,000 player hours varied the most across seasons (51.8 – 144.2) compared to the domestic One Day (24.0 – 64.6) and domestic First-Class (27.5 – 46.6) match formats. Total domestic match injury incidence per 10,000 player hours appeared to reduce over the course of the study period from 50.8 injuries per 10,000 player hours in season 2009-2010 to 36.9 injuries per 10,000 player hours in season 2014-2015.

In international competition, the Twenty20 match format had large variability between seasons, recording 576.9 injuries per 10,000 player hours in 2010-2011 and no match injuries in 2011-2012. The Test cricket match format generally recorded the lowest match injury incidence of all international cricket formats as well as compared to all domestic cricket match formats.

Total domestic and international match injury incidence per 10,000 player hours was seen to reduce over the course of the seasons (figure 4.3). International One Day match injury incidence rates per 10,000 player hours was particularly seen to reduce over the study period.

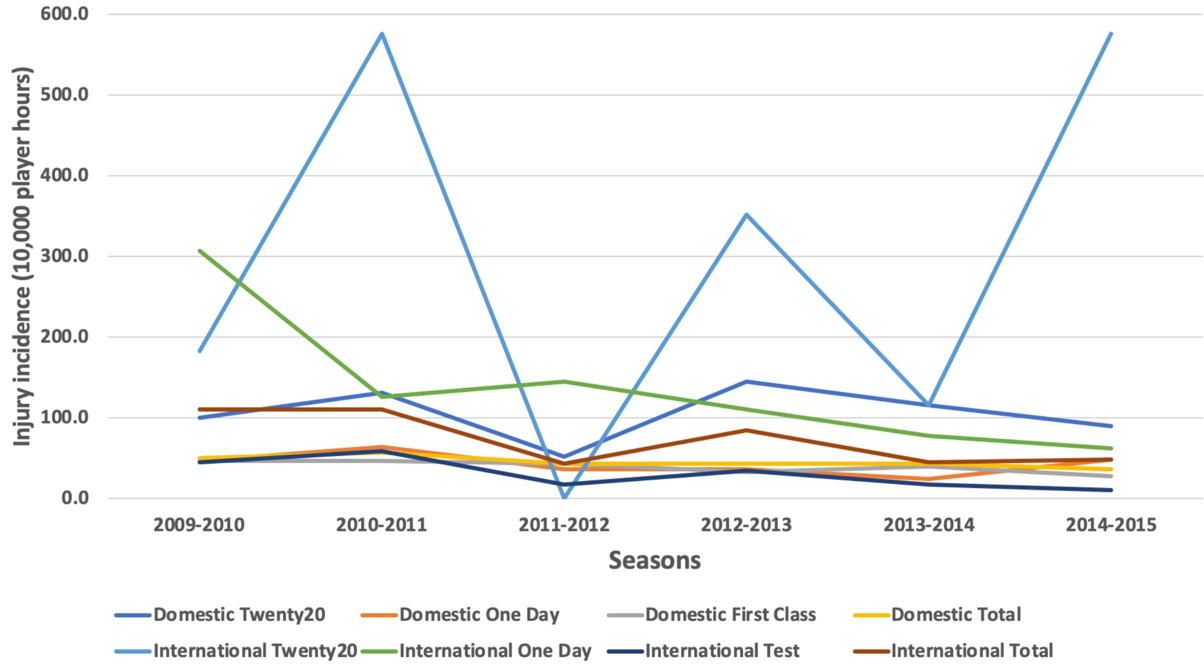

Figure 4.3 Match injury incidence of new and recurrent match injuries per 10,000 player hours per format per season.

4.4 Match injury incidence of new versus recurrent injuries per 10,000 player hours

Figure 4.4 demonstrates match injury incidence of injuries per 10,000 player hours for new injuries only (excluding recurring injuries). These incidence rates are naturally lower than those in figure 4.3 as fewer injuries are captured in this expression of injury incidence. Domestic Twenty20 matches recorded the highest new injury incidence rate across the domestic cricket formats in all but the 2011-2012 season.

The international Twenty20 format also showed variability between seasons ranging from 0 to 571.4 new match injuries per 10,000 player hours. The international One Day and Test match formats also varied in new match injury incidence rates with 62.1–192.3 injuries per 10,000 player hours, and 0–6.6 injuries per 10,000 player hours respectively.

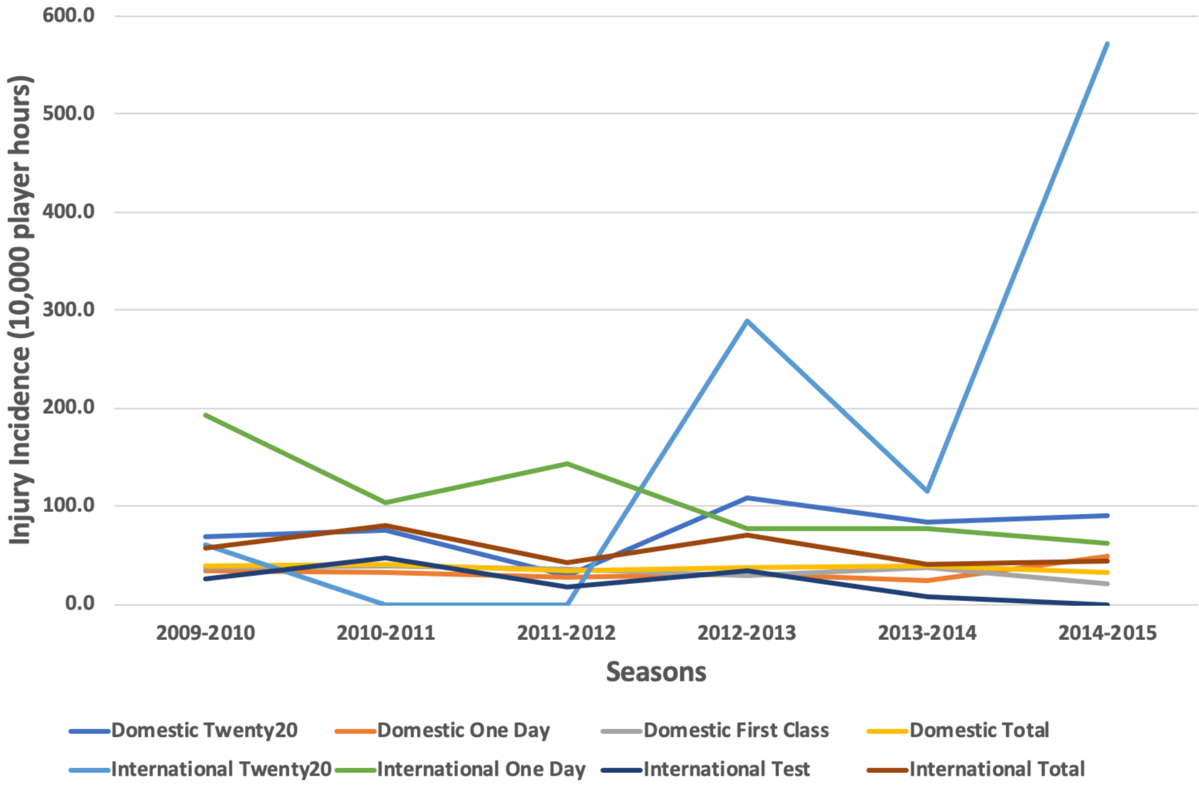

Figure 4.4 Match injury incidence of new (excluding recurrent) injuries per 10,000 player hours per format per season.

Figure 4.5 demonstrates the injury incidence rate of recurring match injuries only. It can be seen that the injury incidence rates of recurring match injuries per 10,000 player hours reduced from 2009 to 2015 in the domestic competition, and more so in the international level of play.

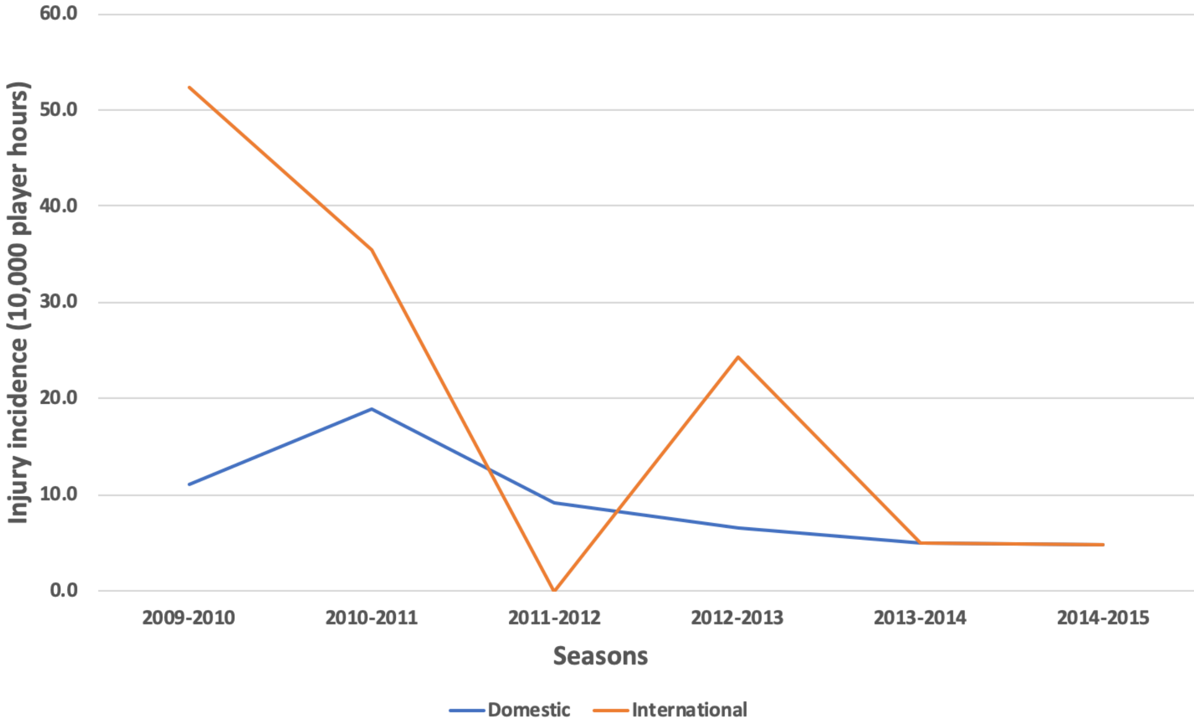

Figure 4.5 Match injury incidence of recurrent injuries per 10,000 player hours per season.

4.5 Match injury incidence per 1,000 player days

Match injury incidence per 1,000 player days was calculated by dividing the number of new and recurrent match injuries by the number of player match days, as described in the methods section. When match injury incidence is presented per 1,000 player days (figure 4.6), domestic Twenty20 matches are no longer the domestic cricket match format with the consistently highest match injury incidence rate. In seasons 2009-2010 and 2011-2012, domestic Twenty20 matches demonstrated the lowest match injury incidence in the domestic competition. However, domestic One Day and First-Class matches also alternated between lowest and highest new and recurrent match injury incidence rates per 1,000 player days between seasons.

For international cricket match formats, new and recurrent match injury incidence rates per 1,000 player days varied between seasons. International Test matches demonstrated the lowest match injury incidence rates in all, but the 2011-2012 season compared to other international cricket match formats. It was observed that total domestic and international match injury incidence per 1,000 player days reduced over the 2009-2015 study period.

While the observed injury incidence rate pattern across competitions between figure 4.3 and 4.6 is similar, the denominator of injuries per 1,000 player days presents injury rates more comparatively along the y-axis which may suggest more accurate comparison between match formats.

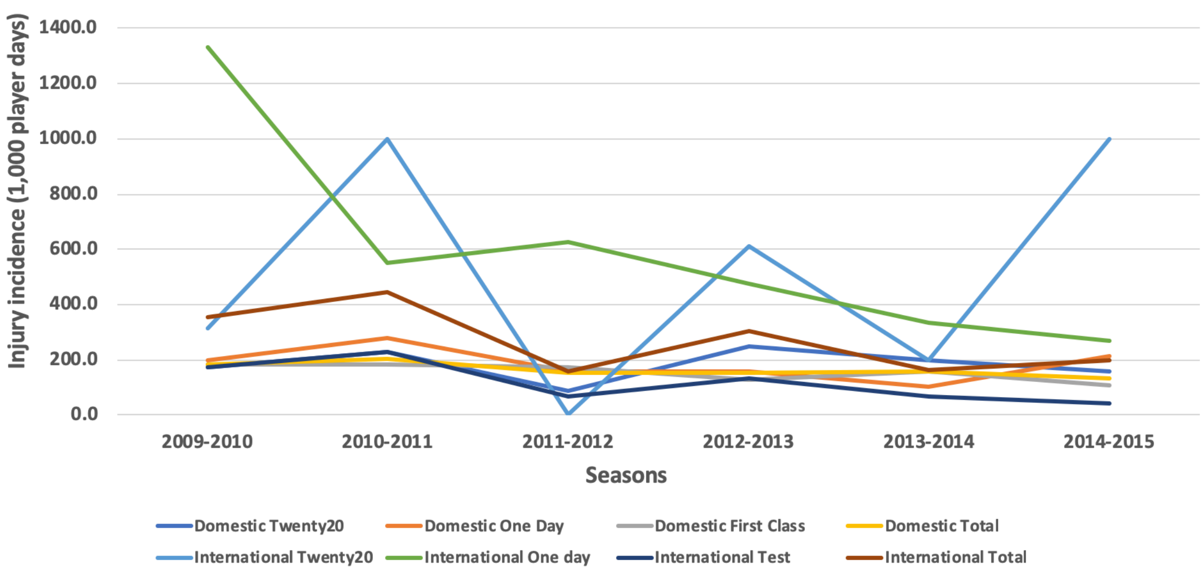

Figure 4.6 Match injury incidence of new and recurrent match injuries per 1,000 player days.

4.6 Seasonal injury incidence per squad per season

Figure 4.7 displays the seasonal injury incidence rates for all injury types (new match injuries, recurring injuries, and training injuries) per squad per season for the domestic and international teams. Domestic team seasonal incidence varied between 11.1 to 14.6 injuries per squad per season and did not clearly demonstrate change over the study period. International team seasonal incidence varied between 12.3 to 33.7 per squad per season and displayed a reduced seasonal injury incidence from 2009 to 2015.

International team seasonal incidence was greater than double compared to domestic seasonal incidence for two seasons. The difference between international and domestic team seasonal injury incidence was closer for the remaining four seasons, however, international team seasonal injury incidence only once lower than domestic team seasonal injury incidence.

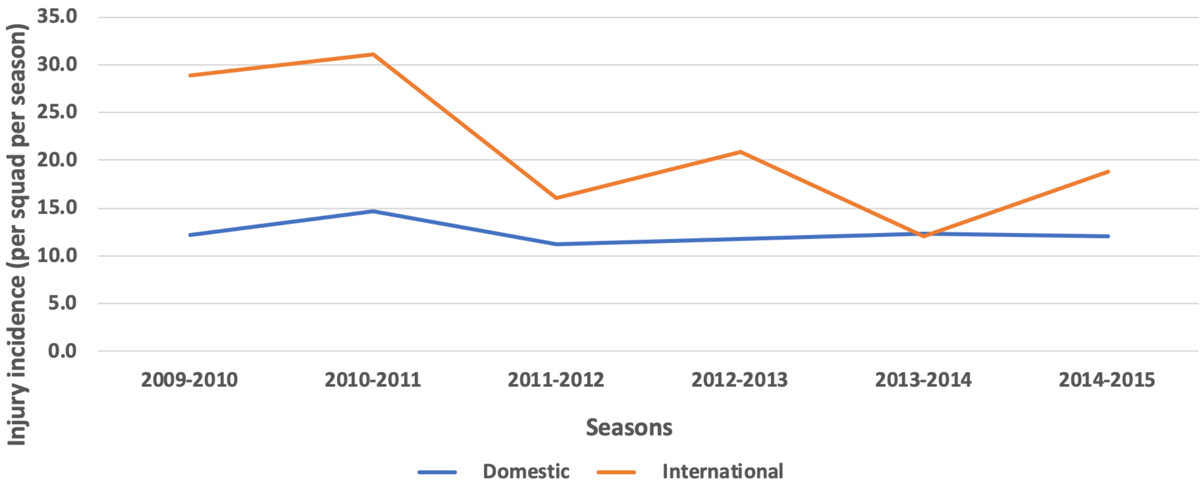

Figure 4.7 Seasonal injury incidence per squad per season.

4.7 Annual injury incidence per 100 players per year

Table 4.2 reports annual injury incidence expressed as 100 players per year. Over the study period, on average the highest annual injury incidences in domestic cricket were from unconfirmed injuries that were not coded to a body site in the injury surveillance system (1.6 injuries per 100 players per year), followed by hamstring (1.4 injuries per 100 players per year), then groin (1.3 injuries per 100 players per year) and knee injuries (1.3 injuries per 100 players per year). Unconfirmed injuries demonstrated the highest annual injury incidence per 100 players per year in only one season (2010-2011) in domestic cricket. Hamstring injuries demonstrated the highest annual injury incidence per 100 players per year most frequently, with two seasons (2012-2013 and 2013-2014).

In international cricket the highest average annual incidence rate was for illness (5.5 injuries per 100 players per year). This was followed by abdominal (3.7 injuries per 100 players per year) and groin injuries (3.7 injuries per 100 players per year), then hamstring (3.3 injuries per 100 players per year) and lumbar spine (3.3 injuries per 100 players per year) injuries. Illness and groin injuries appeared as the highest annual injury incidence in international cricket most frequently with two occasions each.

In every season of the study period, international annual injury incidence per 100 players per year was higher than in domestic cricket. In four of the six seasons under surveillance the annual injury incidence rate per 100 players per year for international level cricket was approximately double the domestic cricket injury rate.

Table 4.2 *Annual incidence of new and recurrent injuries per 100 players*

Season	2009-2010		2010-11		2011-12		2012-13		2013-14		2014-15		Average	
Playing level	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**
Concussion							0.3				0.3	2.0	0.3	2.0
Head	0.3	1.9	0.3	1.8	0.9						0.3		0.4	1.8
Eye									0.3				0.3	
Neck					0.3		0.3						0.3	
Shoulder	1.8		1.2		0.6		0.9	1.1	1.2		0.6	3.9	1.0	2.5
Upper arm				1.8					0.3				0.3	1.8
Elbow											0.3		0.3	
Arm			0.3		0.3	2.2		1.1					0.3	1.7
Wrist					0.3				0.3		0.3	2.0	0.3	2.0
Hand		1.9	1.2				0.6		0.3		0.6		0.7	1.9
Thumb	0.6	1.9	0.3		0.3		0.9		0.3	1.8			0.5	1.8
Finger	1.8		1.2	1.8	1.2	2.2	0.9	1.1	0.9	3.6	0.3	2.0	1.0	2.1
Chest							0.3						0.3	
Rib	0.9								0.6		0.6		0.7	
Lat	0.3												0.3	
Pec	0.3												0.3	
Thoracic spine			0.3										0.3	
Side	0.6		0.9	1.8	1.7		2.0	3.3	0.6	3.6	0.6	2.0	1.1	2.7
Oblique									0.3		0.3		0.3	
Abdomen	0.3	3.7	0.6		0.3		0.3		0.3				0.4	3.7
Lumbar spine	1.2		1.2	7.1	1.4		0.6	2.2	0.9	1.8	1.4	2.0	1.1	3.3
Glute				1.8										1.8
Hip		1.9					0.3		0.3				0.3	1.9
Groin	2.4	7.4	2.2	3.6	0.3	2.2	0.9	3.3	1.5	1.8	0.3	3.9	1.3	3.7
Thigh	0.9		0.6		0.3		0.9						0.7	
Quad	0.9		0.9	1.8	0.6		0.9	4.3	0.6				0.8	3.1
Hamstring	0.6	5.6	0.6	3.6	1.4		2.6	2.2	1.8		1.1	2.0	1.4	3.3
Knee	2.1	5.6	2.2	1.8	0.6		0.3	1.1	1.2		1.1		1.3	2.8
ITB					0.6								0.6	
Calf	0.6	1.9	0.3	3.6	0.9	4.4	0.9	2.2	0.6		0.6		0.6	3.0
Lower leg											0.3		0.3	
Shin					0.3		0.6				0.3		0.4	
Achilles			0.3	1.8	0.3			2.2	0.3		0.3		0.3	2.0
Ankle			0.6	3.6	0.9		0.6	2.2	1.5	3.6	2.0		1.1	3.1
Foot	0.3	3.7	0.6	0.0					0.6		0.6	2.0	0.5	1.9
Illness	0.6		1.5	8.9	1.2	4.4	0.6	3.3	0.9		1.1		1.0	5.5
Unconfirmed	1.5		2.8		0.6			1.1					1.6	1.1
TOTAL	18.2	35.2	20.4	44.6	15.0	15.6	15.5	30.4	15.7	16.4	13.2	21.6	16.3	27.3

4.8 Match injury prevalence rates by season

Injury prevalence considers the proportion of players unavailable for match selection due to injury, expressed as a percentage. This represents the percentage of players missing, on average, due to injury. Figure 4.8 describes this prevalence rate as an average for all six domestic cricket teams and the New Zealand international representative team for the seasons under surveillance.

Injury prevalence per season in domestic cricket ranged from 7.0% to 8.5% across the study period without an obvious observable change over time. Injury prevalence rates in international cricket ranged from 4.6% to 20.4%. In the first four seasons under surveillance the prevalence rate for the international team was higher than for the domestic competition, then lower in the final two seasons. It was observed that the prevalence rate in international competition reduce from 2009 to 2015.

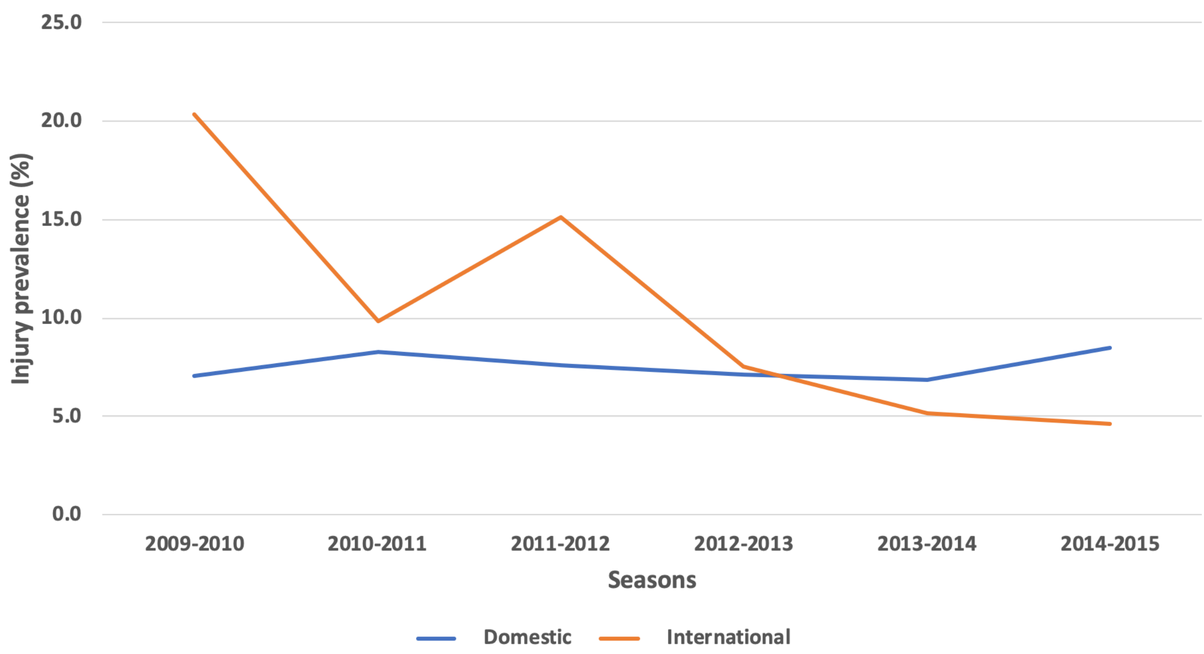

Figure 4.8 Injury prevalence rates (%) by season.

4.9 Match injury prevalence rates by body site

Table 4.3 describes the prevalence rate by body site for all six domestic cricket teams and the New Zealand international representative team for the seasons under surveillance. In the domestic competition the highest average prevalence rate for the study period was for lumbar spine injuries (0.8%), followed by side (0.7%) and ankle injuries (0.7%). Side and lumbar spine injuries appeared the most frequently with the highest prevalence rate across domestic competition seasons, with two occasions each.

In international competition, on average, knee injuries recorded the highest prevalence rate (2.6%), followed by hip (2.3%) then groin injuries (1.8%) across over the study period. However, knee injuries never demonstrated the highest prevalence rates overall for any season under observation in international competition. Lumbar spine and groin injuries recorded the highest injury prevalence rates most frequently, with two seasons each.

Table 4.3 *Injury prevalence rates (%) by body site and season*

Season	2009-2010		2010-11		2011-12		2012-13		2013-14		2014-15		Average	
Playing level	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**
Concussion											0.2	0.2	0.2	0.2
Head		0.1		0.1	0.1								0.1	0.1
Eye														
Neck		0.1												0.1
Shoulder	0.6	3.1	0.6		0.2		0.7	0.2	0.4		1.0	0.3	0.6	1.2
Upper arm				0.3					0.1				0.1	0.3
Elbow		0.1									0.4	0.2	0.4	0.2
Arm						0.2								0.2
Wrist											0.1	0.2	0.1	0.2
Hand		1.1	0.2				0.3		0.1		0.2		0.2	1.1
Thumb	0.1	0.7	0.1				0.3	0.6	0.7	0.9			0.3	0.7
Finger	0.6	0.1	0.4	0.1	0.6	1.2	0.5	0.1	0.4	0.1	0.4	0.2	0.5	0.3
Chest														
Rib	0.3								0.1		0.1		0.1	
Lat	0.4						0.2						0.3	
Pec	0.1												0.1	
Thoracic spine														
Side	0.2		0.5	0.8	1.4		1.3	0.5	0.3	0.6	0.6	0.2	0.7	0.5
Oblique									0.3		0.1		0.2	
Abdomen	0.3	1.3	0.2		0.1		0.1						0.2	1.3
Lumbar spine	0.5	0.4	0.9	0.8	1.3	4.9	0.3	0.3	0.7	0.4	1.2	1.4	0.8	1.4
Glute				0.1										0.1
Hip		0.1	0.1			4.4			0.1				0.1	2.3
Groin	1.6	5.4		2.3	0.2	0.8	0.1	0.7	0.5	0.7	0.1	1.1	0.5	1.8
Thigh	0.1		0.1		0.1		0.6						0.2	
Quad	0.3		0.5	0.3	0.3		0.2	0.9	0.1				0.3	0.6
Hamstring	0.2	0.3	0.5	0.3	0.4	0.4	1.1	0.4	0.8		0.6	0.3	0.6	0.3
Knee	0.9	5.1	0.9	2.2	0.5		0.1	0.5	0.4		0.7		0.6	2.6
ITB		0.1			0.1								0.1	0.1
Calf	0.1	0.1		0.8	0.1	2.0	0.2	0.6	0.2		0.7	0.2	0.2	0.7
Lower leg											0.2		0.2	
Shin			0.4				0.3				0.1		0.2	
Achilles			0.7	1.1	0.2			2.4	0.2				0.4	1.7
Ankle				0.4	1.0		0.5	0.2	0.4	1.7	0.9		0.7	0.8
Foot	0.5	2.2	0.2		0.2				0.9	0.7	0.8	0.2	0.5	1.0
Illness			0.2	0.4	0.1	0.2	0.2	0.2			0.2		0.2	0.2
Unconfirmed	0.3		0.8		0.6	1.1							0.5	1.1
TOTAL	7.0	20.4	8.2	9.9	7.6	15.1	7.1	7.5	6.8	5.1	8.5	4.6	7.5	10.4

4.10 Injury incidents and severity by body site

Figure 4.9 presents new, recurrent, and training injury incidents described per body site for domestic and international competition across the study period. In the domestic competition across the study period, the hamstring (34 injuries, 8.2% of total) was the most frequently injured body site followed by the lumbar spine (32, 7.7%), then knee (30, 7.2%) and groin (30, 7.2%). In international competition the most frequently injured body site was the groin (17, 13.5%) followed by the lumbar spine (13, 10.3%) then the hamstring (10, 7.9%) and illness (10, 7.9%).

Figure 4.10 presents the number of match days that were lost as a result of new, recurrent, and training injury incidents described per body site for domestic and international competition across the study period. In the domestic competition across the study period, lumbar spine injuries resulted in the highest number of match days lost (417, 10.9%). Side injuries resulted in the second highest number of match days lost to injury (371, 9.7%). In international competition, groin injuries (152, 17.2%) resulted in the highest number of lost match days followed by knee injuries (111, 12.

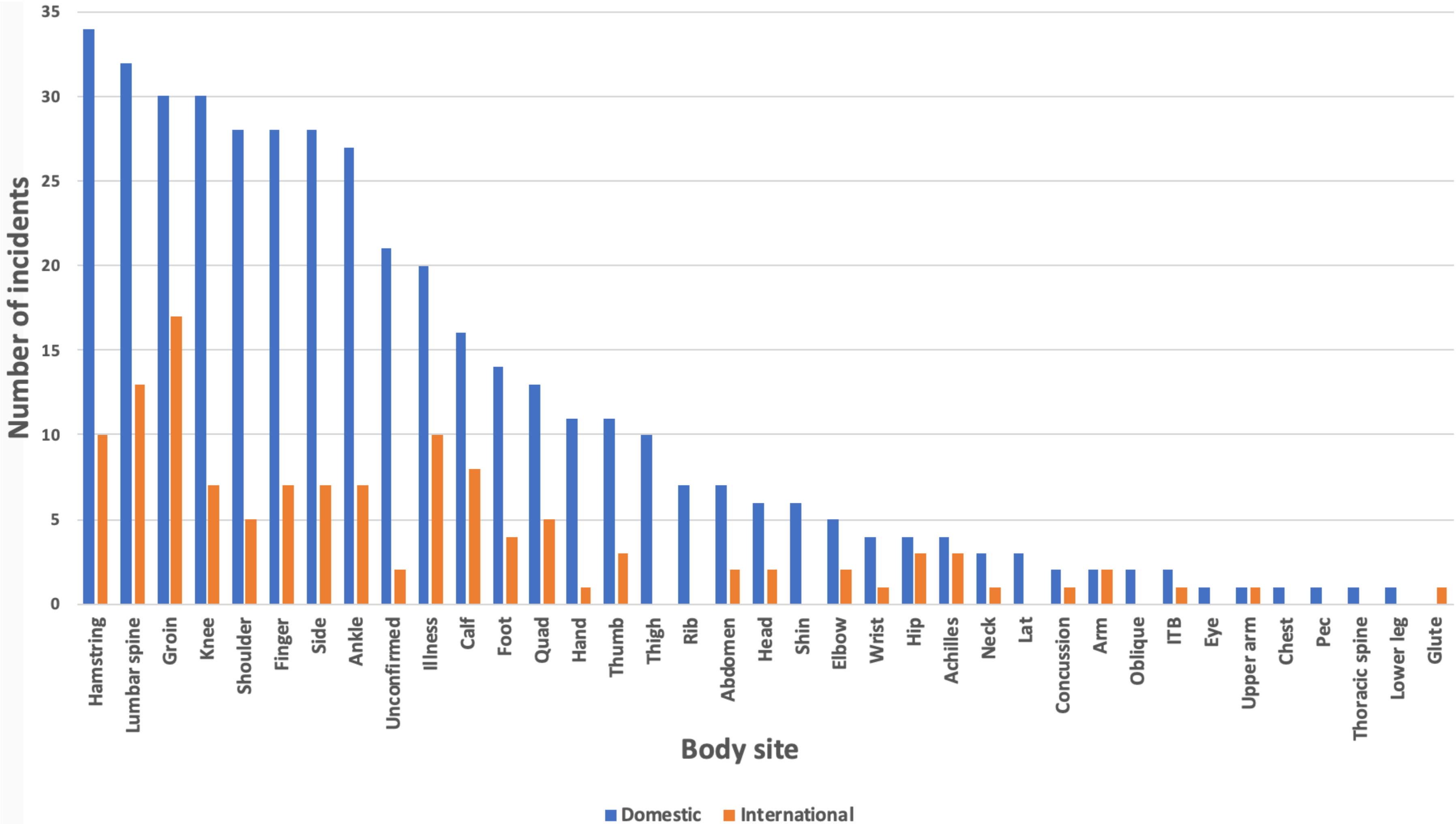

Figure 4.9 Number of new match injuries, recurring injuries, and training injuries from 2009 to 2015 by body site in domestic and international cricket.

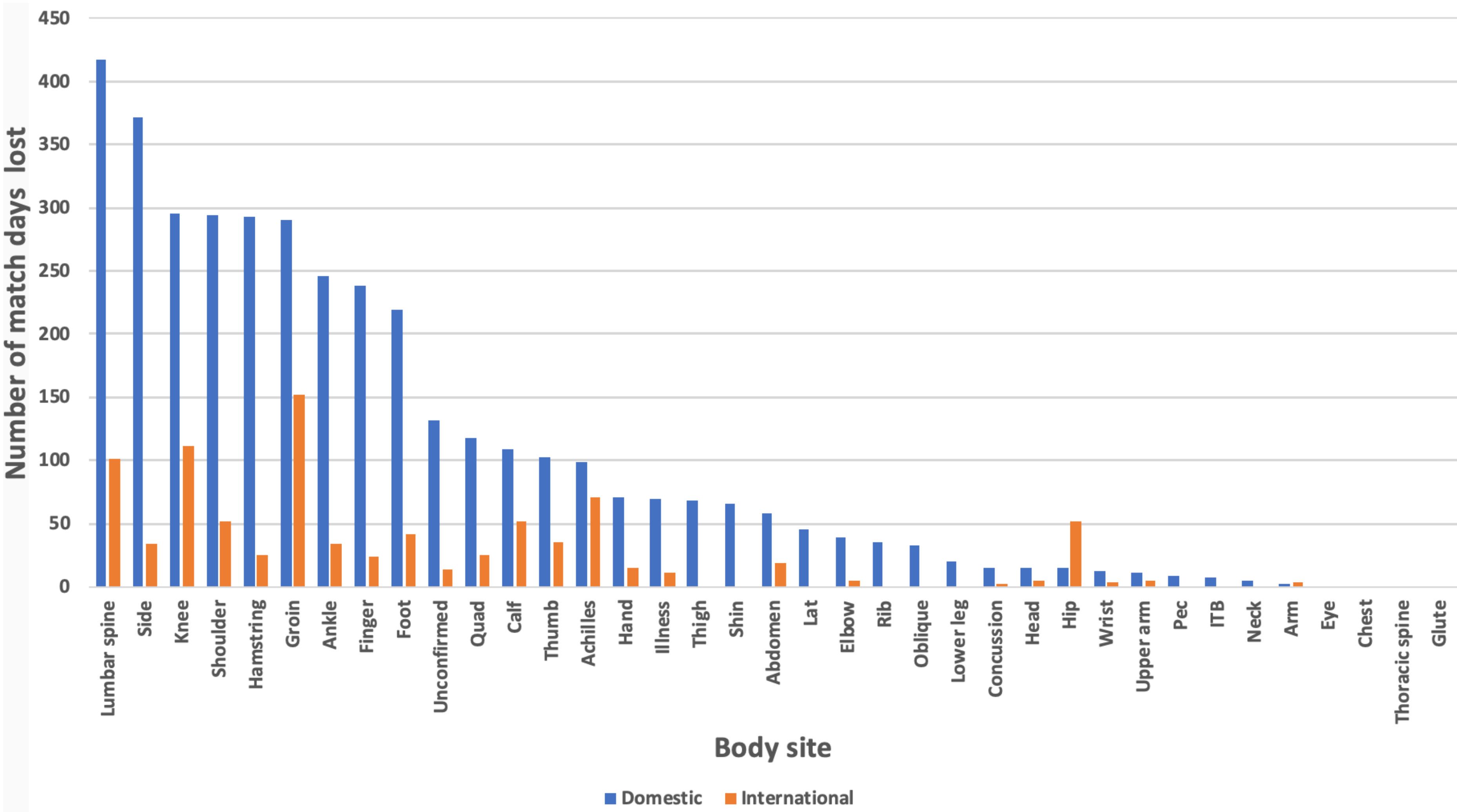

Figure 4.10 Match days lost due to new match injuries, recurring injuries, and training injures from 2009 to 2015 by body site in domestic and international cricket.

4.11 Injury incidents and severity by body region

Table 4.4 presents the number of new, recurring, and training injuries incurred under the period of observation expressed per body region. In every season under observation for both domestic and international competition, lower limb injuries occurred the most frequently compared to the head/neck, upper limb, trunk/upper back, illness, and unconfirmed injuries. Lower limb injuries also accounted for the most match days lost compared to the other body regions for domestic and international competition (table 4.5). The number of lower limb injury incidents and match days lost to injury appeared to reduce for international cricket over the course of the study period.

Table 4.4 *Number of new match injuries, recurring injuries, and training injuries (% total) by body region*

Season	2009-10		2010-11		2011-12		2012-13		2013-14		2014-15	
Playing level	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International
Head/neck	1 (1.5)	2 (7.7)	2 (2.5)	1 (3.4)	4 (6.2)	0	2 (3.0)	0	1 (1.5)	0	2 (2.9)	1 (6.3)
Upper limb	16 (23.9)	5 (19.2)	15 (19.0)	2 (6.9)	10 (15.4)	1 (8.3)	16 (23.9)	4 (12.5)	15 (22.1)	3 (27.3)	18 (25.7)	6 (37.5)
Trunk/upper back	12 (17.9)	4 (15.4)	12 (15.2)	6 (20.7)	17 (26.2)	2 (16.7)	14 (20.9)	7 (21.9)	11 (16.2)	3 (27.3)	16 (22.9)	2 (12.5)
Lower limb	28 (41.8)	15 (57.7)	35 (44.3)	15 (51.7)	28 (43.1)	6 (50.0)	33 (49.3)	17 (53.1)	38 (55.9)	5 (45.5)	30 (42.9)	7 (43.8)
Illness	2 (3.0)	0	5 (6.3)	5 (17.2)	4 (6.2)	2 (16.7)	2 (3.0)	3 (9.4)	3 (4.4)	0	4 (5.7)	0
Unconfirmed	8 (11.9)	0	10 (12.7)	0	2 (3.1)	1 (8.3)	0	1 (3.1)	0	0	0	0
TOTAL	**67**	**26**	**79**	**29**	**65**	**12**	**67**	**32**	**68**	**11**	**70**	**16**

Table 4.5 *Number of match days lost to new match injuries, recurring injuries, and training injuries (% total) by body region*

Season	2009-10		2010-11		2011-12		2012-13		2013-14		2014-15	
Playing level	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International
Head/neck	3 (0.5)	3 (1.1)	3 (0.5)	2 (1.4)	9 (1.4)	0	3 (0.5)	0	1 (0.2)	0	16 (2.2)	2 (3.4)
Upper limb	121 (20.9)	69 (25.1)	107 (16.1)	5 (3.6)	72 (10.9)	16 (9.4)	154 (25.3)	21 (12.1)	140 (24.8)	15 (21.4)	178 (24.1)	13 (22.0)
Trunk/upper back	133 (23.0)	23 (8.4)	125 (18.8)	22 (15.9)	247 (37.5)	55 (32.4)	167 (27.5)	22 (12.7)	120 (21.2)	14 (20.0)	174 (23.5)	21 (35.6)
Lower limb	298 (51.6)	180 (65.5)	351 (52.7)	104 (75.4)	289 (43.9)	85 (50.0)	263 (43.3)	125 (72.3)	301 (53.3)	41 (58.6)	356 (48.1)	23 (39.0)
Illness	2 (0.3)	0	19 (2.9)	5 (3.6)	8 (1.4)	2 (1.2)	21 (3.5)	4 (2.3)	3 (0.5)	0	16 (2.2)	0
Unconfirmed	21 (3.6)	0	61 (9.2)	0	34 (5.2)	12 (7.1)	0	1 (0.6)	0	0	0	0
TOTAL	**578**	**275**	**666**	**138**	**659**	**170**	**608**	**173**	**565**	**70**	**740**	**59**

4.12 Injury incidents and severity by player position

Figures 4.11 and 4.12 display the number of injury incidents and match days lost as a result of new, recurrent, and training injuries respectively, expressed by playing position. The playing positions are batters, fast-medium pace bowlers, slow-spin bowlers, and wicket keepers. In the domestic cricket competition, fast-medium pace bowlers represented the highest number of injury incidents as well as match days lost to injury compared to the other positions. The fewest instances of injury and match days lost to injury in the domestic competition were in wicket keepers.

In international competition, fast-medium bowlers demonstrated the highest number of injury incidents in all but one season (2011-2012) where batters ranked highest (by one incident). International cricket fast-medium bowlers also demonstrated the highest proportion of lost match days in all but one season (2012-2013). In the 2012-2013 season, fast-medium bowlers instead recorded the third highest proportion of match days lost (19.7%) to slow-spin bowlers (43.4%) and batters (35.8%). It can be seen in figure 4.12 that the number of match days lost for fast-medium international level bowlers appeared to reduce over the course of the study period.

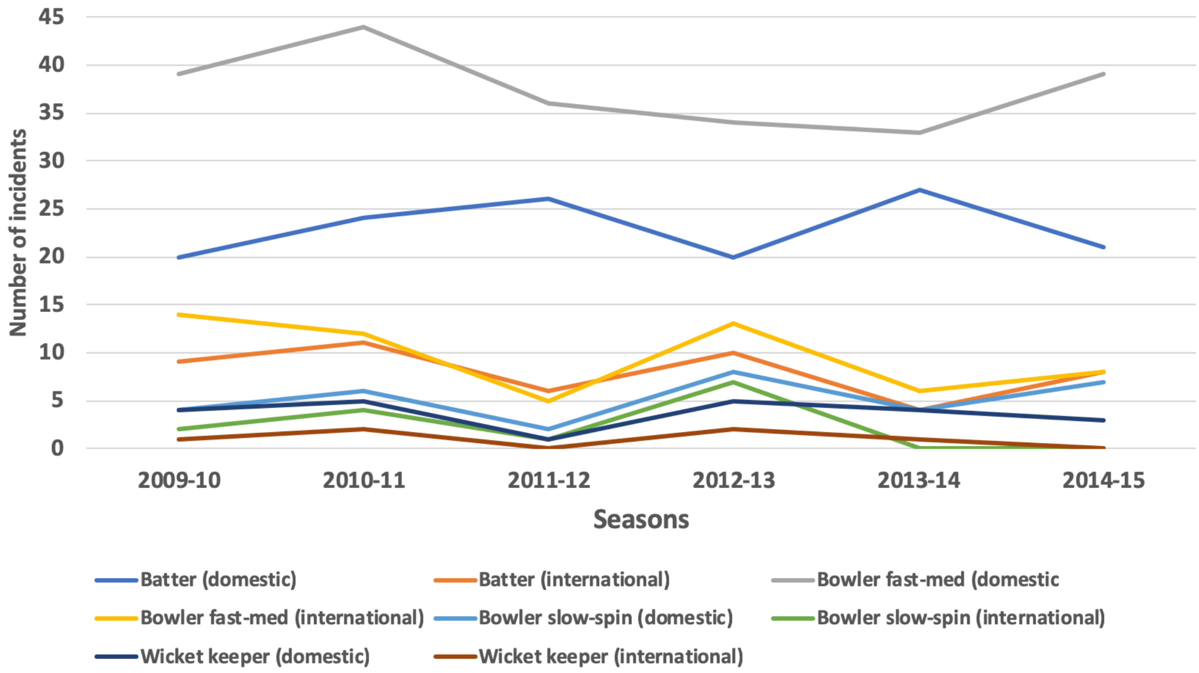

Figure 4.11 Number of new match injuries, recurring injuries, and training injuries by player position.

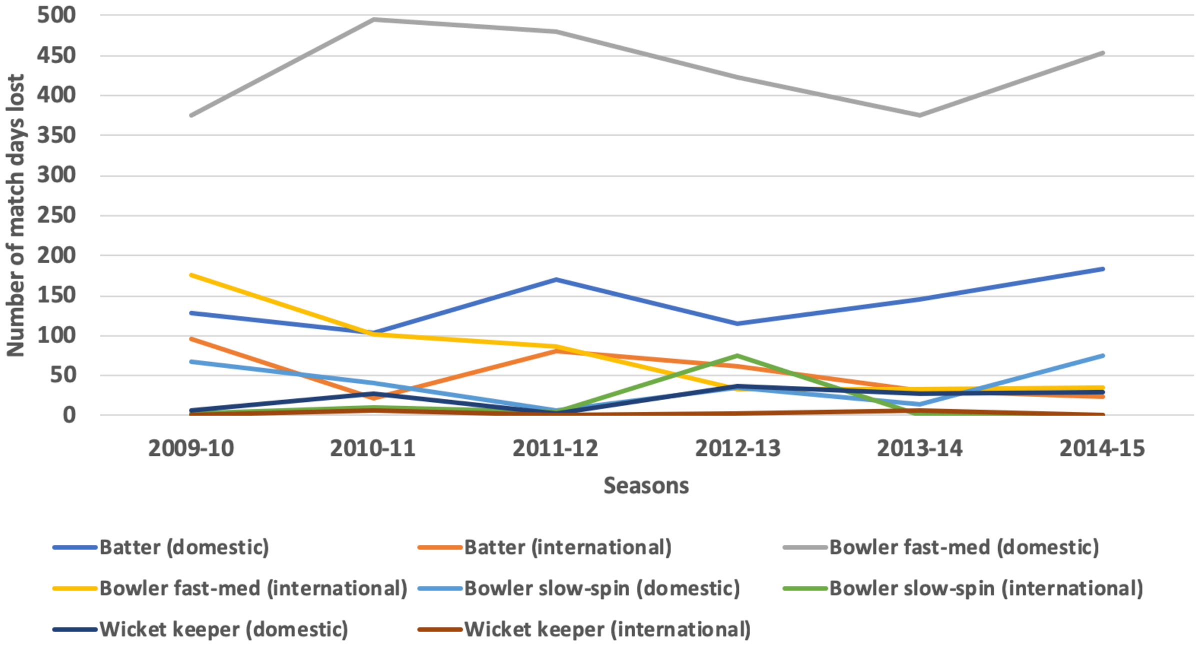

Figure 4.12 Number of match days lost to new match injuries, recurring injuries, and training injuries by player position.

4.13 Comparing injury status between domestic and international players from 2009-2015

A statistically significant difference in injury status between domestic and international level cricketers was identified with a Chi-square test ($\chi^2 = 4.39$, $p = 0.036$, Appendix D). The percentage of international players injured (50.5%) was 7% higher than domestic players (43.5), seen in table 4.6.

Table 4.6 *Injury status of players by playing level*

	Not injured	Injured	Total
Domestic	560 (56.5%)	431 (43.5%)	991
International	139 (49.5%)	142 (50.5%)	281
Total	699	573	1272

4.14 Comparing injury status between player positions from 2009-2015

A statistically significant difference in injury status between playing position was identified with a Chi-square test ($\chi^2 = 42.29$, $p < 0.0001$, Appendix E). In the total cohort of players, slow-spin bowlers were the least injured (29.1%), followed by wicket keepers (31.8%), then batters (41.6%). Fast-medium pace bowlers were the most injured (59.7%), seen in table 4.7.

Table 4.7 Injury status of players by playing position

	Not injured	Injured	Total
Bowlers (fast-med)	255 (40.3%)	303 (59.7%)	558
Bowlers (slow-spin)	110 (70.1%)	47 (29.1%)	157
Batter	274 (58.4%)	195 (41.6%)	469
Wicket keeper	60 (68.2%)	283 (31.8%)	88
Total	688	573	1272

4.15 Relationship between match exposure hours and the number of injuries

Figures 4.13 and 4.14 present the relationship between match exposure and number of match injuries (new and recurrent). In these charts the total match hours of exposure for the domestic and international seasons in the survey period from 2009-2015 have been collated per month, along with all new and recurrent match injuries.

The domestic competition (figure 4.13) match exposure was the greatest in the months of February and March. Domestic match injury occurrence was highest in November, the beginning of the season. It can be seen in that injury occurrence appears to increase or decrease corresponding to an increase or decrease in match exposure in domestic cricket.

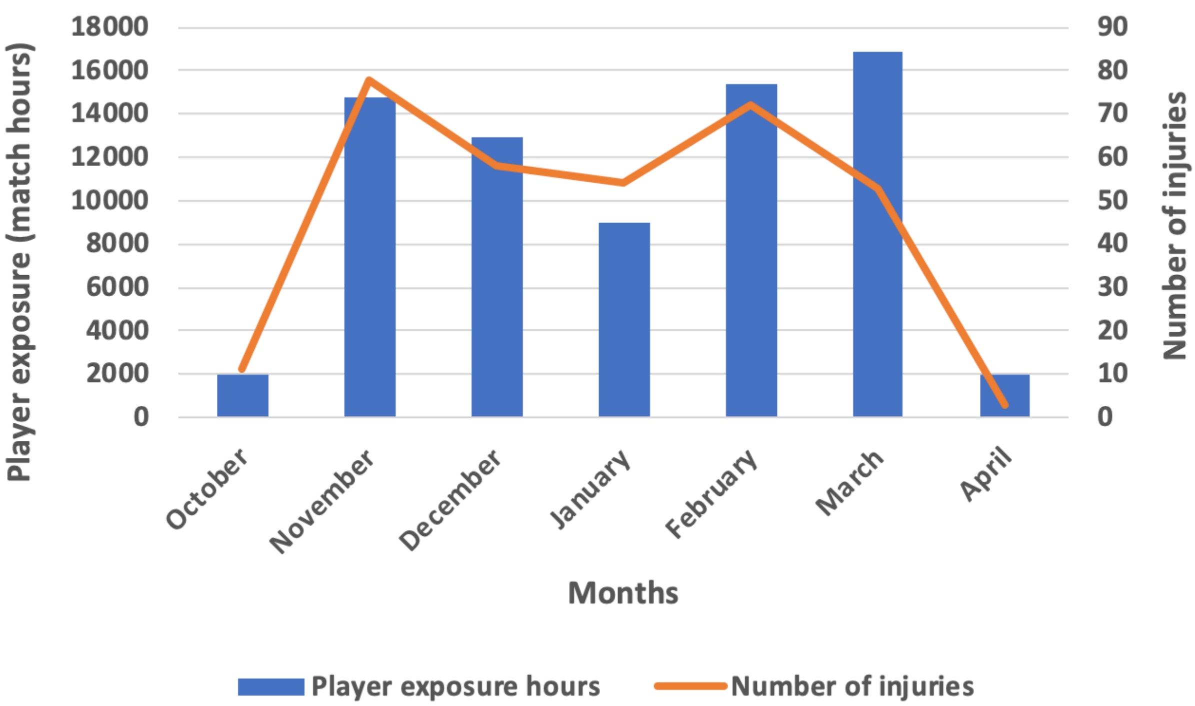

Figure 4.13 Graph of domestic competition match exposure hours with number of injuries from 2009-2015.

The international competition (figure 4.14) match exposure was the greatest between the months of November to March. International competition match injury occurrence was the highest in November, and the lowest in April. These months also demonstrated the highest and lowest match exposure respectively. It can be seen that injury occurrence appears to increase or decrease corresponding to an increase or decrease in match exposure in international cricket.

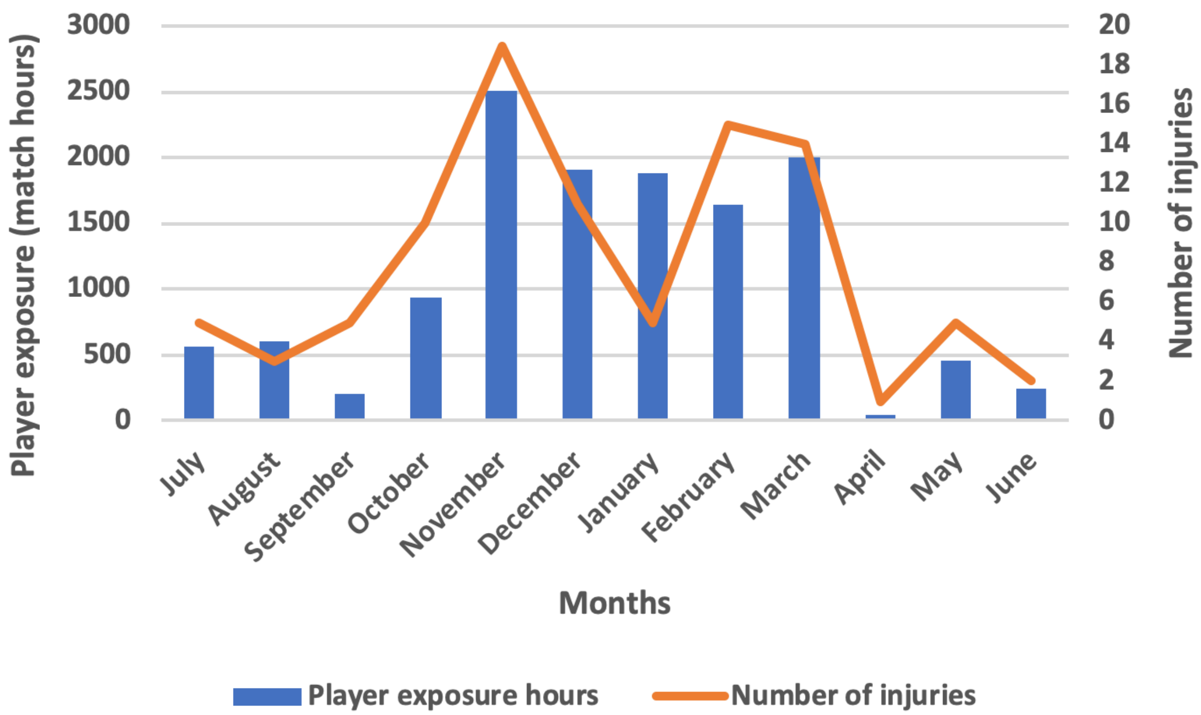

Figure 4.14 Graph of international competition match exposure hours with number of injuries from 2009-2015.

Using linear regression, associations between match exposure hours, playing level, and the number of injuries were identified (Appendix F). The increased number of match exposure hours were statistically significantly associated with increased number of injuries ($p < 0.0001$, Appendix F1). Domestic cricketers had statistically significantly higher injury rates than international cricketers ($\beta = 39.1$, 95% CI = 21.2-56.9, $p <$

0.0001, Appendix F2). Even after accounting for playing level (domestic vs. international), the number of match exposure hours was still statistically significantly associated with increased number of injuries ($p < 0.0001$, Appendix F3). After accounting for playing level, and the time of the season played, it is the number of match exposure hours that is the key variable for predicting increased number of injuries ($p < 0.0001$, Appendix F5).

Chapter 5 – Discussion

Introduction

This chapter will review the main study findings observed in the results, and report statistically analysed data where applicable. This chapter will also compare these findings with a prior epidemiological study of New Zealand domestic competition and international representative team cricketers from 2002-2008 (Frost & Chalmers, 2014). Comparisons will also be made with an epidemiological study of Australian domestic and international cricketers which is currently the only other international study of this type that has observed the 2009-2015 period (Orchard, Kountouris, et al., 2016). Limitations of this study will be reported and suggestions for future research recommended.

5.1 Participants

This study captured injury status data from a combined total of 1,089 male New Zealand domestic and international cricketers between seasons 2009-2010 to 2014-2015. The mean age for domestic cricketers was 28.2 years (17-40 years, SD = 4.6) and 28.9 years (18-38 years, SD = 4.0) for international cricketers with no statistical difference between the two groups. The mean age of participants was not reported in an epidemiological cricket injury study by Mansingh et al. (2006), however their participant's age range (18-37 years) was similar to this study. Other cricket epidemiological studies (Frost & Chalmers, 2014; Orchard et al., 2006; Orchard, Kountouris, et al., 2016; Stretch & Raffan, 2011; Stretch et al., 2009) have not reported mean age or range. Other demographic information, such as BMI, have not been reported by those earlier studies.

5.2 Injury incidence

5.2.1 Match injury incidence rates

Comparing incidence rates between time periods or populations requires a consistent incidence rate. For this reason, the incidence rates in this study have been expressed in terms of both injuries per 10,000 player hours and injuries per 1,000 player days. In these calculations the denominators express different units of measurement rather than a mathematical difference. This was to be consistent with the cricket injury surveillance consensus statements (Orchard et al., 2005; Orchard, Ranson, et al., 2016). It is acknowledged that traditionally in sports epidemiology incidence rates are expressed per 1,000 player hours of exposure (Phillips, 2000; van Mechelen et al., 1992). This has been recognised and expressed in other sports (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Mountjoy et al., 2016; Pluim et al., 2009; Timpka, Alonso, et al., 2014). Although this paper focusses on the incidence expressions as recommended in cricket, injury incidence rates have also been converted to per 1,000 hours player hours, seen in Appendix G, should comparisons with other sports need to be made in the future.

In this study, match injury incidence was expressed as the number of new injuries, recurring injuries, and as a combination of the two. In both international and domestic cricket, the Twenty20 match format demonstrated the highest variability of combined new and recurrent match injury incidence per 10,000 player hours between 2009-2015.

Match injury incidence rates appeared to reduce for the international One Day format and remain stable for the other match formats.

When recurring injuries were excluded from match injury incidence rate calculation, the total new match injury incidence rate in international cricket had increased from 51.6 injuries per 10,000 player hours in 2002-2008 (Frost & Chalmers, 2014) to 58.0 injuries per 10,000 player hours. The New Zealand domestic competition total injury incidence rates had increased from 27.2 injuries per 10,000 player hours in 2002-2008 (Frost & Chalmers, 2014) to 37.0 injuries per 10,000 player hours. This is a proportional increase of total match injury incidence rate from 2002-2008 to 2009-2015 of 12.4% for international level players, and 36.0% for domestic level players. From 2002-2008 (Frost & Chalmers, 2014) the international player match injury incidence rate was almost double the domestic rate, reducing to a difference of approximately 1.5 times in the 2009-2015 period. Although this difference between total match injury incidence rates between international and domestic level players had improved from 2002-2008 to 2009-2015, total match injury incidence increased in both the international and domestic game. Compared to 2002-2008 (Frost & Chalmers, 2014) there has been an increase in total new match injury incidence rates per 10,000 player hours in domestic Twenty20 (45.8 vs 74.5), domestic First-Class (24.1 vs 33.4), international Twenty20 (122.3 vs 144.2), and international One Day (73.1 vs 92.7) match formats. Injury incidence rates per 10,000 player hours reduced in domestic One Day (36.2 vs 33.1) and international Test cricket (30.1 vs 23.4) formats compared to 2002-2008 (Frost & Chalmers, 2014). When match injury incidence rates of recurring injuries were calculated, a decreased incidence rate was seen for domestic, and more so, in international cricket players over the 2009-2015 study period.

Frost and Chalmers (2014) showed that Twenty20 style cricket began to feature in the New Zealand domestic competition from the 2005-2006 season and from 2004-2005 in the international competition. It has also been observed that the overall amount of cricket played has been gradually increasing over the past two decades (Orchard, James, et al., 2010). This is certainly the case in Australian cricket which has seen a general increase in match days played (and subsequently hours of exposure) since 1998 to 2014 (Orchard, James, et al., 2010; Orchard et al., 2014). It has been reported that the introduction of Twenty20 cricket as a mainstream format in 2005 has increased the total amount of cricket played without a concurrent reduction in the amount of cricket played in other formats in most countries (Orchard, James, et al., 2010). A linear regression model in this study demonstrated that the number of match exposure hours that was the key variable for predicting increased number of injuries ($p < 0.0001$, Appendix F4). Twenty20 has also evolved from a novel match format into a serious style of play that is fast paced, intense and places a high demand on players (Petersen et al., 2010). This increased popularity of the Twenty20 format has seen the rise of Twenty20 tournaments globally, providing players options outside of the New Zealand environment which further exposes them to this type of cricket. The growing commercial nature of this style of cricket has provided players with an additional income source, often relative to their performance, further emphasising the need to perform at high level. In addition to increasing total exposure and workload, the Twenty20 format also introduces workload variability. For example, a bowler can bowl four overs in a Twenty20 match but be expected to bowl 20 overs or more in a Test match shortly after. Such spikes in workload as well as fewer days rest between matches due to the increasing amount of days played in a season have been shown to increase the risk of injury (Ahmun et al., 2019; Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Hulin et al., 2014; Kountouris et al., 2018; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Saw et al., 2011; Warren et al., 2018). This prominence in Twenty20 style cricket in domestic and international competition potentially explains the increased match injury incidence seen from 2002-2008 to 2009-2015.

Reporting match injury incidence rates per 1,000 player days was recommended in the updated consensus statement on injury surveillance in cricket by Orchard, Ranson, et al. (2016). This was initially proposed by Orchard, James, et al. (2010). One of the reasons for this recommendation was due to the increased presence of the Twenty20 format. Due to the short match duration of Twenty20 matches, injury incidence rates will appear high when expressed per 10,000 player hours due to a lower denominator in the calculation process (figure 4.3). Expressing injury incidence in terms of player days allows for better comparison between match formats as this denominator instead considers match days played, which is a more consistent denominator for the match formats. This can be visualised when comparing figures 4.3 and 4.6 that show injury incidence per 10,000 player hours and per 1,000 player days respectively. The injury incidence rates per 1,000 player days in this study cannot be compared with the 2002-2008 period reported by Frost and Chalmers (2014) as incidence rates per 1,000 player days were not a recommended reporting standard at their time of publishing. This study can however compare findings to an Australian elite cricket domestic and international population from a study by Orchard, Kountouris, et al. (2016), who included the 2009-2015 period when reporting injury incidence rates per 1,000 player days.

Figure 5.1 Comparing match injury incidence per 1,000 players days between New Zealand and Australia from 2009-2015.

The New Zealand Cricket incidence rates presented in figure 5.1 are a total of all match injuries across all days played between the 2009-2015 seasons, compared to an average incidence rate calculated for the same period in the study of elite Australian domestic and international cricketers by Orchard, Kountouris, et al. (2016). New Zealand Cricket had a lower injury incidence rate per 1,000 player days in the domestic One Day competition (185.7 vs 284.7), but almost double for the international One Day format (486.0 vs 275.2). New Zealand Cricket also demonstrated higher injury incidence in the domestic First-Class competition (153.2 vs 112.7). Injury incidence rates between New Zealand and Australian international Test cricket matches were similar (118.3 vs 117.7). Orchard, Kountouris, et al. (2016) did not present separate incidence rates for domestic and international Twenty20 matches, instead combining them, so this match format was not compared with findings from this study. Orchard, Kountouris, et al. (2016) reported they chose not to report domestic and international Twenty20 injury incidence rates separately because in some seasons only few international Twenty20 matches were played, so the injury incidence data would be misleading. This inconsistent exposure can also be seen in this study, in figure 4.2, showing that international Twenty20 match exposure hours ranged from 35 to 329 hours per season between 2009-2015. This likely explains our variability in international Twenty20 incidence rates between seasons when expressed as both per 10,000 player hours in figure 4.3 (0.0–576.9) and per 1,000 player days in figure 4.6 (0.0–1000.0). One Day international matches also expressed variability in match days played between seasons (6–31 days, figure 4.1) and subsequently exposure hours (260–1343, figure 4.2). These variations in exposure per team hours or match days could also have influenced the varied incidence rates seen for international One Day matches, as they have for the Twenty20 format.

5.2.2 Seasonal injury incidence rates

Although seasonal injury incidence is no longer a recommended unit in the current cricket injury reporting guidelines by Orchard, Ranson, et al. (2016), it was included in this study to compare findings to the 2002-2008 study period. The domestic cricket competition seasonal injury incidence rates per squad per season were slightly lower in this 2009-2015 study compared to the 2002-2008 period reported by Frost and Chalmers (2014), ranging from 11.3-14.7 vs 13.1-17.7 respectively. In 2002-2008 international cricket seasonal injury incidence varied between 10.5-35.6 throughout the seasons without an observable change from year to year. In the 2009-2015 period, international cricket seasonal injury incidence per squad per season ranged from 12.0-31.1 and although similar in range to the 2002-2008 period, was observed to reduce over time. A statistically significant relationship of injury status between domestic and international level cricketers was identified in this study. There was a greater proportion of international level players that were injured versus those not injured, compared to domestic level players ($\chi^2 = 4.39$, $p = 0.036$). Petersen et al. (2011) demonstrated that Test cricket, only played in international level cricket, is physically more demanding than the domestic competition equivalent of the domestic equivalent First-Class cricket. Observing figure 4.1 and figure 4.2 it can be seen that while the proportion of domestic First-Class, One Day, and Twenty20 matches is even between seasons, there is greater variation in the ratio of international Test, One Day, and Twenty20 matches played. The match scheduling also varies between domestic and international competitions. In domestic cricket the match schedule is organised so that typically the one match format is played over a few weeks, exposing players to relatively consistent playing demands. In international cricket, it is typical to play the opposing team in all formats of the game over the duration of the tour. These match schedules can result in having to play the match formats over a short timeframe, with less time available for adaptation to a new style of play and the workload it requires. Because these match formats have varied physical demands (Petersen et al., 2010; Petersen et al., 2011), international players are not exposed to the same regular workload that purely domestic players are, and may subsequently be exposed to an injury risk due the inconsistent workloads (Ahmun et al., 2019; Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Hulin et al., 2014; Kountouris et al., 2018; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Saw et al., 2011; Warren et al., 2018). This may also provide an explanation as to why the international match format injury incidences are higher than domestic match formats.

5.2.3 Annual injury incidence rates

Annual injury incidence is another incidence unit introduced in the updated cricket injury surveillance consensus paper by Orchard, Ranson, et al. (2016). It was recommended that this incidence rate is expressed as per 100 players per year. The current consensus paper considers that international cricket has evolved into a nine-month to full-year schedule for major cricket playing nations. This unit therefore considers exposure over 365 days compared to the 60 days used to calculate seasonal injury incidence as per the original guidelines by Orchard et al. (2005). This new incidence unit is recommended as it better reflects the modern scheduling of the cricket season. Given this change in scheduling, the current consensus guideline also recommends that studies report the number of match days played for a given annual surveillance period. These were presented earlier in figure 4.1. To ensure consistency with the current reporting guidelines (Orchard, Ranson, et al., 2016) and other published cricket injury epidemiology studies (Orchard, Kountouris, et al., 2016), this study reported annual injury incidence per 100 players per year expressed by body site.

In domestic cricket between 2009 and 2015, unconfirmed injuries accounted for the highest total annual injury incidence (1.6 injuries per 100 players per year). When extracted from the injury surveillance dataset, injuries were labelled unconfirmed if they had not been coded to a particular body site or body region in the original surveillance system. That the highest annual injury incidence rate is for unconfirmed injuries, suggests an important proportion of injuries cannot be accounted for per body site and region. In the domestic cricket competition, full-time team physiotherapists were introduced in the 2012-13 season. It can be seen in table 4.2 that from the 2012-13 season there were no unconfirmed injuries in domestic cricket, suggesting that the process of recording injury data could have improved with this change to a model of full-time domestic team physiotherapists who were tasked with being the primary injury surveillance recorders. Hamstring, groin and knee injuries were the next highest reported injuries in domestic cricket respectively. Illness, abdominal and groin, hamstring and lumbar spine injuries reported the highest annual injury incidence in international cricket.

Annual injury incidence was not reported by Frost and Chalmers (2014) for the 2002-2008 period as this was not a recommended unit in the consensus guideline by Orchard et al. (2005), which was the reporting standard at their time of publication. However, the study of elite Australian cricketers by Orchard, Kountouris, et al. (2016) did report average annual injury incidence. These authors grouped domestic and international cricketers together and reported the highest injury incidence from 2009-2015 for hamstring strains (9.5 injuries per 100 players per year), followed by side and abdominal strains (6.5), wrist and hand fractures (5.6), lumbar spine injuries excluding stress fractures (4.8), then groin injuries (4.7).

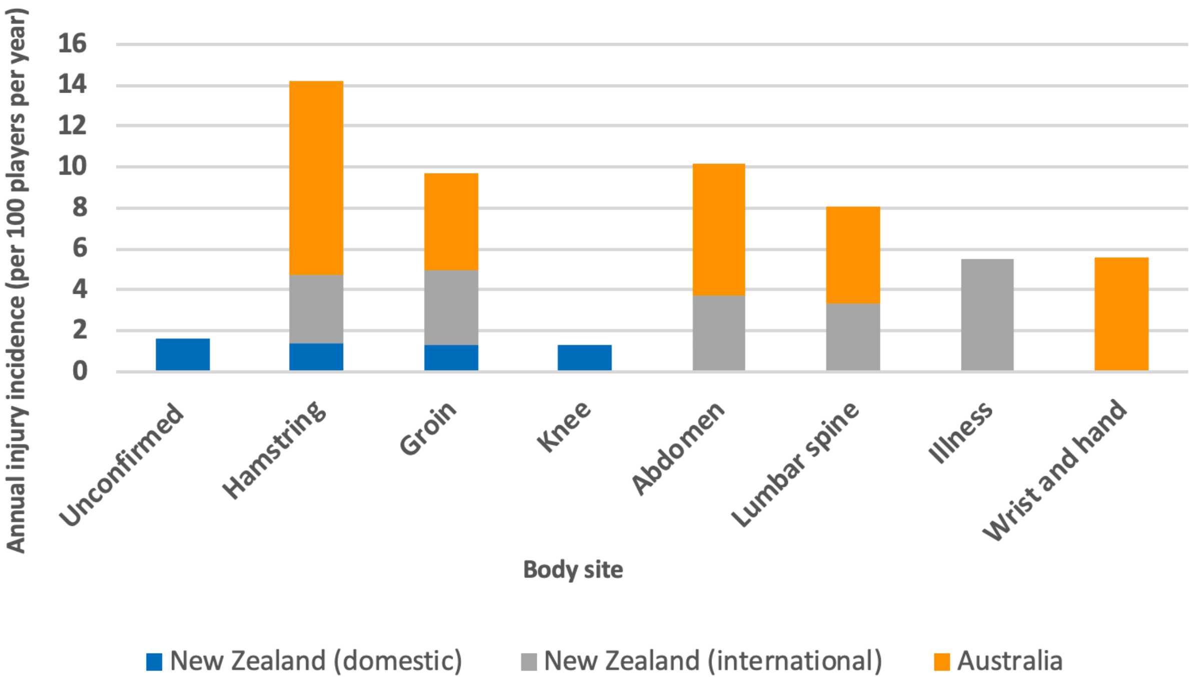

Figure 5.2 Comparing highest annual injury incidence rates per 100 players per year by body site between New Zealand (total) and Australia (average) from 2009-2015.

Figure 5.2 demonstrates the injuries with the highest annual injury incidence rates per 100 player days for New Zealand domestic and international cricket (total), and combined Australian domestic and international cricket (average) from 2009-2015.

Hamstring strains are common across all three populations with Australian cricketers recording the highest incidence overall. Orchard et al. (2017), in another study of elite Australian cricketers, proposed that the rise of Twenty20 cricket has been associated with increased hamstring injury risk. Their findings showed a relative risk (RR) of overall hamstring injury occurring after 2006 of 1.5 (95% CI: 1.1–2.2) compared to before 2006. This time period is associated with the increased prominence of Twenty20 cricket as a mainstream match format. Other risks of hamstring injury in cricket were reported by Orchard et al. (2017) to be previous hamstring injury in the same season compared to no history of hamstring injury (RR = 3.7, 95% CI: 2.5-5.5), and previous hamstring injury in a prior season compared to no history of hamstring injury (RR = 2.7, 95% CI: 1.9-3.7). Three other studies have identified that previous injury is a risk factor for injury in cricket players (Olivier & Gray, 2018; Orchard, 2010; Orchard et al., 2015a). Being a fast bowler compared to a spin bowler has also been shown to increase hamstring injury risk by Orchard et al. (2017) (RR = 2.5, 95% CI: 1.3-4.5). It has been proposed that the fast bowler's run-up speed compared to other positions is associated with this risk (Petersen et al., 2010; Petersen et al., 2011).

Illness was found to have the highest total annual injury incidence per 100 player days for international New Zealand cricketers between 2009-2015. A systematic review by Drew and Finch (2016) explored the relationship between training load and illness and found a positive moderate relationship in six out of eight studies where increased training time and intensity was related to illness. It was previously suggested by Frost and Chalmers (2014) that the total amount of cricket played by international crickets is greater than domestic players. Since international cricketers are selected from the domestic player pool, they are potentially exposed to greater training hours thus increasing risk of illness. This relationship could not be explored in this study as the surveillance system dataset did not capture training load data. Another potential influence on the incidence of illness in international, compared to domestic players, is the effect of travel. In a study by Schwellnus et al. (2012), elite athletes that travelled greater than five time zones had a 2-3-fold increased risk of illness. For the New Zealand international cricket team to travel to a major cricketing nation, excluding Australia, would require crossing more than five time zones compared to the domestic competition where no time zones are crossed during travel.

In addition to training load data not being available, injury coding within the surveillance system could also influence reporting, and comparison of injury rates. For example, when comparing annual injury incidence with the Australian cricket study by Orchard, Kountouris, et al. (2016) it was observed that side and abdominal strains were reported collectively. The injury surveillance dataset for this study separated abdominal, side, and oblique injuries which could arguably be categorised in the same diagnostic group. Instead, they are presented independently and subsequently may be under-represented in analysis than had they been grouped.

5.3 Match injury prevalence

Match injury prevalence rates can be used to represent the average percentage of players missing from match days due to injury. In the 2002-2008 period studied by Frost and Chalmers (2014), domestic cricket prevalence rates were reported as relatively stable with small changes between the six seasons (5.7-13.3%) compared to a fluctuating prevalence rate between years for international competition (9.0-15.7%). For the 2002-2008 period, the total prevalence rate for the domestic competition (9.7%, 95% CI: 9.4-10.1) was less than for international competition (12.0%, 95% CI: 11.3-12.8). Total injury prevalence rates for the 2009-2015 period had improved compared to the 2002-2008 period in both domestic (7.6%) and international (10.0%) competitions. Between 2009-2015 domestic competition incidence rates did not appear to change between years, ranging from 6.8% to 8.5%. International prevalence rates improved, decreasing from 20.4% to 4.6% between 2009-2015. Total match injury prevalence rates for domestic and international teams were not reported by Orchard, Kountouris, et al. (2016) so comparison to the Australian competition could not be made. Injury prevalence rates are generally influenced by the density of match scheduling. While this will still accurately demonstrate the impact of injury as the percentage of match days lost, these rates can also differ for mathematical reasons. For example, the domestic schedule demonstrates more match days played per season compared to international competition. An injury that takes six-weeks to recover will be comparatively expressed as a lower prevalence rate in the domestic competition due to the higher denominator (match days scheduled). This creates a challenge in that the impact of injury could be mathematical rather than clinically significant when comparing competitions that have varied match schedules.

When match injury prevalence was reported by body site (table 4.3), the highest average prevalence rates for 2009-2015 in domestic cricket were for lumbar spine injuries (0.8%), followed by side (0.7%) and ankle injuries (0.7%). The highest outright prevalence rate in domestic cricket was for groin injuries (1.6%) in the 2009-2010 season. These injuries with the highest domestic cricket prevalence (lumbar spine, side, and ankle injuries), do not feature in the top four highest annual incidence rates. This indicates that although they do not occur as frequently, they instead contribute to more match time-loss per incident. The highest average injury prevalence rates in international cricket from 2009-2015 were for knee injuries (2.6%), followed by hip

(2.3%) then groin (1.8%) injuries. Groin injuries also demonstrated the highest incidence rate of international cricket injuries at 5.4% in the 2009-2010 season, similar to domestic cricket but at a higher rate. This high prevalence rate was likely influenced by two players who each missed approximately 75% of the international season matches in that season. Of these international cricket injury prevalence rates, only groin injuries featured in the five highest annual injury incidents rates per body site, indicating that knee, hip, and groin injuries contribute to greater match time-loss than injuries with high annual incidence. In international cricket, knee, hip, and groin injury prevalence rates reduced over 2009-2015. Reasons for this reducing prevalence was discussed with the New Zealand Cricket High performance physiotherapist (D. Shackel, personal communication, June 16, 2019). In response to the high prevalence of groin injury New Zealand Cricket modified their approach to warm up and conditioning to increase focus on change of direction and multi-plane movements, in contrast to sagittal plane-oriented exercises. Multifaceted warm-up programs consisting of strength and neuromuscular control, like the FIFA 11+, have been demonstrated to reduce lower limb injury in other sports such as football (Silvers-Granelli et al., 2015; Soligard et al., 2008) and floorball (Pasanen, Parkkari, Pasanen, & Kannus, 2009).

The injury prevalence rates of this study vary to results from Australia where between 2009-2015 the highest injury prevalence rates were reported in lumbar spine stress fractures (2.2%) and hamstrings strains (1.4%) for combined domestic and international cricketers (Orchard, Kountouris, et al., 2016). Orchard, Kountouris, et al. (2016) report that Australia has a high bias towards fast bowling compared to spin bowling. As fast bowlers are already the most at-risk group for developing lumbar spine stress fracture and hamstring injuries, this increased exposure may lead to a higher incidence of injuries that also contribute to high match days lost. We cannot compare injury prevalence rates of body sites from this study to the period between 2002-2008 as Frost and Chalmers (2014) reported prevalence rates by season only.

5.4 Injury incidents and severity

In the domestic competition between 2009-2015, the body sites most injured were the hamstring (34 injuries, 8.2% of total), lumbar spine (32, 7.7%), knee (30, 7.2%) and groin (30, 7.2%). The two most injured body sites in domestic cricket are similar in rank to the 2002-2008 period (Frost & Chalmers, 2014), which were injuries to the thigh (49, 16.3%), low back (45, 15%), followed by the abdomen (26, 8.7%) and hand (26, 8.7%). The number of these injuries and their percentage of total injuries was lower in the 2009-2015 period. In international competition from 2009-2015, the body sites most injured were the groin (17, 13.5%), lumbar spine (13, 10.3%), hamstring (10, 7.9%) and illness (10, 7.9%). These body sites were commonly injured in 2002-2008, reported by Frost and Chalmers (2014) as thigh injuries (22, 19.1%), illness (17, 14.8%), low back injuries (14, 12.2%).

In this study, injury severity was expressed as the amount of match days lost to injury. In the domestic competition between 2009-2015, lumbar spine injuries recorded the most match days lost (417 match days, 10.9% of total player match days) then side injuries (371, 9.7%), followed closely by injuries to the knee (295, 7.7%), shoulder (294, 7.7%), hamstring (293, 7.7%), and groin (290, 7.6%). These were again similar to the 2002-2008 period reported by Frost and Chalmers (2014) where most match days lost to injury were represented by injuries to the low back (751, 28.3%), knee (296, 11.2%), and thigh (285, 10.8%). Most noticeably in domestic cricket, total match days lost to lumbar spine injury reduced by 44.5% from 2002-2008 to 2009-2015. For the

2009-2015 international competition, most match days were lost due to injury to the groin (152, 17.2%), knee (111, 12.5%), and lumbar spine (101, 11.4%). In the 2002-2008 period (Frost & Chalmers, 2014) most match days were lost due to low back (144, 22.1%), knee (131, 20.1%), and shoulder (71, 10.9%) injuries. This comparison demonstrates that the impact of lumbar spine and knee injuries had reduced between 2009-2015 compared to 2002-2008 for international cricket.

A limitation to reporting these results across seasons and comparing them between the two study periods in elite New Zealand cricket is due to the way the body sites were coded in the injury surveillance dataset. Where in the study by Frost and Chalmers (2014) 20 body sites were recorded, this dataset presented 37 sites. In some ways this allows for more accurate representation of injury. For example, the 2009-2015 dataset featured individual categories for hip and groin diagnoses, whereas in the 2002-2008 period these were grouped as groin only. However, by contrast in 2009-2015 oblique and side strains are separated rather than grouped together as in 2002-2008 which may result in under-reporting of these if grouped as abdominal injuries. Regardless, these coding inconsistencies will influence the way data can be compared.

Grouping injuries into body regions rather than body sites provided a more reliable comparison between study periods as the reported regions were consistent between these study findings and that of 2002-2008 by Frost and Chalmers (2014). The only difference in data collection between study periods was the feature of unconfirmed injuries (injuries un-coded to body region in the surveillance system) in the 2009-2015 period. In every season from 2009-2015 for both domestic and international competition, the most injured region was the lower limb. The lower limb was also the most frequently injured region in domestic and international cricket in the 2002-2008 period. The lower limb region also accounted for the most match days lost in domestic and international cricket across both the 2002-2008 and 2009-2015 periods.

The injury surveillance data provided to the primary researcher in this study lacked diagnostic labels. This meant that the impact of specific diagnoses could not be assessed over this time period. In elite cricket, particularly fast bowlers, lumbar spine stress fractures are known to be a significant problem. In elite New Zealand cricket from 2002-2008 (Frost & Chalmers, 2014) lumbar spine stress fractures were responsible for 22.1% missed match days of all diagnoses. In elite Australian cricket between 2006-2016 they accounted for 15% of all missed play (Orchard, Kountouris, et al., 2016). The same impact could not be assessed in this study.

5.5 Injury and playing position

Between 2009-2015 fast-medium pace bowlers accounted for the highest number of injuries followed by batters, spin bowlers, then wicket keepers. This difference between playing position and injury was shown to be statistically significant ($\chi^2 = 42.29$, $p < 0.0001$). Pace bowlers have also been reported to contribute to the highest injury prevalence of all positions in other studies (Frost & Chalmers, 2014; Orchard et al., 2006; Orchard, Kountouris, et al., 2016). It was expected in our findings that fast bowlers would report the most injuries incurred, and match days lost to injury as fast bowling has been identified as a risk factor by previous studies (Bayne et al., 2016; Crewe, Elliott, Couanis, Campbell, & Alderson, 2012; Dennis et al., 2004; Orchard et al., 2017). Foster, John, Elliott, Ackland, and Fitch (1989) have reported that the repetitive lumbar spine hyperextension action during fast bowling is associated with an incidence of 11-50% for spondylolisthesis in fast bowlers. This hyperextension in fast bowling is thought to exert a shear force through the pars interarticularis (Annear et al., 1992). It has been suggested in a biomechanical bony modelling study by Chosa, Totoribe, and Tajima (2004) that the pars is an anatomically weak structure, placed under the most stress when in a position of extension or rotation, which is repetitively required for the fast bowling action.

Pace bowlers are also prone to high lower limb forces. As fast-medium bowlers demonstrated the highest amount of injuries in this study, it is possible that these forces are related to the high frequency of reported lower limb injuries. Dennis, Finch, McIntosh, and Elliott (2008a) found that reduced ankle dorsiflexion (12.1cm-14cm dorsiflexion lunge compared to >14cm) on the ankle opposite to the bowling arm was associated with an increased risk of injury (OR = 4.03, 95% CI: 1.07-15.21, $p = 0.06$). Reduced dorsiflexion may result in higher ground reaction forces due to less range of movement available to attenuate force and increasing the load placed on the knee (Cook, Khan, & Purdam, 2001). Reduced dorsiflexion can also alter the optimal alignment of the pelvis and lumbar spine (Powers, 2003) compromising postures required to adequately absorb shock. These forces can be greater than five times body weight (Annear et al., 1992). It has been shown that landing with the front knee extended, or extending it during the contact phase of the bowling action is positively correlated with ball release speed (Loram et al., 2005; Portus, Mason, Elliott, Pfitzner, & Done, 2004b; Wormgoor, Harden, & McKinon, 2010; Worthington, King, & Ranson, 2013). However, these bowlers consequently experienced high peak forces, developed force more rapidly and demonstrated a moderate correlation with time to peak braking ($r = -0.41$, $p < 0.01$) and vertical forces ($r = -0.41$, $p < 0.01$) by using an extended knee (Portus et al., 2004b). While landing with an extended knee is advantageous for pace bowlers to generate ball speed, it is at the expense of injury risk.

There have been other risk factors identified specific to fast and fast-medium bowlers. These risk factors include workload (Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Hulin et al., 2014; Kountouris et al., 2018; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Warren et al., 2018), muscle morphology (Gray et al., 2016; Kountouris et al., 2012, 2013; Martin et al., 2017a), lumbopelvic control and balance (Bayne et al., 2016; Martin et al., 2017b; Olivier et al., 2015), lower limb mechanics (Dennis et al., 2008b; Martin et al., 2017a; Martin et al., 2017b) and previous injury (Orchard, 2010; Orchard et al., 2015a).

5.6 Relationship between load and injury frequency

In the context of this study, load was defined as hours of match exposure. The relationship between match exposure and number of match injuries (new and recurrent) for domestic and international competition is displayed in figures 4.13 and 4.14 respectively. These figures demonstrate that as match exposure increased or decreased, there was a corresponding change to the number of injuries for that period. Statistical analysis of these findings demonstrated with statistical significance, that hours of match exposure was the key variable for predicting the number of injuries even after accounting for playing level, and the time of the season played ($p < 0.0001$, Appendix F4). Findings between injury and exposure have also been reported in other sports such as rugby league (Gabbett, 2004) and rowing (Newlands, Reid, & Parmar, 2015). Workload has also been shown to be a risk factor for injury in cricket in other studies (Ahmun et al., 2019; Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Hulin et al., 2014; Kountouris et al., 2018; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Saw et al., 2011; Warren et al., 2018). Excluding the studies by Ahmun et al. (2019) and

Saw et al. (2011), who included cricketers from all playing positions, these studies exclusively investigated injury in fast bowlers. Therefore, the number of balls or overs bowled was the most common expression of workload. The majority of these studies consistently identified that fast bowlers were at an increased risk of injury during periods where the amount of bowling suddenly exceeded their previous amount of bowling, an example of an acute spike in load relative to their pre-conditioned chronic load (Gabbett, 2016; Hulin et al., 2014). Interestingly, results from Dennis et al. (2003) reported the opposite can also be true where bowlers who bowled less than 123 deliveries per week (compared to 123-188 weekly deliveries) were also an injury risk (RR = 1.4). This is consistent with exposure loads depicted by Gabbett (2016) from cricket, rugby league, and Australian football, demonstrating that under-training could also present an injury risk, thus suggesting that an optimal balance between acute and chronic workloads exists where injury risk is relatively lower.

5.7 Limitations

A limitation of this study was that external load was collected as an expression of match days and match hours only. While this is appropriate to be able to express match injury incidence as recommended in cricket injury reporting guidelines by Orchard et al. (2005) and Orchard, Ranson, et al. (2016), the effect of training load on injury incidence cannot be determined as training exposure was not collected. As workload studies have demonstrated that sudden changes in load are associated with injury, understanding exposure not just terms of match hours, but also training load, would allow a more robust analysis. The current cricket injury surveillance consensus statement also recommends quantifying exposure in terms of overs bowled for players who bowled, and deliveries faced for players who batted. However, as the need for collecting load-related data in an appropriate level of detail increases, it can become difficult to collect this consistently. Consistency and compliance of data collection is required to ensure that accurate analysis of the injury surveillance system is possible (Phillips, 2000).

Another limitation of the injury surveillance system was that player injury status was recorded on match days only. This was again appropriate as the inability to take part in a match is the requirement for the definition of injury in both Orchard et al. (2005) and Orchard, Ranson, et al. (2016) cricket injury reporting consensus papers. However, this definition has been previously noted to risk under-estimating the true impact of injury (van Mechelen et al., 1992). The definition of injury was expanded in current consensus guidelines by Orchard, Ranson, et al. (2016) so that multiple definitions could be considered in future studies. This included the considering player status on non-match or non-training days, defined as a general time-loss injury. Events that required medical attention, player-reported injuries, and abnormalities found on imaging were also recommended categories for injury surveillance systems in the updated guidelines. Reporting against these categories would certainly provide a more accurate reflection on the injury incidence rates and the impact of injury. The majority of cricket injuries are considered to be overuse (Orchard, Kountouris, et al., 2016) and surveillance systems that capture only match time-loss may underestimate the impact of such injuries (Clarsen et al., 2013).

The coding of injury by body site and body region in the injury surveillance system is another potential source of bias on the injury impacts seen in this study. As reported earlier in this chapter, there were possible coding variations between this and the 2002-2008 research period, in particular with the presence of unconfirmed injuries (injuries not coded to a body part). To reduce this as a source of bias, consistent methods for future data collection are recommended. These methods have been outlined in the latest in the current injury surveillance consensus statement by Orchard, Ranson, et al. (2016), including suggested diagnostic groupings. For specific diagnoses, the OSICS system is encouraged (Orchard et al., 2005).

Full time physiotherapists were introduced into the domestic cricket teams in the 2012-2013 season. It is possible that the increased presence of medical staff could influence an increased reporting of injuries.

Another source of bias can occur due to match scheduling in a season and the date of injury. If a player was to get injured towards the end of a season, the final day recorded as injured would be the final match for that season. The impact of injuries that traditionally take longer to fully recover (e.g. lumbar spine stress fractures) may therefore be under-estimated as there are no more match-days to measure them against once the season concludes. This under-estimation could skew the real impact of such injuries and influence the focus towards injury prevention of less burdensome injuries.

The injury surveillance system from which the data was gathered did not provide details of the mode of onset per injury. Current guidelines now recommend reporting mode of injury onset in terms of a sudden onset non-contact injury, impact/traumatic injury, gradual with an identifiable mode of onset, insidious without identifiable mode of onset, or medical illness (Orchard, Ranson, et al., 2016). Greater detail surrounding mode of onset could be considered for consistency with the comprehensive injury causation model proposed by Bahr and Krosshaug (2005).

Finch and Cook (2014) have described a model for categorising subsequent injuries against initial index injuries. In both the 2005 and 2016 cricket injury surveillance consensus statements, recurrent injury has been defined as an injury of same type reoccurring in the same season or surveillance period after being defined as recovered. The Finch and Cook (2014) model is more comprehensive and could lead to a greater understanding of recurrent injury. This is especially relevant given evidence that previous injury can be a risk factor for injury in cricket (Olivier & Gray, 2018; Orchard, 2010; Orchard et al., 2015a; Orchard et al., 2017).

This study assessed the injury surveillance date for only male domestic and international New Zealand cricketers. Therefore these results may not reflect the injury rates in the equivalent female competitions as these rates and exposures are not known.

Although the injury surveillance data was collected by New Zealand prospectively, the analysis of the data was conducted retrospectively. The primary researcher therefore had no influence data collection methods which may have produced fewer limitations. Despite this limitation, prospectively collected data is more reliable as retrospective data collection can lead to bias (Phillips, 2000).

5.8 Conclusion

The strength in this study is that in total 1,272 data points were analysed over six cricket seasons from 2009 to 2015 in domestic and international New Zealand cricketers. The methods for data collection and reporting were consistent with a previous study investigating the injury epidemiology of elite New Zealand cricketers between 2002-2008 so direct comparison could be made, then expanded with statistical analysis.

This study was able to describe the injury epidemiology in elite New Zealand cricketers from 2009-2015, draw comparisons with other international studies from the same period, and compare findings to a previous 2002-2008 study. The findings in this study were that match injury incidence rate per 10,000 player hours had increased in 2009-2015 compared to 2002-2008, potentially due to the increase of the Twenty20 format in the domestic and international game. The injury incidence rate of international Twenty20 matches per 1,000 player days appears to be increasing. The injury incidence of recurring injuries was seen to reduce from 2009-2015, particularly in international cricket. Injury prevalence rates in 2009-2015 had improved from 2002-2008, with injury prevalence rates of international cricket also reducing over the 2009-2015 period. Lower limb and lumbar spine injuries contributed to the highest injury incidence and prevalence in international and domestic cricket, however, match days lost to lumbar spine injuries in domestic cricket had reduced in the 2009-2015 period compared to 2002-2008. Fast-medium pace international level bowlers lost fewer match days to injury during the course of the study period, but along with domestic fast-medium bowlers, were the most injured players in this population which is consistent with the previous 2002-2008 study and other current international cricket studies. A statistically significant relationship was identified between injury and the level of cricket played, injury and playing position, and injury frequency with match hours of exposure.

This study additionally expressed incidence rates using methods described by the updated consensus statement in cricket injury surveillance so that comparisons could be made with recent international publications and future studies. It is recommended that the current and future methods for collecting injury surveillance data in New Zealand Cricket are consistent with these methods.

5.9 Future directions

This study was able to describe the injury epidemiology of elite New Zealand domestic and international cricketers from 2009-2015. The injury surveillance reporting standards used in this study to describe the epidemiology of injuries were consistent with the current international recommendations (Orchard, Ranson, et al., 2016). It is recommended that future epidemiological studies of New Zealand Cricket maintain this standard of reporting so that meaningful comparison between time periods can be made. The methods used to collect data for the New Zealand Cricket injury surveillance system were appropriately consistent with the international guidelines reported by Orchard et al. (2005). This guideline has been updated so it is recommended that current injury surveillance collection methods reflect this (Orchard, Ranson, et al., 2016). These changes include updates to the definition of injury, subsequent definition of recovery, and reporting mode of onset. Diagnostically grouping injuries by body site and region should also be consistent with the updated surveillance consensus. Future injury surveillance system should also include exposure and injury information from the equivalent New Zealand female competitions.

While it is not included as a recommendation in the current cricket injury surveillance guideline, it could be considered that due to the nature of overuse injuries in cricket, an OSTRC overuse injury questionnaire-style monitoring system be implemented to capture the overuse injury burden in these players. Given the influence that previous injury can have on subsequent injury, expanding the definition of recurrent injuries (Finch & Cook, 2014) can also be considered.

Currently, workload is the most cited risk factor for injury in cricket (Ahmun et al., 2019; Dennis et al., 2004; Dennis et al., 2003; Dennis et al., 2005; Hulin et al., 2014; Kountouris et al., 2018; Orchard et al., 2015a, 2015b; Orchard et al., 2009; Saw et al., 2011; Warren et al., 2018). There have been reports that sudden fluctuations in load can increase the risk of injury while maintaining a consistent state of chronic load can be protective from injury (Gabbett, 2016). In cricket this load is typically defined as the number of balls bowled for bowlers, or balls faced for batters for both match days and training days. As the number of studies identifying workload as a risk factor for injury has increased, it would seem sensible that future injury surveillance systems record training load exposure to accurately express all workloads so the effects can be assessed with greater accuracy so injury prevention interventions can better incorporate workload as a key variable. Given these known relationships between workload and injury, it would be appropriate to begin monitoring the current cohort of elite New Zealand cricketers for balls faced and bowled at trainings and matches to understand and manage their exposure to such workload to reduce injury risk.

The current international cricket schedule has changed from the previous study period so there are now two Twenty20 world cups, and a single One Day World Cup every four-year cycle. The amount of games played in that format increases in preparation for the respective competition. This study has identified that there has been an increased match injury incidence in international and domestic cricket with possible influence due to the increase in Twenty20 games played. Conditioning and load monitoring strategies should be considered as international scheduling dictates an increase in Twenty20 matches, and findings in this study suggest that the injury incidence rate of Twenty20 matches may also be increasing.

Improvement in the burden of lumbar spine injuries in domestic cricket has been identified in this study period compared to 2002-2008. This finding would suggest that strategies to reduce the impact of lumbar spine injuries on lost match days have shown promise and should continue. Lower limb and lumbar spine injuries contribute the greatest injury burden in international and domestic cricket so future interventions to reduce injury burden can be considered here.

The van Mechelen et al. (1992) approach to injury prevention has been explored in this study. The extent of the injury burden in New Zealand domestic and international cricket has been presented using injury incidence and prevalence rates. Statistically significant relationships have been identified with injury and international level players, fast-medium bowlers, and hours of match exposure. A literature review has identified current known risks factors for injury in cricket. Future interventions may look to target these variables. Following the implementation of interventions aimed at reducing targeted injuries by addressing their risk factors, descriptive injury epidemiology should be repeated to assess whether there has been a meaningful change in injury incidence, prevalence and overall burden.

References

Ahmun, R., McCaig, S., Tallent, J., Williams, S., & Gabbett, T. (2019). Association of daily workload, wellness, and injury and illness during tours in international cricketers. *International Journal of Sports Physiology and Performance, 14*(3), 369-377. https://doi.org/10.1123/ijspp.2018-0315

Annear, P. T., Chakera, T. M. H., Foster, D. H., & Hardcastle, P. H. (1992). Pars interarticularis stress and disc degeneration in cricket's potent strike force: The fast bowler. *Australian and New Zealand Journal of Surgery, 62*(10), 768-773.

Bahr, R. (2009). No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *British Journal of Sports Medicine, 43*(13), 966-972. https://doi.org/10.1136/bjsm.2009.066936

Bahr, R., & Krosshaug, T. (2005). Understanding injury mechanisms: A key component of preventing injuries in sport. *British Journal of Sports Medicine, 39*(6), 324-329. https://doi.org/10.1136/bjsm.2005.018341

Bartlett, R. M. (2003). The science and medicine of cricket: An overview and update. *Journal of Sports Sciences, 21*(9), 733-752. https://doi.org/10.1080/0264041031000140257

Bayne, H., Elliott, B., Campbell, A., & Alderson, J. (2016). Lumbar load in adolescent fast bowlers: A prospective injury study. *Journal of Science and Medicine in Sport, 19*(2), 117-122. https://doi.org/10.1016/j.jsams.2015.02.011

Bjørneboe, J., Flørenes, T. W., Bahr, R., & Andersen, T. E. (2011). Injury surveillance in male professional football; is medical staff reporting complete and accurate? *Scandinavian journal of medicine & science in sports, 21*(5), 713-720. https://doi.org/10.1111/j.1600-0838.2009.01085.x

Chosa, E., Totoribe, K., & Tajima, N. (2004). A biomechanical study of lumbar spondylolysis based on a three-dimensional finite element method. *Journal of Orthopaedic Research, 22*(1), 158-163. https://doi.org/10.1016/s0736-0266(03)00160-8

Clarsen, B., & Bahr, R. (2014). Matching the choice of injury/illness definition to study setting, purpose and design: One size does not fit all! *British Journal of Sports Medicine, 48*(7), 510-512. https://doi.org/10.1136/bjsports-2013-093297

Clarsen, B., Myklebust, G., & Bahr, R. (2013). Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: The Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *British Journal of Sports Medicine, 47*(8), 495-502. https://doi.org/10.1136/bjsports-2012-091524

Cook, J. L., Khan, K. M., & Purdam, C. R. (2001). Conservative treatment of patellar tendinopathy. *Physical Therapy in Sport 2*(2), 54-65.

Crewe, H., Elliott, B., Couanis, G., Campbell, A., & Alderson, J. (2012). The lumbar spine of the young cricket fast bowler: An MRI study. *Journal of Science and Medicine in Sport, 15*(3), 190-194. https://doi.org/10.1016/j.jsams.2011.11.251

Dennis, R., Farhart, P., Clements, M., & Ledwidge, H. (2004). The relationship between fast bowling workload and injury in first-class cricketers: A pilot study. *Journal of Science and Medicine in Sport, 7*(2), 232-236.

Dennis, R., Farhart, P., Goumas, C., & Orchard, J. (2003). Bowling workload and the risk of injury in elite cricket fast bowlers. *Journal of Science and Medicine in Sport, 6*(3), 359-367.

Dennis, R., Finch, C. F., McIntosh, A. S., & Elliott, B. C. (2008a). Use of field-based tests to identify risk factors for injury to fast bowlers in cricket. *British Journal of Sports Medicine, 42*(6), 477-482. https://doi.org/10.1136/bjsm.2008.046698

Dennis, R. J., Finch, C. F., & Farhart, P. J. (2005). Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *British Journal of Sports Medicine, 39*(11), 843-846; discussion 843-846. https://doi.org/10.1136/bjsm.2005.018515

Dennis, R. J., Finch, C. F., McIntosh, A. S., & Elliott, B. C. (2008b). Use of field-based tests to identify risk factors for injury to fast bowlers in cricket. *British Journal of Sports Medicine, 42*(6), 477-482. https://doi.org/10.1136/bjsm.2008.046698

Drew, M. K., & Finch, C. F. (2016). The relationship between training load and injury, illness and soreness: A systematic and literature review. *Sports Medicine, 46*(6), 861-883. https://doi.org/10.1007/s40279-015-0459-8

Engebretsen, L., Steffen, K., Alonso, J. M., Aubry, M., Dvorak, J., Junge, A., . . . Wilkinson, M. (2010). Sports injuries and illnesses during the Winter Olympic Games 2010. *British Journal of Sports Medicine, 44*(11), 772-780. https://doi.org/10.1136/bjsm.2010.076992

Finch, C. (2006). A new framework for research leading to sports injury prevention. *Journal of Science and Medicine in Sport, 9*(1-2), 3-9; discussion 10. https://doi.org/10.1016/j.jsams.2006.02.009

Finch, C. F., & Cook, J. (2014). Categorising sports injuries in epidemiological studies: The subsequent injury categorisation (SIC) model to address multiple, recurrent and exacerbation of injuries. *British Journal of Sports Medicine, 48*(17), 1276-1280. https://doi.org/10.1136/bjsports-2012091729

Finch, C. F., Elliott, B. C., & McGrath, A. C. (1999). Measures to prevent cricket injuries. *Sports Medicine, 28*(4), 263-272.

Finch, C. F., Orchard, J. W., Twomey, D. M., Saad Saleem, M., Ekegren, C. L., Lloyd, D. G., & Elliott, B. C. (2012). Coding OSICS sports injury diagnoses in epidemiological studies: does the background of the coder matter? *British Journal of Sports Medicine, 48*(7), 552-556. https://doi.org/10.1136/bjsports-2012-091219

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., . . . Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research, 15*(1), 109-115.

Foster, D., John, D., Elliott, B., Ackland, T., & Fitch, K. (1989). Back injuries to fast bowlers in cricket: A prospective study. *British Journal of Sports Medicine, 23*(3), 150-154.

Frost, W. L., & Chalmers, D. J. (2014). Injury in elite New Zealand cricketers 2002-2008: descriptive epidemiology. *British Journal of Sports Medicine, 48*(12), 1002-1007. https://doi.org/10.1136/bjsports-2012-091337

Fuller, C. W., Bahr, R., Dick, R. W., & Meeuwisse, W. H. (2007). A framework for recording recurrences, reinjuries, and exacerbations in injury surveillance. *Clinical Journal of Sport Medicine, 17*(3), 197-200.

Fuller, C. W., Ekstrand, J., Junge, A., Andersen, T. E., Bahr, R., Dvorak, J., . . . Meeuwisse, W. H. (2006). Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scandinavian journal of medicine & science in sports, 16*(2), 83-92. https://doi.org/10.1111/j.1600-0838.2006.00528.x

Fuller, C. W., Molloy, M. G., Bagate, C., Bahr, R., Brooks, J. H., Donson, H., . . . Wiley, P. (2007). Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *British Journal of Sports Medicine, 41*(5), 328-331. https://doi.org/10.1136/bjsm.2006.033282

Fulton, J., Wright, K., Kelly, M., Zebrosky, B., Zanis, M., Drvol, C., & Butler, R. (2014). Injury risk is altered by previous injury: A systematic review of the literature and presentation of causative neuromuscular factors. *The international journal of sports physcial therapy, 9*(5), 583-595.

Gabbett, T. J. (2004). Influence of training and match intensity on injuries in rugby league. *Journal of Sports Sciences, 22*(5), 409-417. https://doi.org/10.1080/02640410310001641638

Gabbett, T. J. (2016). The training-injury prevention paradox: Should athletes be training smarter and harder? *British Journal of Sports Medicine, 50*(5), 273-280. https://doi.org/10.1136/bjsports-2015-095788

Gissane, C., White, J., Kerr, K., & Jennings, D. A. (2001). An operational model to investigate contact sports injuries. *Medicine & Science in Sports & Exercise, 33*(12).

Gray, J., Aginsky, K. D., Derman, W., Vaughan, C. L., & Hodges, P. W. (2016). Symmetry, not asymmetry, of abdominal muscle morphology is associated with low back pain in cricket fast bowlers. *Journal of Science and Medicine in Sport, 19*(3), 222-226. https://doi.org/10.1016/j.jsams.2015.04.009

Hammond, L. E., Lilley, J., & Ribbans, W. J. (2009). Coding sports injury surveillance data: Has version 10 of the Orchard Sports Injury Classification System improved the classification of sports medicine diagnoses? *British Journal of Sports Medicine, 43*(7), 498-502. https://doi.org/10.1136/bjsm.2008.051979

Hammond, L. E., Lilley, J. M., & Ribbans, W. J. (2013). Defining recovery: An overlooked criterion in sports injury surveillance. *Clinical Journal of Sport Medicine, 23*(3), 157-159.

Hodgson, L., Gissane, C., Gabbett, T. J., & King, D. A. (2007). For debate: Consensus injury definitions in team sports should focus on encompassing all Injuries. *Clinical Journal of Sport Medicine, 17*(3), 118-191.

Hodgson, L., Standen, P. J., & Batt, M. E. (2006). An analysis of injury rates after the seasonal change in rugby league. *Clinical Journal of Sport Medicine, 16*(4), 305-310.

Hulin, B. T., Gabbett, T. J., Blanch, P., Chapman, P., Bailey, D., & Orchard, J. W. (2014). Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *British Journal of Sports Medicine, 48*(8), 708-712. https://doi.org/10.1136/bjsports-2013-092524

Junge, A., Engebretsen, L., Alonso, J. M., Renstrom, P., Mountjoy, M., Aubry, M., & Dvorak, J. (2008). Injury surveillance in multi-sport events: The International Olympic Committee approach. *British Journal of Sports Medicine, 42*(6), 413-421. https://doi.org/10.1136/bjsm.2008.046631

Kountouris, A., Portus, M., & Cook, J. (2012). Quadratus lumborum asymmetry and lumbar spine injury in cricket fast bowlers. *Journal of Science and Medicine in Sport, 15*(5), 393-397. https://doi.org/10.1016/j.jsams.2012.03.012

Kountouris, A., Portus, M., & Cook, J. (2013). Cricket fast bowlers without low back pain have larger quadratus lumborum asymmetry than injured bowlers. *Clinical Journal of Sport Medicine, 23*(4), 300-304.

Kountouris, A., Sims, K., Beakley, D., Saw, A. E., Orchard, J., Rotstein, A., & Cook, J. L. (2018). MRI bone marrow oedema precedes lumbar bone stress injury diagnosis in junior elite cricket fast bowlers. *British Journal of Sports Medicine*. https://doi.org/10.1136/bjsports-2017-097930

Loram, L. C., McKinon, W., Wormgoor, S., Rogers, G. G., Nowak, I., & Harden, L. M. (2005). Determinants of ball release speed in schoolboy fast-medium bowlers in cricket. *Journal of Sports Medicine and Physical Fi tness, 45*(4), 483-490.

Mansingh, A., Harper, L., Headley, S., King-Mowatt, J., & Mansingh, G. (2006). Injuries in West Indies cricket 2003-2004. *British Journal of Sports Medicine, 40*(2), 119-123; discussion 119-123. https://doi.org/10.1136/bjsm.2005.019414

Martin, C., Olivier, B., & Benjamin, N. (2017a). Asymmetrical abdominal muscle morphometry is present in injury free adolescent cricket pace bowlers: A prospective observational study. *Physical Therapy in Sport, 28*, 34-42. https://doi.org/10.1016/j.ptsp.2017.08.078

Martin, C., Olivier, B., & Benjamin, N. (2017b). The Functional Movement Screen in the prediction of injury in adolescent cricket pace bowlers: An observational study. *Journal of Sport Rehabilitation, 26*(5), 386-395. https://doi.org/10.1123/jsr.2016-0073

Meeuwisse, W. H. (1994). Assessing causation in sport injury: A multifactorial model. *Clinical Journal of Sport Medicine, 4*(3), 166-170.

Meeuwisse, W. H., Tyreman, H., Hagel, B., & Emery, C. A. (2007). A dynamic model of etiology in sport injury: The recursive nature of risk and causation. *Clinical Journal of Sport Medicine, 17*(3), 215-219.

Mitchell, R., & Hayen, A. (2005). Defining a cricket injury [letter to the editor]. *Journal of Science and Medicine in Sport, 8*(3), 357-358.

Mountjoy, M., Junge, A., Alonso, J. M., Clarsen, B., Pluim, B. M., Shrier, I., . . . Khan, K. M. (2016). Consensus statement on the methodology of injury and illness surveillance in FINA (aquatic sports). *British Journal of Sports Medicine, 50*(10), 590-596. https://doi.org/10.1136/bjsports-2015-095686

Newlands, C., Reid, D., & Parmar, P. (2015). The prevalence, incidence and severity of low back pain among international-level rowers. *British Journal of Sports Medicine, 49*(14), 951-956. https://doi.org/10.1136/bjsports-2014-093889

Olivier, B., Gillion, N., Stewart, A. V., & McKinon, W. (2017). Reduced nondominant lumbar multifidi cross-sectional area is a precursor of low back injury in cricket fast bowlers. *Scandinavian journal of medicine & science in sports, 27*(12), 1927-1933. https://doi.org/10.1111/sms.12814

Olivier, B., & Gray, J. (2018). Musculoskeletal predictors of non-contact injury in cricketers - Few and far between? A longitudinal cohort study. *Physical Therapy in Sport, 34*, 208-215. https://doi.org/10.1016/j.ptsp.2018.10.014

Olivier, B., Stewart, A. V., & McKinon, W. (2014). Injury and lumbar reposition sense in cricket pace bowlers in neutral and pace bowling specific body positions. *The Spine Journal, 14*(8), 1447-1453. https://doi.org/10.1016/j.spinee.2013.08.036

Olivier, B., Stewart, A. V., Olorunju, S. A. S., & McKinon, W. (2015). Static and dynamic balance ability, lumbo-pelvic movement control and injury incidence in cricket pace bowlers. *Journal of Science and Medicine in Sport, 18*(1), 19-25. https://doi.org/10.1016/j.jsams.2013.10.245

Olsen, O. E., Myklebust, G., Engebretsen, L., Holme, I., & Bahr, R. (2003). Relationship between floor type and risk of ACL injury in team handball. *Scandinavian journal of medicine & science in sports, 13*(5), 299-304.

Orchard, J. (2010). Pace bowlers in cricket with history of lumbar stress fracture have increased risk of lower limb muscle strains, particularly calf strains. *Open Access Journal of Sports Medicine*. https://doi.org/10.2147/oajsm.S10623

Orchard, J., & Hoskins, W. (2007). For debate: Consensus injury definitions in team sports should focus on missed playing time. *Clinical Journal of Sport Medicine, 17*(3), 192-196.

Orchard, J., James, T., Alcott, E., Carter, S., & Farhart, P. (2002). Injuries in Australian cricket at first class level 1995/1996 to 2000/2001. *British Journal of Sports Medicine, 36*, 270-275.

Orchard, J., James, T., Kountouris, A., & Portus, M. (2010). Changes to injury profile (and recommended cricket injury definitions) based on the increased frequency of Twenty20 cricket matches. *Open Access Journal of Sports Medicine, 1*, 63-76.
Orchard, J., Kountouris, A., Sims, K., Orchard, J., Beakley, D., & Brukner, P. (2014). Injury Report 2014: Cricket Australia. *Sport Health, 32*(4), 14-18.
Orchard, J., Rae, K., Brooks, J., Hägglund, M., Til, L., Wales, D., & Wood, T. (2010). Revision, uptake and coding issues related to the open access Orchard Sports Injury Classification System (OSICS) versions 8, 9 and 10.1. *Open Access Journal of Sports Medicine, 1*, 207-214. https://doi.org/10.2147/oajsm.S7715
Orchard, J., & Seward, H. (2002). Epidemiology of injuries in the Australian Football League, seasons 1997-2000. *British Journal of Sports Medicine, 36*(1), 39-44.
Orchard, J. W., Blanch, P., Paoloni, J., Kountouris, A., Sims, K., Orchard, J. J., & Brukner, P. (2015a). Cricket fast bowling workload patterns as risk factors for tendon, muscle, bone and joint injuries. *British Journal of Sports Medicine, 49*(16), 1064-1068. https://doi.org/10.1136/bjsports-2014-093683
Orchard, J. W., Blanch, P., Paoloni, J., Kountouris, A., Sims, K., Orchard, J. J., & Brukner, P. (2015b). Fast bowling match workloads over 5-26 days and risk of injury in the following month. *Journal of Science and Medicine in Sport, 18*(1), 26-30. https://doi.org/10.1016/j.jsams.2014.09.002
Orchard, J. W., James, T., Portus, M., Kountouris, A., & Dennis, R. (2009). Fast Bowlers in Cricket Demonstrate Up to 3- to 4-Week Delay Between High Workloads and Increased Risk of Injury. *The American Journal of Sports Medicine, 37*(6), 1186-1192. https://doi.org/10.1177/0363546509332430
Orchard, J. W., James, T., & Portus, M. R. (2006). Injuries to elite male cricketers in Australia over a 10-year period. *Journal of Science and Medicine in Sport, 9*(6), 459-467. https://doi.org/10.1016/j.jsams.2006.05.001
Orchard, J. W., Kountouris, A., & Sims, K. (2016). Incidence and prevalence of elite male cricket injuries using updated consensus definitions. *Open Access Journal of Sports Medicine, 7*, 187-194. https://doi.org/10.2147/OAJSM.S117497
Orchard, J. W., Kountouris, A., & Sims, K. (2017). Risk factors for hamstring injuries in Australian male professional cricket players. *Journal of Sport and Health Science, 6*(3), 271-274. https://doi.org/10.1016/j.jshs.2017.05.004
Orchard, J. W., Newman, D., Stretch, R., Frost, W., Mansingh, A., & Leipus, A. (2005). Methods for injury surveillance in international cricket. *British Journal of Sports Medicine, 39*(4), e22. https://doi.org/10.1136/bjsm.2004.012732
Orchard, J. W., Ranson, C., Olivier, B., Dhillon, M., Gray, J., Langley, B., . . . Finch, C. F. (2016). International consensus statement on injury surveillance in cricket: a 2016 update. *British Journal of Sports Medicine, 50*(20), 1245-1251. https://doi.org/10.1136/bjsports-2016-096125
Pasanen, K., Parkkari, J., Pasanen, M., & Kannus, P. (2009). Effect of a neuromuscular warm-up programme on muscle power, balance, speed and agility: A randomised controlled study. *British Journal of Sports Medicine, 43*(13), 1073-1078. https://doi.org/10.1136/bjsm.2009.061747
Petersen, C. J., Pyne, D., Dawson, B., Portus, M., & Kellett, A. (2010). Movement patterns in cricket vary by both position and game format. *Journal of Sports Sciences, 28*(1), 45-52. https://doi.org/10.1080/02640410903348665
Petersen, C. J., Pyne, D. B., Portus, M. R., & Dawson, B. T. (2011). Comparison of player movement patterns between 1-day and test cricket. *Journal of Strength and Conditioning Research, 25*(5), 1368-1373.
Phillips, L. H. (2000). Sports injury incidence. *British Journal of Sports Medicine, 34*(2), 133-136.

Pluim, B. M., Fuller, C. W., Batt, M. E., Chase, L., Hainline, B., Miller, S., . . . Wood, T. O. (2009). Consensus statement on epidemiological studies of medical conditions in tennis, April 2009. *British Journal of Sports Medicine, 43*(12), 893-897. https://doi.org/10.1136/bjsm.2009.064915

Portus, M. R., Mason, B. R., Elliott, B. C., Pfitzner, M. C., & Done, R. P. (2004a). Technique factors related to ball release speed and trunk injuries in high performance cricket fast bowlers. *Sports Biomechanics, 3*(2), 263-284. https://doi.org/10.1080/14763140408522845

Portus, M. R., Mason, B. R., Elliott, B. C., Pfitzner, M. C., & Done, R. P. (2004b). Technique factors related to ball release speed and trunk injuries in high performance cricket fast bowlers. *Sports Biomechanics, 3*(2), 263-284. https://doi.org/10.1080/14763140408522845

Powers, C. M. (2003). The influence of altered lower-extremity kinematics on patellofemoral joint dysfunction: a theoretical perspective. *Journal of Orthopaedic and Sports Physical Therapy, 33*(11), 639-646.

Ranson, C. A., Burnett, A. F., & Kerslake, R. W. (2010). Injuries to the lower back in elite fast bowlers. *The Journal of Bone and Joint Surgery, 92*(12), 1664-1668. https://doi.org/10.1302/0301-620X.92B12

Raysmith, B. P., & Drew, M. K. (2016). Performance success or failure is influenced by weeks lost to injury and illness in elite Australian track and field athletes: A 5-year prospective study. *Journal of Science and Medicine in Sport, 19*(10), 778-783. https://doi.org/10.1016/j.jsams.2015.12.515

Saw, R., Dennis, R. J., Bentley, D., & Farhart, P. (2011). Throwing workload and injury risk in elite cricketers. *British Journal of Sports Medicine, 45*(10), 805-808. https://doi.org/10.1136/bjsm.2009.061309

Schwellnus, M. P., Derman, W. E., Jordaan, E., Page, T., Lambert, M. I., Readhead, C., . . . Webb, S. (2012). Elite athletes travelling to international destinations >5 time zone differences from their home country have a 2-3-fold increased risk of illness. *British Journal of Sports Medicine, 46*(11), 816-821. https://doi.org/10.1136/bjsports-2012-091395

Silvers-Granelli, H., Mandelbaum, B., Adeniji, O., Insler, S., Bizzini, M., Pohlig, R., . . . Dvorak, J. (2015). Efficacy of the FIFA 11+ injury prevention program in the collegiate male soccer player. *The American Journal of Sports Medicine, 43*(11), 2628-2637. https://doi.org/10.1177/0363546515602009

Soligard, T., Myklebust, G., Steffen, K., Holme, I., Silvers, H., Bizzini, M., . . . Andersen, T. E. (2008). Comprehensive warm-up programme to prevent injuries in young female footballers: Cluster randomised controlled trial. *British Medical Journal, 337*, a2469. https://doi.org/10.1136/bmj.a2469

Stretch, R., & Raffan, R. P. (2011). Injury patterns of South African international cricket players over a two-season period. *South African journal of sports medicine, 23*(2), 45-49.

Stretch, R., Raffan, R. P., & Allan, N. (2009). Injury patterns of South African provincial cricket players over two seasons. *South African journal of sports medicine, 21*(4), 151-155.

Timpka, T., Alonso, J. M., Jacobsson, J., Junge, A., Branco, P., Clarsen, B., . . . Edouard, P. (2014). Injury and illness definitions and data collection procedures for use in epidemiological studies in Athletics (track and field): Consensus statement. *British Journal of Sports Medicine, 48*(7), 483-490. https://doi.org/10.1136/bjsports-2013-093241

Timpka, T., Jacobsson, J., Bickenbach, J., Finch, C. F., Ekberg, J., & Nordenfelt, L. (2014). What is a sports injury? *Sports Medicine, 44*(4), 423-428. https://doi.org/10.1007/s40279-014-0143-4 van Mechelen, W., Hlobil, H., & Kemper, H. C. G. (1992). Incidence, severity, aetiology and prevention of sports injuries: A review of concepts. *Sports Medicine, 14*(2), 82-99.

Warren, A., Williams, S., McCaig, S., & Trewartha, G. (2018). High acute:chronic workloads are associated with injury in England & Wales Cricket Board Development Programme fast bowlers. *Journal of Science and Medicine in Sport, 21*(1), 40-45. https://doi.org/10.1016/j.jsams.2017.07.009

Wormgoor, S., Harden, L., & McKinon, W. (2010). Anthropometric, biomechanical, and isokinetic strength predictors of ball release speed in high-performance cricket fast bowlers. *Journal of Sports Sciences, 28*(9), 957-965. https://doi.org/10.1080/02640411003774537

Worthington, P. J., King, M. A., & Ranson, C. A. (2013). Relationships between fast bowling technique and ball release speed. *Journal of Applied Biomechanics, 29*(1), 78-84.

Appendices

Appendix A

Ethical approval

AUTEC Secretariat
Auckland University of Technology
D-88, WU406 Level 4 WU Building City Campus
T: +64 9 921 9999 ext. 8316
E: ethics@aut.ac.nz
www.aut.ac.nz/researchethics

27 April 2016
Duncan Reid
Faculty of Health and Environmental Sciences

Dear Duncan

Re Ethics Application: **16/121 Injury incidence and movement screening in New Zealand cricket, an update from 2010-15.**

Thank you for providing evidence as requested, which satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC).

Your ethics application has been approved for three years until 27 April 2019.

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/researchethics. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 27 April 2019;
- A brief report on the status of the project using form EA3, which is available online through http://www.aut.ac.nz/researchethics. This report is to be submitted either when the approval expires on 27 April 2019 or on completion of the project.

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 responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to obtain this.
To enable us to provide you with efficient service, please use the application number and study title in all correspondence with us. If you have any enquiries about this application, or anything else, please do contact us at ethics@aut.ac.nz.
All the very best with your research,

Kate O'Connor
Executive Secretary
Auckland University of Technology Ethics Committee
Cc: Tim Dovbysh tim.dovbysh@gmail.com

Appendix B

New Zealand Cricket injury surveillance system coding

NZC ISP Summary Codes for Player Participation Sheets

Injury Codes - Training & Match

Training Injury

		Example	
I	Injured in Training: (1st Instance of this injury)	"I-<body part>"	
Y	Injured in Training: Recurrent injury (1st Recurrence)	"Y-<body part>"	**R**
J	Injury occurred in match because of previous training	"J-<body part>	

New Match Injury (Codes for the match in which the injury happened)

E	Injury occurring during a match (new injury)	"E-<body part>"
D	Disabled and not selected due to Match Injury on (1st Instance)	"D-<body part>

Recurrent Match Injury (Codes for the match in which the injury happened)

K	Recurrance of an injury that Occured in a Previous Match	"K-<body part>"	**R**
X	Disabled & not selected due to Recurring Match Injury (1st Recurrence)	"X-<body part>"	**R**

Subsequent Match Codes and Illness

F	Infection or Illness	"F-<illness>"
Q	Unavailable because of Injury (2nd and subsequent matches)	"Q-<body part>"

Non Injury Codes

P	Playing	"P"
R	Rested	"R"
O	unavailable, other reasons - suspended	"O"
Z	Unavailable, NZ team comittments	"Z"
N	Not selected	"N"
W	Washout - no play	"W"

For Match & Competition - please enter the following for the various associations:	
Match vs	
Domestic Teams:	
Auckland	A
Northern Districts	N
Central Districts	CD
Wellington	W
Canterbury	CA
Otago	O
International Teams: abbreviate to 3 letters e.g:	
India	IND
Australia	AUS
South Africa	SAF
Pakistan	PAK
England	ENG
Bangladesh	BAG
Match ID	
Twenty/20	TT
State Shield	SS
State Championship	SC
State League (women)	SL
Warm-Up/Preseason match	WU
e.g. State Championship v Canterbury	CASC
e.g. State Shield Match v Northern Districts	NSS
International Games:	
First three initials of country & day of game	
e.g. India 2nd day of 3 day game	IND2

Appendix C

Match exposure, injury incidence and prevalence rates, injury incidents, and match days lost

1. Match days played between 2009-2015

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015
Domestic T20	58	53	78	64	55	64
Domestic 1D	55	50	51	51	48	52
Domestic First Class	216	220	217	228	228	233
Domestic total	329	323	346	343	331	349
International T20	19	3	8	18	10	2
International 1D	6	31	8	21	15	26
International Test	29	22	29	53	30	23
International total	54	56	45	92	55	51

Note. T20 = Twenty20, 1D = One Day.

2. Team exposure hours per match format per season

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Total
Domestic T20	1005	919	1387	1109	953	1109	6482
Domestic 1D	2383	2167	2210	2210	2080	2253	13303
Domestic First Class	8931	8814	8541	8892	8892	9087	53157
Domestic total	12319	11900	12138	12211	11925	12449	72942
International T20	329	52	139	312	295	35	1162
International 1D	260	1343	347	910	650	1127	4637
International Test	1131	858	1131	2067	1170	897	7254
International total	1720	2253	1967	3289	2115	2059	13403

Note. T20 = Twenty20, 1D = One Day.

3. Match injury incidence of new and recurrent injuries per 10,000 player hours per format per season

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Total
Domestic T20	99.5	130.6	51.8	144.2	115.4	90.1	102.4
Domestic 1D	46.2	64.6	36.2	36.2	24.0	48.8	42.9
Domestic First Class	46.3	46.6	43.7	32.6	40.5	27.5	39.4
Domestic total	50.8	56.6	43.2	43.4	43.6	36.9	45.6
International T20	182.2	576.9	0.0	352.6	115.4	576.9	230.8
International 1D	307.7	126.6	144.2	109.9	76.9	62.1	112.2
International Test	44.2	58.3	17.7	33.9	17.1	11.1	30.3
International total	110.4	110.9	43.3	85.1	45.2	48.6	75.8

Note. T20 = Twenty20, 1D = One Day.

4. **Match injury incidence of new (excluding recurrent) injuries per 10,000 player hours per format per season**

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Total
Domestic T20	69.7	76.2	29.6	108.2	83.9	90.2	74.5
Domestic 1D	33.6	32.3	27.1	31.7	24.0	48.8	33.1
Domestic First Class	38.0	39.6	36.6	29.2	37.1	20.9	33.4
Domestic total	39.8	41.1	34.1	36.9	38.6	32.1	37.0
International T20	60.8	0.0	0.0	288.5	115.6	571.4	144.2
International 1D	192.3	104.2	144.1	76.9	76.9	62.1	92.7
International Test	26.5	46.6	17.7	33.9	8.5	0.0	23.4
International total	58.1	79.9	43.3	69.9	40.1	43.7	58.0

Note. T20 = Twenty20, 1D = One Day.

5. **Match injury incidence of recurrent injuries per 10,000 player hours per season**

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Total
Domestic	11.0	18.9	9.1	6.6	5.0	4.8	9.2
International	52.3	35.5	0.0	24.3	5.0	4.9	20.9

6. **Match injury incidence rate of new and recurrent match injuries per 1,000 player days per format per season**

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Total
Domestic T20	172.4	226.4	89.7	250.0	200.0	156.3	117.4
Domestic 1D	200.0	280.0	156.9	156.9	104.2	211.5	185.7
Domestic First Class	180.6	181.8	170.5	127.2	157.9	107.3	153.5
Domestic total	182.4	204.3	150.3	154.5	157.1	131.8	162.8
International T20	315.8	1000.0	0.0	611.1	200.0	1000.0	400.0
International 1D	1333.3	548.4	625.0	476.2	333.3	269.2	486.0
International Test	172.4	227.3	69.0	132.1	66.7	43.5	118.3
International total	351.9	446.4	155.6	304.3	163.6	196.1	277.6

Note. T20 = Twenty20, 1D = One Day.

7. Seasonal injury incidence per squad per season

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015
Domestic	12.2	14.7	11.3	11.7	12.3	12.0
International	28.9	31.1	16.0	20.9	12.0	18.8

8. Injury prevalence rates (%) by season

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Total
Domestic	7.0	8.2	7.6	7.1	6.8	8.5	7.6
International	20.4	9.9	15.1	7.5	5.2	4.6	10.0

9. Number of new match injuries, recurring injuries, and training injuries (% total) by body site

Season	2009-2010		2010-11		2011-12		2012-13		2013-14		2014-15		Total	
Playing level	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**	**Domestic**	**International**
Concussion							1 (1.5)				1 (1.4)	1 (6.3)	2 (0.5)	1 (0.8)
Head	1 (1.5)	1 (3.8)	1 (1.3)	1 (3.4)	3 (4.6)						1 (1.4)		6 (1.4)	2 (1.6)
Eye									1 (1.5)				1 (0.2)	
Neck		1 (3.8)	1 (1.3)		1 (1.5)		1 (1.5)						3 (0.7)	1 (0.8)
Shoulder	6 (9.0)	1 (3.8)	5 (6.3)		2 (3.1)		5 (7.5)	1 (3.1)	5 (7.4)		5 (7.1)	3 (18.8)	28 (6.7)	5 (4.0)
Upper arm				1 (3.4)					1 (1.5)				1 (0.2)	1 (0.8)
Elbow		1 (3.8)							1 (1.5)		4 (5.7)	1 (6.3)	5 (1.2)	2 (1.6)
Arm			1 (1.3)		1 (1.5)	1 (8.3)		1 (3.1)					2 (0.5)	2 (1.6)
Wrist					1 (1.5)				1 (1.5)		2 (2.9)	1 (6.3)	4 (1.0)	1 (0.8)
Hand		1 (3.8)	4 (5.1)				3 (4.5)		1 (1.5)		3 (4.3)		11 (2.6)	1 (0.8)
Thumb	3 (4.5)	1 (3.8)	1 (1.3)		1 (1.5)		3 (4.5)	1 (3.1)	3 (4.4)	1 (9.1)			11 (2.6)	3 (2.4)
Finger	6 (9.0)	1 (3.8)	4 (5.1)	1 (3.4)	5 (7.7)	1 (8.3)	5 (7.5)	1 (3.1)	3 (4.4)	2 (18.2)	5 (7.1)	1 (6.3)	28 (6.7)	7 (5.6)
Chest							1 (1.5)						1 (0.2)	
Rib	3 (4.5)								2 (2.9)		2 (2.9)		7 (1.7)	
Lat	2 (3.0)						1 (1.5)						3 (0.7)	
Pec	1 (1.5)												1 (0.2)	
Thoracic spine			1 (1.3)										1 (0.2)	
Side	2 (3.0)		4 (5.1)	1 (3.4)	7 (10.8)		7 (10.4)	3 (9.4)	3 (4.4)	2 (18.2)	5 (7.1)	1 (6.3)	28 (6.7)	7 (5.6)
Oblique									1 (1.5)		1 (1.4)		2 (0.5)	
Abdomen	1 (1.5)	2 (7.7)	3 (3.8)		1 (1.5)		1 (1.5)		1 (1.5)				7 (1.7)	2 (1.6)
Lumbar spine	4 (6.0)	2 (7.7)	4 (5.1)	5 (17.2)	9 (13.8)	1 (8.3)	4 (6.0)	3 (9.4)	4 (5.9)	1 (9.1)	7 (10.0)	1 (6.3)	32 (7.7)	13 (10.3)
Glute				1 (3.4)										1 (0.8)
Hip		1 (3.8)	1 (1.3)			2 (16.7)	1 (1.5)		2 (2.9)				4 (1.0)	3 (2.4)
Groin	9 (13.4)	4 (15.4)	8 (10.1)	3 (10.3)	2 (3.1)	1 (8.3)	3 (4.5)	3 (9.4)	6 (8.8)	2 (18.2)	2 (2.9)	4 (25.0)	30 (7.2)	17 (13.5)
Thigh	3 (4.5)		2 (2.5)		1 (1.5)		4 (6.0)						10 (2.4)	
Quad	3 (4.5)		3 (3.8)	1 (3.4)	2 (3.1)		3 (4.5)	4 (12.5)	2 (2.9)				13 (3.1)	5 (4.0)
Hamstring	2 (3.0)	3 (11.5)	3 (3.8)	2 (6.9)	5 (7.7)	1 (8.3)	12 (17.9)	3 (9.4)	8 (11.8)		4 (5.7)	1 (6.3)	34 (8.2)	10 (7.9)
Knee	7 (10.4)	3 (11.5)	8 (10.1)	2 (6.9)	3 (4.6)		2 (3.0)	2 (6.3)	6 (8.8)		4 (5.7)		30 (7.2)	7 (5.6)
ITB		1 (3.8)			2 (3.1)								2 (0.5)	1 (0.8)
Calf	2 (3.0)	1 (3.8)	1 (1.3)	2 (6.9)	3 (4.6)	2 (16.7)	3 (4.5)	2 (6.3)	3 (4.4)		4 (5.7)	1 (6.3)	16 (3.8)	8 (6.3)
Lower leg											1 (1.4)		1 (0.2)	
Shin			2 (2.5)		1 (1.5)		2 (3.0)				1 (1.4)		6 (1.4)	
Achilles			1 (1.3)	1 (3.4)	1 (1.5)			2 (6.3)	1 (1.5)		1 (1.4)		4 (1.0)	3 (2.4)
Ankle			4 (5.1)	3 (10.3)	5 (7.7)		3 (4.5)	2 (6.3)	7 (10.3)	2 (18.2)	8 (11.4)		27 (6.5)	7 (5.6)
Foot	2 (3.0)	2 (7.7)	2 (2.5)		2 (3.1)				3 (4.4)	1 (9.1)	5 (7.1)	1 (6.3)	14 (3.4)	4 (3.2)
Illness	2 (3.0)		5 (6.3)	5 (17.2)	4 (6.2)	2 (16.7)	2 (3.0)	3 (9.4)	3 (4.4)		4 (5.7)		20 (4.8)	10 (7.9)
Unconfirmed	8 (11.9)	0	10 (12.7)	0	3 (4.6)	1 (8.3)	0	1 (3.1)	0	0	0	0	21 (5.0)	2 (1.6)
TOTAL	**67**	**26**	**79**	**29**	**65**	**12**	**67**	**32**	**68**	**11**	**70**	**16**	**416**	**126**

10. Number of match days lost to new match injuries, recurring injuries, and training injuries (% total) by body site

Season	2009-2010		2010-11		2011-12		2012-13		2013-14		2014-15		Total	
Playing level	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International
Concussion							1 (0.2)				14 (1.9)	2 (3.4)	15 (0.4)	2 (0.2)
Head	3 (0.5)	2 (0.7)	2 (0.3)	2 (1.4)	8 (1.2)						2 (0.3)		15 (0.4)	4 (0.5)
Eye									1 (0.2)				1 (0.0)	
Neck		1 (0.4)	1 (0.2)		1 (0.2)		2 (0.3)						4 (0.1)	1 (0.1)
Shoulder	52 (9.0)	42 (15.3)	46 (6.9)		18 (2.7)		59 (9.7)	5 (2.9)	36 (6.4)		83 (11.2)	4 (6.8)	294 (7.7)	51 (5.8)
Upper arm				4 (2.9)					11 (1.9)				11 (0.3)	4 (0.5)
Elbow		2 (0.7)							1 (0.2)		38 (5.1)	3 (5.1)	39 (1.0)	5 (0.6)
Arm			1 (0.2)		1 (0.2)	2 (1.2)		1 (0.6)					2 (0.1)	3 (0.3)
Wrist					3 (0.5)				1 (0.2)		8 (1.1)	3 (5.1)	12 (0.3)	3 (0.3)
Hand		15 (5.5)	20 (3.0)				26 (4.3)		5 (0.9)		20 (2.7)		71 (1.9)	15 (1.7)
Thumb	10 (1.7)	9 (3.3)	7 (1.1)		1 (0.2)		30 (4.9)	13 (7.5)	54 (9.6)	13 (18.6)			102 (2.7)	35 (4.0)
Finger	52 (9.0)	1 (0.4)	33 (5.0)	1 (0.7)	49 (7.4)	14 (8.2)	39 (6.4)	2 (1.2)	32 (5.7)	2 (2.9)	33 (4.5)	3 (5.1)	238 (6.2)	23 (2.6)
Chest							1 (0.2)						1 (0.0)	
Rib	24 (4.2)								5 (0.9)		6 (0.8)		35 (0.9)	
Lat	29 (5.0)						16 (2.6)						45 (1.2)	
Pec	8 (1.4)												8 (0.2)	
Thoracic spine			1 (0.2)										1 (0.0)	
Side	16 (2.8)		38 (5.7)	11 (8.0)	122 (18.5)		115 (25.5)	12 (6.9)	28 (5.0)	8 (11.4)	52 (7.0)	3 (5.1)	371 (9.7)	34 (3.8)
Oblique									27 (4.8)		6 (0.8)		33 (0.9)	
Abdomen	23 (4.0)	18 (6.5)	15 (2.3)		10 (1.5)		9 (1.5)		1 (0.2)				58 (1.5)	18 (2.0)
Lumbar spine	40 (6.9)	5 (1.8)	71 (10.7)	11 (8.0)	115 (17.5)	55 (32.4)	26 (4.3)	6 (3.5)	59 (10.4)	6 (8.6)	106 (14.3)	18 (30.5)	417 (10.9)	101 (11.4)
Glute				1 (0.7)										1 (0.1)
Hip		1 (0.4)	6 (0.9)			50 (29.4)	1 (0.2)		8 (1.4)				15 (0.4)	51 (5.8)
Groin	129 (22.3)	73 (26.5)	80 (12.0)	32 (23.2)	17 (2.6)	9 (5.3)	12 (2.0)	15 (8.7)	44 (7.8)	9 (12.9)	8 (1.1)	14 (23.7)	290 (7.6)	152 (17.2)
Thigh	5 (0.9)		7 (1.1)		7 (1.1)		49 (8.1)						68 (1.8)	
Quad	27 (4.7)		42 (6.3)	4 (2.9)	23 (3.5)		17 (2.8)	21 (12.1)	8 (1.4)				117 (3.1)	25 (2.8)
Hamstring	15 (2.6)	4 (1.5)	39 (5.9)	4 (2.9)	33 (5.0)	4 (2.4)	94 (10.5)	9 (5.2)	64 (11.3)		48 (6.5)	4 (6.8)	293 (7.7)	25 (2.8)
Knee	72 (12.5)	69 (25.1)	71 (10.7)	31 (22.5)	44 (6.7)		7 (1.2)	11 (6.4)	37 (6.5)		64 (8.6)		295 (7.7)	111 (12.5)
ITB		1 (0.4)			7 (1.1)								7 (0.2)	1 (0.1)
Calf	7 (1.2)	2 (0.7)	1 (0.2)	11 (8.0)	10 (1.5)	22 (12.9)	14 (2.3)	13 (7.5)	15 (2.7)		61 (8.2)	3 (5.1)	108 (2.8)	51 (5.8)
Lower leg											20 (2.7)		20 (0.5)	
Shin			29 (4.4)		4 (0.6)		27 (4.4)				6 (0.8)		66 (1.7)	
Achilles			57 (8.6)	15 (10.9)	21 (3.2)			55 (31.8)	18 (3.2)		3 (0.4)		99 (2.6)	70 (7.9)
Ankle			4 (0.6)	6 (4.3)	90 (13.7)		42 (6.9)	5 (2.9)	34 (6.0)	23 (32.9)	76 (10.3)		246 (6.4)	34 (3.8)
Foot	43 (7.4)	30 (10.9)	15 (2.3)		18 (2.7)				73 (12.9)	9 (12.9)	70 (9.5)	2 (3.4)	219 (5.7)	41 (4.6)
Illness	2 (0.3)		19 (2.9)	5 (3.6)	8 (1.2)	2 (1.2)	21 (3.5)	4 (2.3)	3 (0.5)		16 (2.2)		69 (1.8)	11 (1.2)
Unconfirmed	21 (3.6)	0	61 (9.2)	0	49 (7.4)	12 (7.1)	0	1 (0.6)	0	0	0	0	131 (3.4)	13 (1.5)
TOTAL	**578**	**275**	**666**	**138**	**659**	**170**	**608**	**173**	**565**	**70**	**740**	**59**	**3816**	**885**

11. Number of new match injuries, recurring injuries, and training injuries (% total) by player position

Season	2009-10		2010-11		2011-12		2012-13		2013-14		2014-15	
Playing level	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International
Batter	20 (29.9)	9 (34.6)	24 (30.4)	11 (37.9)	26 (40.0)	6 (50.0)	20 (29.9)	10 (31.3)	27 (39.7)	4 (36.4)	21 (30.0)	8 (50.0)
Bowler (fast-med)	39 (58.2)	14 (53.8)	44 (55.7)	12 (41.4)	36 (55.4)	5 (41.7)	34 (50.7)	13 (40.6)	33 (48.5)	6 (54.5)	39 (55.7)	8 (50.0)
Bowler (slow-spin)	4 (6.0)	2 (7.7)	6 (7.6)	4 (13.8)	2 (3.1)	1 (8.3)	8 (11.9)	7 (21.9)	4 (5.9)	0	7 (10.0)	0
Wicket keeper	4 (6.0)	1 (3.8)	5 (6.3)	2 (6.9)	1 (1.5)	0	5 (7.5)	2 (6.3)	4 (5.9)	1 (9.1)	3 (4.3)	0
TOTAL	**67**	**26**	**79**	**29**	**65**	**12**	**67**	**32**	**68**	**11**	**70**	**16**

12. Number of match days lost to new match injuries, recurring injuries, and training injuries (% total) by player position

Season	2009-10		2010-11		2011-12		2012-13		2013-14		2014-15	
Playing level	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International	Domestic	International
Batter	129 (22.3)	95 (34.5)	103 (15.5)	21 (15.2)	170 (25.8)	80 (47.1)	115 (18.9)	62 (35.8)	146 (25.8)	31 (44.3)	183 (24.7)	24 (40.7)
Bowler (fast-med)	375 (64.9)	176 (64.0)	495 (74.3)	101 (73.2)	480 (72.8)	86 (50.6)	422 (69.4)	34 (19.7)	376 (66.5)	33 (47.1)	453 (61.2)	35 (59.3)
Bowler (slow-spin)	68 (11.8)	3 (1.1)	40 (6.0)	10 (7.2)	7 (1.1)	4 (2.4)	35 (5.8)	75 (43.4)	15 (2.7)	0	74 (10.0)	0
Wicket keeper	6 (1.0)	1 (0.4)	28 (4.2)	6 (4.3)	2 (0.3)	0	36 (5.9)	2 (1.2)	28 (5.0)	6 (8.6)	30 (4.1)	0
TOTAL	**578**	**275**	**666**	**138**	**659**	**170**	**608**	**173**	**565**	**70**	**740**	**59**

Appendix D

Chi-square test comparing injury status between domestic and international players

Level of play * Was the player injured Crosstabulation

			Was the player injured		Total
			not injured	injured	
Level of play	domestic	Count	560	431	991
		% within Level of play	56.5%	43.5%	100.0%
	international	Count	139	142	281
		% within Level of play	49.5%	50.5%	100.0%
Total		Count	699	573	1272
		% within Level of play	55.0%	45.0%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	4.386[a]	1	.036		
Continuity Correction[b]	4.106	1	.043		
Likelihood Ratio	4.370	1	.037		
Fisher's Exact Test				.041	.022
Linear-by-Linear Association	4.383	1	.036		
N of Valid Cases	1272				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 126.58.

b. Computed only for a 2x2 table

Appendix E

Chi-square test comparing injury status between player positions

Player type * Was the player injured Crosstabulation

			Was the player injured		Total
			not injured	injured	
Player type	bowler (fast-med)	Count	255	303	558
		% within Player type	45.7%	54.3%	100.0%
	bowler (slow-spin)	Count	110	47	157
		% within Player type	70.1%	29.9%	100.0%
	batter	Count	274	195	469
		% within Player type	58.4%	41.6%	100.0%
	wicket keeper	Count	60	28	88
		% within Player type	68.2%	31.8%	100.0%
Total		Count	699	573	1272
		% within Player type	55.0%	45.0%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	42.286[a]	3	.000
Likelihood Ratio	42.917	3	.000
Linear-by-Linear Association	24.447	1	.000
N of Valid Cases	1272		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 39.64.

Appendix F

Linear regression analysis: number of injuries as dependent variable

1. Independent variable: match exposure hours

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11146.111	1	11146.111	190.246	.000[b]
	Residual	995.994	17	58.588		
	Total	12142.105	18			

a. Dependent Variable: Number of injuries

b. Predictors: (Constant), Match hours of exposure

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	3.274	2.234		1.466	.161	-1.439	7.986
	Match hours of exposure	.004	.000	.958	13.793	.000	.004	.005

a. Dependent Variable: Number of injuries

2. Independent variable: playing level

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	6753.189	1	6753.189	21.304	.000[b]
	Residual	5388.917	17	316.995		
	Total	12142.105	18			

a. Dependent Variable: Number of injuries

b. Predictors: (Constant), Playing level

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	86.083	14.407		5.975	.000	55.688	116.479
	Playing level	-39.083	8.468	-.746	-4.616	.000	-56.949	-21.218

a. Dependent Variable: Number of injuries

3. Independent variable: playing level and match exposure hours

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11146.548	2	5573.274	89.570	.000[b]
	Residual	995.557	16	62.222		
	Total	12142.105	18			

a. Dependent Variable: Number of injuries

b. Predictors: (Constant), Match hours of exposure, Playing level

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	2.300	11.839		.194	.848	-22.798	27.397
	Playing level	.505	6.023	.010	.084	.934	-12.262	13.272
	Match hours of exposure	.424	.050	.966	8.403	.000	.317	.531

a. Dependent Variable: Number of injuries

4. Independent variable: playing month, playing level, and match exposure hours

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11209.058	3	3736.353	60.067	.000[b]
	Residual	933.047	15	62.203		
	Total	12142.105	18			

a. Dependent Variable: Number of injuries

b. Predictors: (Constant), Match hours of exposure, Month, Playing level

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	6.572	12.581		.522	.609	-20.243	33.388
	Month	-.605	.603	-.072	-1.002	.332	-1.891	.681
	Playing level	.327	6.024	.006	.054	.957	-12.513	13.167
	Match hours of exposure	.425	.050	.969	8.428	.000	.318	.533

a. Dependent Variable: Number of injuries

Appendix G

Match injury incidence rates per 1,000 player hours per format per season

	2009-2010	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Total
Domestic T20	9.9	13.1	5.2	14.4	11.5	9.0	10.2
Domestic 1D	4.6	6.5	3.6	3.6	2.4	4.9	4.3
Domestic First class	4.6	4.7	4.4	3.3	4.0	2.8	3.9
Domestic total	5.1	5.7	4.3	4.3	4.4	3.7	4.6
International T20	18.2	57.7	0.0	35.3	11.5	57.7	23.1
International 1D	30.8	12.7	14.4	11.0	7.7	6.2	11.2
International Test	4.4	5.8	1.8	3.4	1.7	1.1	3.0
International total	11.0	11.1	4.3	8.5	4.5	4.9	7.6

Note. T20 = Twenty20, 1D = One Day.