Injury Surveillance in Elite Australian Sport: Understanding Subsequent Injury for Tertiary Injury Prevention

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Statement of Authorship

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis.

This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

All research procedures reported in the thesis were approved by the La Trobe University Human Research Ethics Committee (HREC).

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List of Abbreviations

ACL	Anterior Cruciate Ligament
AF	Australian football
AFL	Australian Football League
AU	Arbitrary Units
CI	Confidence interval
GPS	Global Positioning System
HREC	Human Research Ethics Committee
ICD	International Classification of Diseases
ID	Identifier code
IOC	International Olympic Committee
n	number of participants in a sample
OSICS	Orchard Sports Injury Classification System
p	p-value
PDF	Portable document format
RR	Relative risk
RTP	Return to play
SIC	Subsequent Injury Categorisation
SMDCS	Sport Medicine Diagnostic Coding System
WHO	World Health Organisation

Abstract

Most athletes sustain multiple injuries every season, impacting individual health and team performance. Understanding the relationships between these injuries, rather than each injury in isolation, is important for effective injury prevention. This thesis aimed to explore methods of subsequent injury analysis to improve longitudinal injury surveillance. A comprehensive literature review and two studies were conducted to address this aim.

Chapter one introduced sports injury surveillance and identified the shortcomings of modern surveillance systems. Chapter two summarised the ambiguity involved in defining injury and the important role subsequent injuries play in injury prevention; identifying the subsequent injury categorisation (SIC-2.0) model as a suitable tool to understand the relationships between previous and subsequent injuries. Chapter three applied the SIC-2.0 model to an injury dataset containing all time-loss injuries from the 2016 Australian Football League season (n=455). Subsequent injury patterns and the association between index (first) injury nature and subsequent injury type were described. Chapter four adopted similar methodology using a dataset containing all medical attention injuries from the 2018 and 2019 Super Rugby seasons (n=196). Additionally, the association between the nature of an immediately preceding injury and subsequent injury type were described.

Subsequent injuries were common in both cohorts, most of which were at a different site and of a different nature to the previous injuries. Both studies also established that previous injury nature may alter the subsequent injury risk profile of an athlete. Categorising subsequent injuries relative only to the immediately preceding injury, rather than all preceding injuries, altered the subsequent injury patterns and risk profile in rugby union.

This research explored several approaches to subsequent injury analysis, demonstrating their importance for consideration in all sports injury epidemiological studies. It is important to continue developing a strong understanding of the methods impacting subsequent injury calculations to better inform injury prevention targets.

Chapter 1

General Introduction

Injury in elite athletes impacts individual health and club success (Eirale, Tol et al. 2013, Hagglund, Walden et al. 2013, Williams, Trewartha et al. 2016, O'Brien and Finch 2017). The prevention of injury is therefore an important issue for many professional sports clubs. Injury prevention begins with injury surveillance; a process that systematically collects and reports injury data (Finch 1997, Wiese-Bjornstal, Franklin et al. 2015). Injury surveillance is essential to identify injuries that occur most frequently and those that are most severe (van Mechelen, Hlobil et al. 1992, Finch 2006). Identification of injuries enables sporting organisations to prioritise specific injury prevention strategies (Finch 2006). Many leading sports bodies and professional teams have injury surveillance systems in place to support protection of athlete health (Orchard and Seward 2002).

The quality of the information that is inputted, and extracted from, the surveillance system is important to understand. Key aspects of injury surveillance are injury definitions, categorisation and coding of injuries, date of injury and recovery, personnel involved in data entry, and the reports and analysis that are generated. Modern sports injury surveillance is supported through consensus statements for recording and reporting injury (Appendix A, page 99) (Orchard, Newman et al. 2005, Fuller, Ekstrand et al. 2006, Fuller, Molloy et al. 2007, Pluim, Fuller et al. 2009, Timpka, Alonso et al. 2014, Mountjoy, Junge et al. 2016, Orchard, Ranson et al. 2016, Bahr, Clarsen et al. 2020, Murray, Junge et al. 2020, Verhagen, Clarsen et al. 2021). In these publications, key stakeholders and prominent researchers attempt to standardise important features of injury surveillance within the context of the given sport (contextual factors may include: the level of competition and the severity of injuries, among other factors). An example is the International Olympic Committee (IOC) recommendations for the recording and reporting of injury in sport (Bahr, Clarsen et al. 2020). This document is intended to form the basis of surveillance in various sports, with sport-specific adaptations documented separately where relevant (Verhagen, Clarsen et al. 2021). It is likely that sports with existing consensus statements (e.g. rugby union, soccer and cricket, among others) will update in near future to align with the recent IOC statement as consistency in systems is critical to support future comparisons. Doing so ensures that the quality of injury surveillance remains high across the various sporting contexts for accurate reporting of injury occurrence.

A major challenge of all sports injury surveillance systems is the management of longitudinal injury data. Many athletes sustain more than one injury in a season and across their career. The ability to capture and report longitudinal injury data in elite sports is critical to ensure an accurate understanding of the occurrence of subsequent injuries (i.e. all injuries after the first within a surveillance period) following index injuries (i.e. the first injury within a surveillance period) (Finch and Marshall 2016, Fortington, van der Worp et al. 2017, Finch and Fortington 2018). To better manage longitudinal injury data, epidemiological studies must look beyond the typical cohort-level approach, which neglects the relationship between injuries within the same athlete (e.g. five athletes who sustain 5 injuries assumes that all athletes are at the same risk of injury, but it is possible that only one athlete sustained all 5 injuries). New approaches are now being adopted to establish how within-player injuries relate over time.

The aim of this thesis is to explore methods of subsequent injury analysis in professional men's Australian football (AF) and Australian rugby union injury surveillance. These two sports have been chosen because of the availability of data and relative frequency of subsequent injuries.

In the following chapter (**Chapter 2**), a detailed review is presented on the injury definitions, diagnostic coding, categorisation, and the concepts relating to inter-injury relationships that are applied in the two empirical studies (**Chapter 3**, focused on AF and **Chapter 4**, focused on rugby union). Specific aims and hypotheses associated with each study are presented within the chapters (structured for future publication in peer reviewed journals). Finally, **Chapter 5** presents an overall discussion of key findings, clinical implications, strengths and limitations of the research, and recommendations for future investigation.

Chapter 2

Literature review of subsequent injury categorisation

This chapter defines and reviews the methodological concepts applied in the empirical research chapters. The concepts are presented with a review of existing literature.

2.1 Definitions of a sport injury

The first consideration for sports epidemiologists is to define a sports injury. Although seemingly simple, this is a rather complex and contentious topic that has resulted in various definitions being used.

The most commonly used, yet ambiguous term in the literature, is ‘injury’. A frequently documented definition of injury in the health sector is any physical or observable manifestation, resultant of an exchange of forces, causing damage to tissue(s) (Langley and Brenner 2004, Sacker and Cable 2006, Doll, Haas et al. 2007). Alternatively, a ‘sports injury’ denotes a loss of, or limitation in bodily function due to, or as observed by, structural change (Timpka, Jacobsson et al. 2014). This definition has proved difficult to apply in sports injury surveillance, likely due to the difficulty quantifying structural changes and a loss in bodily function. Current consensus statements on injury surveillance in sport use various injury definitions (Table 2.1). The use of these definitions is important to accurately delineate an injury occurrence from a non-recordable occurrence for injury surveillance. The variation in definitions chosen by different sporting bodies, clubs, or data collectors may be due to several contributing factors, such as resources available for injury surveillance or the injury profile of the sport.

Table 2.1 Injury recording approaches currently used to demarcate a recordable injury event.

Injury recording approach	Definition
Medical attention	*The medical attention recording protocol requires an athlete to be deemed injured by a qualified practitioner to demarcate a recordable injury from a non-recordable event.*
Time-loss	*The time-loss recording protocol demarcates a recordable injury occurrence from a non-recordable event when a player loses match or training time.* ▪ *Match-loss: deems an athlete injured upon the loss of competitive match play against an opposition team/club.* ▪ *Training-loss: deems an athlete injured upon the loss of time from any elite level involvement in training or games.*
Athlete registered	*The athlete registered recording protocol is any physical complaint, resultant of a manifestation of pain or functional deficit, sustained during match or training play by the athlete. Recording of this complaint is irrespective of the medical attention attained or time lost from play.*

Note: Definitions adapted from consensus reports (listed in Appendix A, page 99).

2.2 Identification of an injury

It is essential to have an understanding of each of the different injury definitions and classifications used to ensure they are appropriate for the research aims (van Mechelen, Hlobil et al. 1992). Table 2.2 illustrates the suitability of the different injury reporting definitions for different sporting injuries. Docking, Rio et al. (2018) reported that using a match-loss reporting definition for Achilles and patellar tendinopathy would not accurately capture the prevalence of these injuries given that they rarely result in missing competitive games. This is one of many factors (discussed below) that need to be considered when determining the most suitable method for defining the occurrence of a sports injury.

Table 2.2 Examples of injury reporting options and their suitability to different sporting injuries.

	Medical Attention	Match-loss	Training-loss	Athlete registered
Acute ACL rupture	✓	✓	✓	✓
Face laceration	✓	✗	✗	✓
Gastrocnemius contusion	✓	✗	✓	✓
Achilles tendinopathy	✗	✗	✗	✓

Face laceration occurring during game or training session; gastrocnemius contusion occurring during training with typical return to sport 2-3 days post-injury, therefore no games missed; Achilles tendinopathy typically impacts rapid movements and performance before symptoms arise. Ticks represent a suitable reporting regimen for the respective injury. Crosses represent an unsuitable reporting regimen for the respective injury, suggesting the reporting regimen would not adequately capture the respective injury. ACL: anterior cruciate ligament.

2.2.1 Resources available for data collection

Depending on the setting (i.e. elite/non-elite sport), access to medical resources may differ substantially. Sporting bodies and clubs with limited financial resources may lack medical team coverage. Due to infrequent training and match attendance of club medical professionals, a medical attention injury definition may be limited. This may lead to poor quality data being captured and incorrect prevalence estimates.

2.2.2 Sports specific injury profile

Another key feature of sports injury surveillance is that different sports have vastly different physical demands, such as the frequency and intensity of body contact and repetition of movements. Thus athletes of different sports are exposed to different injury risk factors (Bueno, Pilgaard et al. 2018), causing certain injuries to be more frequent in some sports than others (i.e. concussion in rugby compared to marathon runners). It is essential to ensure that data collection is tailored to capture the injuries of interest, depending on the sport or research questions.

2.3 Classifying Injuries

Sports injuries need to be recorded with sufficient detail about the nature of the injury (i.e. body part, tissue/organ injured, side, etc.) and also need to be classified using standardised terminology to enable reporting. To capture each diagnosis as accurately as possible, injuries can be classified using various diagnostic codes, allowing diagnoses to be condensed from clinical notes into discrete codes.

The evolution of diagnostic coding systems began outside of the sporting context with the International Classification of Diseases (ICD), created by the World Health Organisation (WHO) to address the need for a standardised classification system for diseases and health conditions. Since its inception, the ICD has been revised ten times (ICD-11) (World Health Organization 2018) and has been implemented across a range of clinical and research environments (World Health Organization 2021). Despite its widespread application, the ICD is limited in sporting environments due to some sport-specific injury classifications not being accounted for (e.g. hamstring strain and exercise-associated postural hypotension) (Bahr, Clarsen et al. 2020). For this reason, two sport-specific classification systems have become widely used. The Sport Medicine Diagnostic Coding System (SMDCS) and Orchard Sports Injury Classification System (OSICS) take similarly hierarchical approaches to the ICD, however, contain classifications that are essential in sporting populations (Orchard, Meeuwisse et al. 2020). These diagnostic coding systems were updated in the October 2019 IOC consensus meeting by a subgroup of the meeting invitees (Bahr, Clarsen et al. 2020, Orchard, Meeuwisse et al. 2020). The IOC recommends using either of these systems to provide accurate diagnostic codes for sports injury research (Bahr, Clarsen et al. 2020). No direct comparison of the uptake of these models has been made, however, the OSICS versions may be popular in elite Australian sport due to its Australian origin in 1992 (Bahr, Clarsen et al. 2020). Other reasons for widespread application in Australian sport may include the increased number of diagnostic codes, ease of use, or the accessibility of the free-to-use system (Orchard, Rae et al. 2010, Orchard, Meeuwisse et al. 2020). The studies included in this thesis used version 10.1 of the OSICS (OSICS-10.1), as it was the coding system (and version) of choice for both AF and rugby union at the time of research design (Orchard, Rae et al. 2010).

2.3.1 Orchard Sports Injury Classification System

The OSICS is a free-to-use sports injury diagnostic classification tool first designed for application in AF (Rae and Orchard 2007). It has since undergone adaptations to suit a wider variety of sports, including cricket (Orchard, Newman et al. 2005), rugby union (Moore, Ranson et al. 2015) and soccer (Andersen, Floerenes et al. 2004), and also been updated to OSICS version 13 by Orchard, Meeuwisse et al. (2020). The version at the time of research design (OSICS-10.1) requires the medical team to form their diagnoses, then translate it to a 4-character code (Table 2.3). The four characters represent anatomical location (first letter), general pathology (second letter), specific/structural (third letter) and finally, more detailed information about the specific diagnoses (fourth letter) (Rae and Orchard 2007). The details of other versions are not necessary to understand for this thesis, however, are discussed in detail within the most recent OSICS revision (Orchard, Meeuwisse et al. 2020).

Due to the extensive detail required for the third and fourth letters of an OSICS-10.1 diagnostic code, injuries can be incorrectly or inaccurately coded (Hammond, Lilley et al. 2009, Orchard, Rae et al. 2010). The increased injury coding detail demands an increased need for clinical reasoning skills, which may not be available in non-elite sporting environments or data collection teams where medical expertise is less accessible (Finch, Orchard et al. 2014). As such, coders lacking clinical expertise may be limited in their ability to transcribe accurate injury codes from the notes obtained from injury diagnoses. Due to the increased chance of coding errors with increasing diagnostic specificity, particularly when coders are not medically trained, restriction of the analysis to the first and second characters should be considered at all levels of athletic professionalism (Finch, Orchard et al. 2014).

Table 2.3 OSICS-10.1 coding examples for different knee injuries. OSICS characters organised hierarchically, increasing in specificity from left to right.

1st Character (Region)	2nd Character (Pathology)	3rd Character (Structure)	4th Character (Detail)	OSICS code
Knee				
	Sprains/Ligament injuries			KJXX
		Acute ACL Injury		KJAX
			Partial ACL tear	KJAP
			ACL rupture	KJAR
		MCL injury		KJMX
			Grade 1 MCL tear	KJMA
			Grade 2 MCL tear	KJMB
			MCL rupture	KJMR

ACL: Anterior Cruciate Ligament; MCL: Medical Cruciate Ligament; OSICS: Orchard Sports Injury Classification System.

2.3.2 Other information required for injury classification

In addition to the features of injury classification that have been described to this point, another important consideration is to identify the laterality of an injury to the appendices. If the side (left, right, bilateral) of the injury is not separately noted, one cannot distinguish whether an injury is a recurrent injury (same site, same nature, same side) or an injury of the same nature but on the contralateral limb (Finch and Fortington 2018). This level of information is necessary when attempting to understand the relationship between previous and subsequent injuries.

The important role of injury and recovery date is recognised and well described by Finch and Fortington (2018). Recovery date remains a contentious topic due to the lack of a robust method to delineate this injury milestone. This is because very little is known about recovery, and exactly when this status is achieved by the athlete. Previous work has recognised return-to-play (RTP) as a commonly used proxy for recovery date as it can be defined with relative ease (Finch and Fortington 2018). Yet, there can still be ambiguity in this definition as RTP can be considered when an athlete returns to the gym, training, competition, or other means of sport inclusion. Additionally, severity measures may be distorted for injuries sustained at the end of the season given these athletes cannot RTP until the following season. Recovery definitions typically depend on the injury definition selected, whereby a time-loss injury definition would usually rely on a return to competition for recovery date, while a medical attention injury definition might use the cessation of medical treatment as a proxy (Timpka, Alonso et al. 2014, Raysmith and Drew 2016, Toohey, Drew et al. 2018). The use of a proxy measure (either return to competition or cessation of medical treatment) does not accurately determine when an athlete has fully recovered. This is a limitation of many sports epidemiology studies, potentially implicating the severity and recurrence rates reported (Hammond, Lilley et al. 2013). However, this thesis does not aim to investigate the recovery phenomenon that currently challenges sports epidemiology. Therefore, recovery definition is in line with the injury definition for both empirical studies.

2.4 Reporting and analysis of more than one injury in elite athletes

2.4.1 Accuracy in injury estimates when athletes sustain multiple injuries

Injuries in elite sport are commonly reported at a team level (Fortington, van der Worp et al. 2017). For example, the total number of hamstring injuries sustained by an entire team across a single season. This approach does not account for some athletes sustaining multiple injuries and other athletes remaining injury free throughout the surveillance period.

Figure 2.1 (Finch and Marshall 2016) demonstrates the definitions of injury introduced so far: with 6 injuries occurring in a cohort of five players. This does not accurately describe an individual's injury profile. Some players are observed to sustain multiple injuries throughout the season, whereas some players sustain none. This is an important consideration because despite the different injury profiles within Figure 2.1, these players are grouped into one cohort where all individuals are assumed to have the same injury risk.

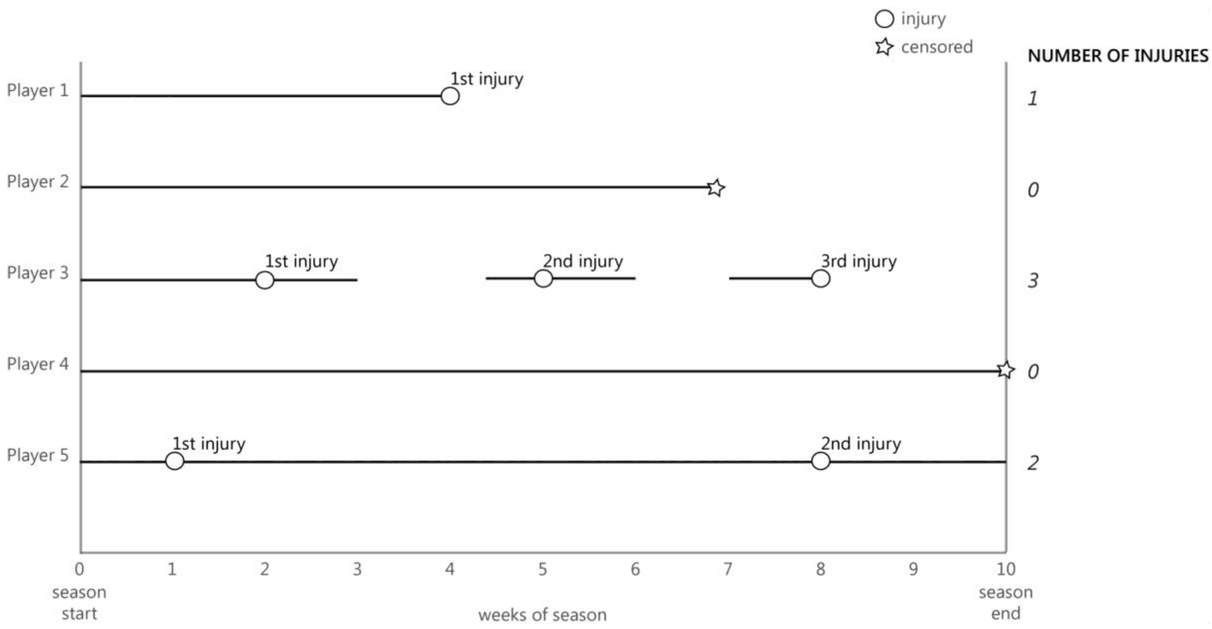


Figure 2.1 Illustration of the relationship between subsequent injuries and the prior (index) injuries.

Circles represent the occurrence of an injury; Stars represent the censoring of an athlete (termination of surveillance); Lines represent competitive match/training participation; No lines (gap) represent no participation in competitive match/training play. Reproduced from Finch and Marshall (2016) with permission.

It is important for sports injury surveillance and the reporting of the data to consider that not all players are at the same risk of injury. Previous injury can alter the likelihood of future injury (Hagglund, Walden et al. 2006, de Visser, Reijman et al. 2012, Ullah, Gabbett et al. 2014, Toohey, Drew et al. 2017), yet the mechanisms to explain this association remain unclear. Players who sustain multiple injuries must be considered to allow for accurate injury surveillance and appropriately inform injury prevention strategies. This is a substantial limitation in current sports epidemiology.

2.4.2 Recurrent injuries represent one part of the problem

Injuries may also be recognised as a repeated occurrence – for example, injuries that are the exact same in nature, anatomical location, side and structure, but occur after the athlete has returned to sport; these are termed recurrent injuries (usually when it occurs within the same season). Some sports recognise the temporal relationship of the recurring injury to the prior injury by acknowledging early recurrent injuries (reinjury within 2 months), late recurrent injuries (reinjury within 12 months), and delayed recurrent injuries (reinjury after 12 months) (Fuller, Ekstrand et al. 2006, Fuller, Molloy et al. 2007). Accounting for recurrent injuries is important to identify those of high prevalence and provoke further research to establish protective rehabilitation interventions. However, preventing recurrent injuries represents only one aspect of subsequent injury prevention.

Clinical experience has suggested that non-recurrent subsequent injuries can also be linked, are more prevalent (Finch and Cook 2014, Ullah, Gabbett et al. 2014), and are often considered to have a greater burden than the associated index injury (Ekstrand and Gillquist 1983, Brooks, Fuller et al. 2006, Ekstrand, Hagglund et al. 2011). For example, an athlete that sustains an ankle sprain (index injury) may endure a loss in their ankle range of motion and strength. This increased demand on the Achilles tendon, may ultimately lead to the development of Achilles tendinopathy (subsequent injury) (Finch and Cook 2014). These injuries may be associated – despite being different in many ways. Therefore, a method to account for linked but different injuries was required.

2.4.3 Subsequent Injury Categorisation

The Subsequent Injury Categorisation (SIC) model, developed by Finch and Cook (2014) and updated (SIC-2.0) by Toohey, Drew et al. (2018), was designed in response to the growing awareness that subsequent injuries are common and their risk is associated with prior injuries (Hagglund, Walden et al. 2006, de Visser, Reijman et al. 2012, Ullah, Gabbett et al. 2014, Toohey, Drew et al. 2017). As the epidemiological approaches outlined above did not account for the individual aspect of a single player sustaining two or more injuries within a data collection period, the SIC model was designed to address this issue and in doing so, provides a greater capacity to classify and understand individual injury occurrences over time.

2.4.3.1 Application of SIC models to sports injury datasets

The SIC-1.0 model was designed with 10 mutually exclusive categories that were manually applied to an injury dataset containing OSICS-10 diagnostic codes (Finch and Cook 2014). First, injuries must be chronologically ordered so that the sequence of each player's injuries may be compared for categorisation. Second, clinical adjudication of the region, nature and text description of each injury observation (i.e. a row in the dataset) determined what SIC-1.0 category a subsequent injury should be denoted (Finch and Cook 2014). Subsequent injuries were only categorised relative to index injuries, which were retrospectively assigned by the investigators. For this model, index injuries were defined as the first chronological injury within the surveillance period and any subsequent injury considered to be unrelated to the previous injuries by the investigator (Finch and Cook 2014). For this reason, the SIC-1.0 model was limited by the need to clinically adjudicate whether subsequent injuries were related or unrelated to previous injuries, which cannot be concluded if investigators are not directly involved in the medical treatment of the athlete (Toohey, Drew et al. 2018). Finally, the model did not account for the laterality of injuries, the specific structure (i.e. third OSICS-10 letter), or injury nature (i.e. second OSICS-10 letter) if the anatomical location was different.

To address these flaws, Toohey, Drew et al. (2018) created the SIC-2.0 model with eight data-driven categories, designed to eliminate the need for clinical adjudication and involvement in the athletes' primary care for application of the model (Toohey 2019). Similar to the SIC-1.0 model, the newer model requires diagnostic injury codes to be in the form of OSICS-10. Application of the model to the data-driven level of categorisation can be completed manually by organising injuries into their chronological sequence for each player, then categorising each injury using the flowchart provided by Toohey, Drew et al. (2018) (Figure 2.2). The authors also created an automated script using the statistical software Stata (StataCorp, USA) to offer data-driven categorisation in an automatic process. This script consists of a series of commands that categorise each subsequent injury to all previous injuries sustained by the athlete. It is not available to the public, however, is available upon request.

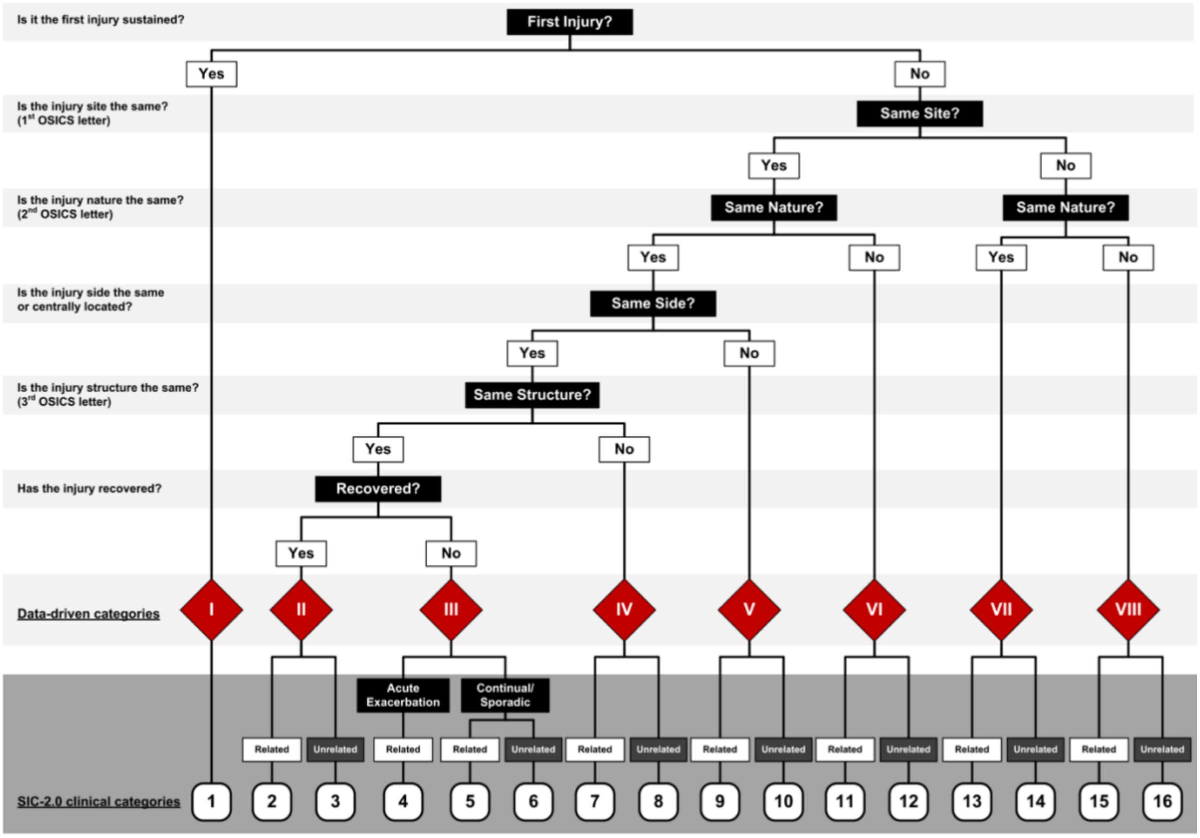


Figure 2.2 Flowchart for manual application of the SIC-2.0 model.

SIC-2.0 categories defined in Table 2.4; OSICS: Orchard Sports Injury Classification System; SIC: Subsequent Injury Categorisation. Reproduced from Toohey, Drew et al. (2018) with permission.

2.4.3.2 Improvements provided by the revised SIC model

Although similar, the original and updated variations of the SIC model are not entirely congruent, and due to the reliance on clinical adjudication of the first model, distributions may vastly differ based on the study resources available. Toohey, Drew et al. (2019) compared the two models, and despite having somewhat similar findings, any comparisons might not be accurate due to the decreased precision and mutual exclusivity of the original model's categories.

A major barrier of the SIC-1.0 model was the high degree of subjectivity involved in categorisation. Between two team clinicians, the inter-rater reliability of the categorisation output is strong, remaining moderate to strong between team and non-team clinicians (Moore, Mount et al. 2018). However, comparing the categorisation output between a clinician and non-clinician revealed a reduced level of agreement, suggesting that non-clinicians are challenged by the level of clinical adjudication required to apply SIC-1.0 (Moore, Mount et al. 2018). Moreover, there is currently no standardised method to deduce whether an injury is related or not, which is likely very complex and multi-factorial (Moore, Mount et al. 2018). Some factors have been suggested, however, have not been investigated. These include, but are not limited to: anatomical and biomechanical relationships between injury sites, time between injuries, or even potential psychological factors following previous injury occurrences (Toohey 2019). Rather than attempting to speculate on a matter that requires global consensus, the revised SIC model (SIC-2.0) addressed this limitation by providing the tiered hierarchical categorisation system, whereby the data-driven tier requires no clinical inferences to be made for application. This also permits automated application, given no reasoning is required, increasing the reproducibility of the application by eliminating human error or variability. The model still underwent reliability testing, confirming that between two physiotherapists and also a physiotherapist and the automated script, inter-rater reliability was 100% (Toohey, Drew et al. 2018).

2.4.3.3 SIC-2.0 improves upon previous methods of injury estimation

There are two important applications for subsequent injury classification in elite sports. The first is the improved estimation of injury incidence rates: subsequent injuries are related to the index injury even when they are clinically distinct because they occur in the same athlete (Finch and Cook 2014, Ullah, Gabbett et al. 2014, Finch and Marshall 2016). Unless subsequent injuries are considered, injury aetiology and incidence rates cannot be inferred from sports injury datasets, further increasing the difficulty of implementing effective injury prevention strategies (Finch and Marshall 2016, Fortington, van der Worp et al. 2017, Finch and Fortington 2018).

The second application of SIC-2.0 for elite team-based sports permits stronger understanding of the clinical links between injuries. The chance of incurring an injury has been shown to increase after an initial injury (Hagglund, Walden et al. 2006, de Visser, Reijman et al. 2012, Ullah, Gabbett et al. 2014, Toohey, Drew et al. 2017). Therefore, the understanding of how injuries such as an ankle ligament tear might lead to Achilles tendinopathy, or injuries elsewhere in the lower limb (i.e. hamstring strain), is essential to prevent linked injuries. The identification of these relationships ultimately creates better understanding of the risk factors that increase chance of injury.

2.4.3.4 Literature on SIC distributions

The introduction of the SIC model has been well-received and has been applied to injury data in AF (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Stares, Dawson et al. 2019), cricket (Moore, Mount et al. 2018), rugby union (Moore, Mount et al. 2018), rugby sevens (Toohey, Drew et al. 2018, Toohey, Drew et al. 2019), and water polo (Toohey, Drew et al. 2019). In doing so, the relationships between injuries have been described across multiple populations with varying sample sizes and data collection periods. Representing up to 1 in 5 subsequent injuries using the original SIC model (Moore, Mount et al. 2018), recurrent injuries are less common than subsequent injuries that occur at a different anatomical site (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Moore, Mount et al. 2018, Toohey, Drew et al. 2019). Using the updated and more reliable SIC model (Toohey, Drew et al. 2018), the proportions are less favourable, with recurrent injuries representing between 0 and 2.9% of all subsequent injuries; compared to the 75-80.7% of subsequent injuries represented by those at a different site and of a different nature to the index injury (category VIII) (Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019).The high proportion of subsequent injuries at a different site and of a different nature to the previous injuries have received little attention relative to the problem that they represent in previous literature.

2.4.3.5 Risk factors for subsequent injury

The categories making up the SIC models describe a particular type of relationship between two injuries (Table 2.4). While the SIC model takes a holistic approach at describing injury dependency, some relationships described within the SIC models have received considerable attention using pathology-specific approaches. These investigations reveal somewhat complex relationships between injuries that may have some degree of dependency on one another. Some of the risk factors for subsequent injury, mostly pre-defined subsequent injuries in single-pathology studies, have been described in previous work. These risk factors are discussed in detail as they pertain to the relevant chapters of this thesis.

The most documented risk factor for subsequent injury is an individual's injury history. Not only does a previous injury increase the risk of subsequent injury (Fulton, Wright et al. 2014), this risk is elevated for up to 12-weeks post-RTP and increases as the athlete accumulates more injuries throughout the season (Hagglund, Walden et al. 2006, Stares, Dawson et al. 2019). The impact of injury history on subsequent injury risk has also been established indirectly, revealing that session availability may influence the risk of subsequent injury (Ruddy, Pietsch et al. 2019). Few factors not related to injury history have also been established as subsequent injury risk factors. These factors mostly involve variables relating to workload, such as high acute:chronic workload ratios, which may increase subsequent injury risk (Blanch and Gabbett 2016). Higher running workloads during rehabilitation have also been suggested to reduce subsequent injury risk (Stares, Dawson et al. 2017, Stares, Dawson et al. 2018). However, due to the complexity of these analyses, in particular the difficulty of mitigating confounding, the literature remains largely focussed on previous injury as a risk factor for subsequent injury. For this reason, many studies have endeavoured to establish the influence of specific pathologies, most often concussion, on subsequent injury risk.

Table 2.4 Description of the SIC-2.0 categories and comparison to SIC-1.0 model

SIC-2.0 data-driven category	SIC-2.0 clinical category	Category description	SIC-1.0 category
I	1	No subsequent injury; only one injury was sustained by the athlete throughout the surveillance period	1
II	2	Re-injury after recovery, to the same site, same nature, same side, and same structure (related)	2[a]
	3	Re-injury after recovery, to the same site, same nature, same side, and same structure (unrelated)	6[a]
III	4	Acute exacerbation before recovery, to the same site, same nature, same side, and same structure	3[a]
	5	Continual/sporadic exacerbation before recovery, to the same site, same nature, same side, and same structure (related)	4[a]
	6	Continual/sporadic exacerbation before recovery, to the same site, same nature, same side, and same structure (unrelated)	5a
IV	7	Injury to the same site, same nature, same side, but of a different structure (related)	2-6[a]
	8	Injury to the same site, same nature, same side, but of a different structure (unrelated)	2-6[a]
V	9	Injury to the same site, same nature, but different side (related)	2-6[a]
	10	Injury to the same site, same nature, but different side (unrelated)	2-6[a]
VI	11	Injury to the same site but of a different nature (related)	7
	12	Injury to the same site but of a different nature (unrelated)	8
VII	13	Injury to a different site, but of the same nature (related)	9[b]
	14	Injury to a different site, but of the same nature (unrelated)	10[b]
VIII	15	Injury to a different site and of a different nature (related)	9[b]
	16	Injury to a different site and of a different nature (unrelated)	10b

[a]*side and structure of injury was not differentiated in the SIC-1.0 model;* [b]*injury nature at a different site was not differentiated in the SIC-1.0 model*

Reproduced from Toohey, Drew et al. (2018) with permission.

Clinically distinct subsequent injuries (i.e. SIC-2.0 data-driven category VIII) received some attention prior to the introduction of the SIC model, yet received very little interest within the literature. An example of this type of subsequent injury; a meta-analysis of three studies concluded that a history of anterior cruciate ligament (ACL) injury was statistically associated with an increased risk of subsequent hamstring injury (RR = 2.25, 95% CI = 0.29 to 4.51, p = 0.002) (Toohey, Drew et al. 2017). The same meta-analysis also found that concussion index injuries were associated with an increase in the odds of sustaining a subsequent lower limb musculoskeletal injury — two injuries that would not have been suspected of being associated (Toohey, Drew et al. 2017). This literature review and meta-analysis conducted by Toohey, Drew et al. (2017) highlights that previous injury may be a risk-factor for subsequent injury even when they are different. There is a need for sports injury epidemiologists to reconsider the potential dependency of subsequent injuries on previous injuries, even if drastically different. However, identifying which two injuries may be correlated is very difficult. For this reason, few injuries have been linked in this manner. The introduction of the SIC models has the potential to expose inter-injury relationships from an epidemiological viewpoint, reducing selective reporting given highly prevalent injury associations are likely to stand out compared to other relationships. These analyses must extend beyond a recurrent injury approach, and SIC-2.0 allows investigators to do so while still accounting for recurrent injury as a risk factor.

Recognition of all subsequent injury types and their prevalence in sporting populations may also reveal the lesser-known factors involved in subsequent injury aetiology. Unlike recurrent injuries, different subsequent injuries may be linked by factors previously unthought, such as, the nature of the previous injuries where injuries might be systemically linked. Subsequent injuries may also be linked by their sequential order; where injuries that are closer, sequentially, to the subsequent injury are more or less related. There are many potential factors to be investigated with the implementation of the SIC. Such experimentation is a requirement of sports injury epidemiology to highlight the important methodological consideration for investigators. Exploring different risk factors, and the different methodologies required to examine these risk factors, may reveal insights for injury prevention and rehabilitation programs.

2.4.3.6 Issues relating to use of SIC-2.0

Application of the SIC-2.0 model has been based on the same method since being introduced. Typically, each subsequent injury receives a SIC-2.0 code (i.e. the category it was assigned) that defines its relationship to each previous injury. Doing so quantifies a more holistic interpretation of subsequent injury relationships (hereafter referred to as the 'all injuries' method). One study has attempted the converse; comparing subsequent injuries only to the immediately preceding injury for one part of the analysis (hereafter referred to as the 'preceding injuries' method). Stares, Dawson et al. (2019) conducted a 'preceding injuries' method to calculate the absolute risk of a time-loss subsequent injury within 12-weeks of the index injury. An index injury was defined as the initial (first) injury during the surveillance period, therefore, this absolute risk represents the risk of sustaining the first subsequent injury in the 12-weeks following the first injury. Stares, Dawson et al. (2019) revealed that AF players have a heightened risk of time-loss subsequent injury for 12-weeks following RTP from an index injury (Stares, Dawson et al. 2019). However, the literature is yet to compare how the different methods of categorisation might impact the SIC distributions observed. The impact of different methods for subsequent injury analysis is unclear and requires further investigation to better understand the application of the SIC model for sports injury surveillance.

2.4.3.7 Subsequent injury in elite Australian football and rugby union

Uptake of the SIC models is strongest for rugby and AF; cumulatively involved in 7 of the 8 SIC applications (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Moore, Mount et al. 2018, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). Among the studies that have applied the SIC-2.0 model, clinically distinct subsequent injuries (category VIII) have accounted for 75 to 80.7 percent of all subsequent injuries (Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019, Toohey, Drew et al. 2019). In rugby-specific studies only, this range narrows to 78.7-80.7% (Toohey, Drew et al. 2018, Toohey, Drew et al. 2019). The few studies that have begun to explore the relationships between different injuries have been summarised in a systematic review and meta-analysis that identifies many different but related, and even associated injuries within several sports (Toohey, Drew et al. 2017). One of these studies was conducted in a rugby union cohort, however, found no association between different injuries (Bourne, Opar et al. 2015). Further investigation into subsequent injuries builds on what is currently known about the relationships between injuries. However, a better understanding of subsequent injury analysis and the appropriate methodology is required to improve clinical applications of this research.

There are several key concepts that require further investigation to better understand subsequent injury. For example, there is little understanding of the relationships between injuries in rugby union unless they are selectively studied. Pathology-specific inter-injury analyses, such as concussion and lower limb musculoskeletal injury (Cross, Kemp et al. 2016), remain more common than the epidemiological subsequent injury approach. Therefore, application of SIC-2.0 to a rugby union injury dataset would provide valuable insight of the sport-specific injury epidemiology and the potential relationships between these injuries. AF studies are comprehensive in their subsequent injury analyses, however, the literature remains void of a larger sample with application of the updated SIC model, for more reliable and generalisable findings. In the cumulative subsequent injury literature, little has been done to investigate whether injury nature influences the risk of subsequent injury, or the risk of sustaining a specific SIC-2.0 category. These are important steps for the progression of subsequent injury analyses and are key objectives for the following empirical studies.

Chapter 3

Index concussion or index muscle injury alters subsequent injury risk profile in elite Australian football players.

3.1 Preface

3.1.1 Contributors

All authors contributed to the original concept and participated in the drafting and approval of the final manuscript. Mr Smith was the lead author and was responsible for the drafting and redrafting of the manuscript following feedback from co-authors. Mr Smith, Mr Girdwood and Dr Rio contributed to the diagnostic coding (i.e. classification) of the injury dataset. Mr Smith and Dr Toohey contributed to the categorisation (i.e. SIC-2.0) of the injury dataset. Mr Smith conducted all data cleaning, analyses and reporting. This work was completed by Mr Smith under the supervision of Dr Docking, Dr Fortington and Dr Rio as a component of his Master's thesis.

3.1.2 Publication status

The study in this chapter is currently under review at the *Journal of Science and Medicine in Sport*. The manuscript has been revised based on the feedback received from the original submission on 19 October, 2020 (JSAMS-D-20-00546). Tables, figures and references have been renumbered and reformatted to maintain consistency within the thesis.

3.2 Abstract

Objectives: To investigate the number, nature, and patterns of subsequent injuries sustained by elite Australian football players in a single season.

Design: Descriptive epidemiological study

Methods: Prospectively collected injury data from the men's 2016 Australian Football League season were obtained. Match-loss injuries (i.e. ≥ one match missed) were classified and categorised using the Orchard Sports Injury Classification System v10 and the Subsequent Injury Categorisation 2.0 model, respectively. Relative risk (RR) of the subsequent injury categories were calculated based on the index injury nature and significance asserted using contingency tables and chi-square test of independence.

Results: Three-hundred and twenty players sustained an injury, accumulating 567 injuries in total. Subsequent injuries at a different site and nature to the index injury accounted for 57.1% of subsequent injuries, followed by injuries of the same nature but different location (12.4%) and recurrent injuries (12.4%). Following an index concussion, the relative risk of a recurrent concussion was significantly increased compared to the risk of recurrent injuries after other index injuries (RR = 3.23; 95% CI [1.18, 8.87]; $p = 0.02$). Subsequent injuries of the same nature but different site were more likely to occur if the index injury was a muscle injury (e.g. hamstring injury subsequent to calf injury) (RR = 2.76; 95% CI [1.34, 5.72]; $p = 0.005$).

Conclusions: Most subsequent injuries were different to previous injuries, however, proportionately fewer than previous studies. These findings demonstrate that index concussion or muscle injuries are associated with recurrent concussion or subsequent muscle injury at a different site, respectively. Based on these data, tertiary injury prevention strategies are required to reduce the risk of subsequent injury.

MeSH keywords: sports medicine, athletic injuries/classification, athletic injuries/epidemiology, athletic injuries/prevention, athletic injuries/etiology, retrospective studies, epidemiologic studies.

3.3 Introduction

Subsequent injury is an encompassing term accounting for multiple, recurrent, and exacerbated injury occurrences (Hamilton, Meeuwisse et al. 2011, Finch and Cook 2014). Multiple subsequent injuries significantly impact athletes' health and can impact team success (Eirale, Tol et al. 2013, Hagglund, Walden et al. 2013, Raysmith and Drew 2016, Williams, Trewartha et al. 2016, Liptak and Angel 2017). Understanding the relationship between subsequent injuries and index injuries (i.e. the first in a chronological sequence) may provide insights for the development of tertiary (i.e. subsequent and beyond) injury prevention strategies (Stares, Dawson et al. 2019). Recent literature has begun exploring these relationships, finding many injury types to be statistically linked, despite being different in anatomical location and tissue type. One such example exists between concussion and lower limb musculoskeletal injury, which have been shown to be associated in various athletic populations (Lynall, Mauntel et al. 2015, Pietrosimone, Golightly et al. 2015, Brooks, Peterson et al. 2016, Howell, Lynall et al. 2018, McPherson, Nagai et al. 2019, Reneker, Babl et al. 2019, Hunzinger, Costantini et al. 2021). This is in addition to the abundant literature highlighting that athletes are at an inflated risk of sustaining the same identical injury (i.e. recurrent injury) following return-to-play (RTP) (Toohey, Drew et al. 2017, Green, Bourne et al. 2020, Green, Lin et al. 2020, Orchard, Chaker Jomaa et al. 2020). Therefore, athletes are at an increased risk of sustaining a multitude of subsequent injury types that vary in relatedness to the previous injuries. This is an important consideration for the prevention of future injury, which requires more data-driven approaches to holistically account for subsequent injury risk.

The subsequent injury categorisation (SIC) model was developed to allow reporting of within-player injury occurrences over time, describing a subsequent injury's relationship with an index injury. The model was originally developed with ten distinct categories (SIC-1.0) (Finch and Cook 2014) and was later revised to eight categories (SIC-2.0) (Toohey, Drew et al. 2018). The SIC-2.0 model has been used to describe injury occurrences in Australian football (AF) (Stares, Dawson et al. 2019), rugby sevens (Toohey, Drew et al. 2018), and water polo (Toohey, Drew et al. 2019). These studies report that subsequent injuries represent a substantial problem in team sports. Injuries of a different site and of different nature to the index injury (SIC VIII) are most prevalent, accounting for 75% to 79% of subsequent injuries (Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). In contrast, recurrent injuries (SIC II: those identical to previous injuries sustained after a full recovery) are infrequent, representing 0% to 1.7% of subsequent injuries over 8 to 24 months (Toohey, Drew et al. 2018, Toohey, Drew et al. 2019), despite this injury type being at the forefront of the clinicians' mind. These findings are consistent with the previous SIC model, in which various studies have found that players sustain far fewer recurrent injuries than those different to the previous (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Stares, Dawson et al. 2019). However, only one study has applied the SIC-2.0 model in the population of interest (AF), investigating injury occurrence in 79 athletes from one team over a 5-year period (Stares, Dawson et al. 2019). Absolute risk of subsequent injury was reported to be increased for the 12-week period following RTP, yet it is unclear whether the nature (i.e. the tissue type injured) of the index injury influences the risk of subsequent injury (e.g. muscle injury may predispose players to a recurrent injury). Understanding how index injury nature impacts the type of subsequent injuries sustained may have implications for the development of tertiary injury prevention strategies.

The objective of this study was to quantify the number and nature of subsequent injuries in elite male AF players and identify patterns of injury across a single season. Additionally, we aimed to investigate whether the nature of an index injury was associated with a subsequent injury type.

3.4 Methods

The governing body of the sport, the Australian Football League (AFL), prospectively collect injury data each season. Medical staff from each club record all injuries that have occurred during a match, training, or other environments (i.e. outside of club commitments), that resulted in the loss of an entire match (the match following the respective injury). The AFL Research Board provided data from the 2016 AFL season, entitled the Annual AFL Injury Survey, for a related study investigating the impact and prevalence of Achilles and patellar tendon injuries (Docking, Ooi et al. 2015, Docking, Rio et al. 2018, Docking, Rio et al. 2019). Data provided included player identifier code (ID), written injury diagnosis, date of injury, date of RTP, and the number of matches missed. These data were quality checked for missing, incomplete or inaccurate records, however, found no inconsistencies. Ethical approval for the project was granted by the * Human Research Ethics Committee (HEC19109).

All match-loss injuries were assigned an OSICS-10.1 diagnostic code translated from the written injury diagnoses provided in the dataset. Two raters (authors *), both familiar and trained with using the system, coded all the match-loss injuries independently; this was to ensure codes were accurate and to reduce misclassification. Conflicts between the two raters (n=152) were resolved by a third rater, a qualified sports physiotherapist with 16 years of experience (co-author *). The match-loss injury data were categorised with the SIC-2.0 model using a programmable syntax (Stata/IC 14.2) (Toohey, Drew et al. 2018). The SIC-2.0 model provided a data-driven subsequent injury category for each subsequent injury; describing the relationship between each subsequent injury and all previous injuries. Therefore, the players' second injury receives one SIC-2.0 code, the third injury receives two SIC-2.0 codes (comparing it to the first and second injury sustained), and so on.

A descriptive analysis of the total number of injuries, number of injured players, number of injuries per player, number of injuries in each SIC category, and number of matches lost to injury were performed. The prevalence for the cumulative injury categories (number of players who sustained a certain number of injuries) was calculated as a percentage of the total number of players. Prevalence measures for SIC categories were taken as a percentage of the total number of allocated codes; this is because a single injury may have multiple codes allocated if multiple injuries are sustained prior. Severity metrics did not include injuries which had not recovered by the end of the surveillance period (n = 100). The remaining analyses compared the nature of injuries (i.e. the type of injury) by creating substrings of the first 2 characters from each OSICS-10.1 code. These categories included muscle, tendon, bone, joint, medical illness, undiagnosed/pain, concussion and other (bruising/haematoma, laceration/abrasion, organ damage) injuries. All prevalence measures of injury nature represent the percentage of the total number of injuries, given each injury has one injury nature.

Calculation of the relative risk was undertaken using the 'csi' command in Stata®/SE 16. This Stata command computed relative risk by compiling a contingency table and using the 2x2 table to conduct a chi-squared test of independence. The relative risk of sustaining any subsequent injury, sustaining a recurrent injury (SIC II), sustaining a subsequent injury of the same nature at a different site (SIC VII), and sustaining a subsequent injury of a different nature and site (SIC VIII) were calculated individually based on the index injury nature (i.e. muscle, joint, bone, etc.). These three categories were analysed as they were the most prevalent within the dataset. Medical illnesses were excluded from this analysis due to a small sample. All reports of relative risk (RR) are presented with 95% CI and p-value.

All data were prepared and analysed using Microsoft Excel (Version 16.28. Microsoft Office), IBM SPSS Statistics (Subscription version. IBM Corp., Armonk, NY), and Stata (SE 16; StataCorp, College Station, TX, USA).

3.5 Results

Four hundred and fifty-five (455) elite male AF players from 12 out of the 18 clubs provided informed consent to participate in the aforementioned related study (Docking, Ooi et al. 2015, Docking, Rio et al. 2018, Docking, Rio et al. 2019). A total of 567 match-loss injuries were recorded. The injuries included in the severity metrics (n = 467) resulted in 1356 missed games (median = 2 games missed per injury, IQR = 1-3, range = 0-23). One hundred and thirty-five players (29.7% of all included players; 95% CI [25.6, 34.0]) did not sustain an injury during the data collection period. One hundred and fifty-four players (33.8%; 95% CI [29.6, 38.3]) sustained one injury and 166 players (36.5%; 95% CI [32.2, 41.0]) sustained two or more injuries (two injuries n = 106, 23.3%, 95% CI [19.6, 27.4]; three injuries n = 44, 9.7%, 95% CI [7.3, 12.8]; four injuries n = 11, 2.4%, 95% CI [1.3, 4.3]; five injuries n = 5, 1.1%, 95% CI [0.5, 2.6]).

Joint injuries comprised the most common nature, accounting for 165 injuries (29.1% of all injuries, 95% CI [25.5, 33.0]), followed by muscle injuries (n = 161, 28.4% of all injuries, 95% CI [24.8, 32.3]). A total of 320 index injuries were sustained (56.4% of all injuries, 95% CI [52.3, 60.5]), most of which were joint injuries (n = 100, 31.3% of index injuries, 95% CI [26.4, 36.6]). Two hundred and forty-seven subsequent injuries were recorded (43.6% of all injuries; 95% CI [39.5, 47.7]), giving a total of 347 SIC codes. The most common subsequent injury nature was muscle injury (30.8% of subsequent injuries, 95% CI [25.3, 36.8]).

The nature of the index injury (i.e. muscle, joint, etc.) did not impact the risk of sustaining any subsequent injury (Table 3.1: $p > 0.20$), except for index injuries that were classified as ‘other’. Due to the low number of ‘other’ index injuries and the wide confidence intervals, this result needs to be interpreted with caution (Table 3.1: RR = 0.49, 95% CI [0.23, 1.05], $p = 0.02$).

Subsequent injuries at a different site and nature to the index injury (SIC VIII) were the most common category (n = 198 SIC codes, 57.2% of subsequent injuries, 95% CI [51.9, 62.4], Figure 3.1). Within this category, joint injuries were the most common nature (n = 45, 28.3% of SIC VIII; 95% CI [21.8, 35.9]), followed by muscle injuries (n = 41, 25.8%; 95% CI [19.5, 33.2]). The relative risk of sustaining a subsequent injury of a different site and nature was not influenced by the nature of the index injury (Table 3.1).

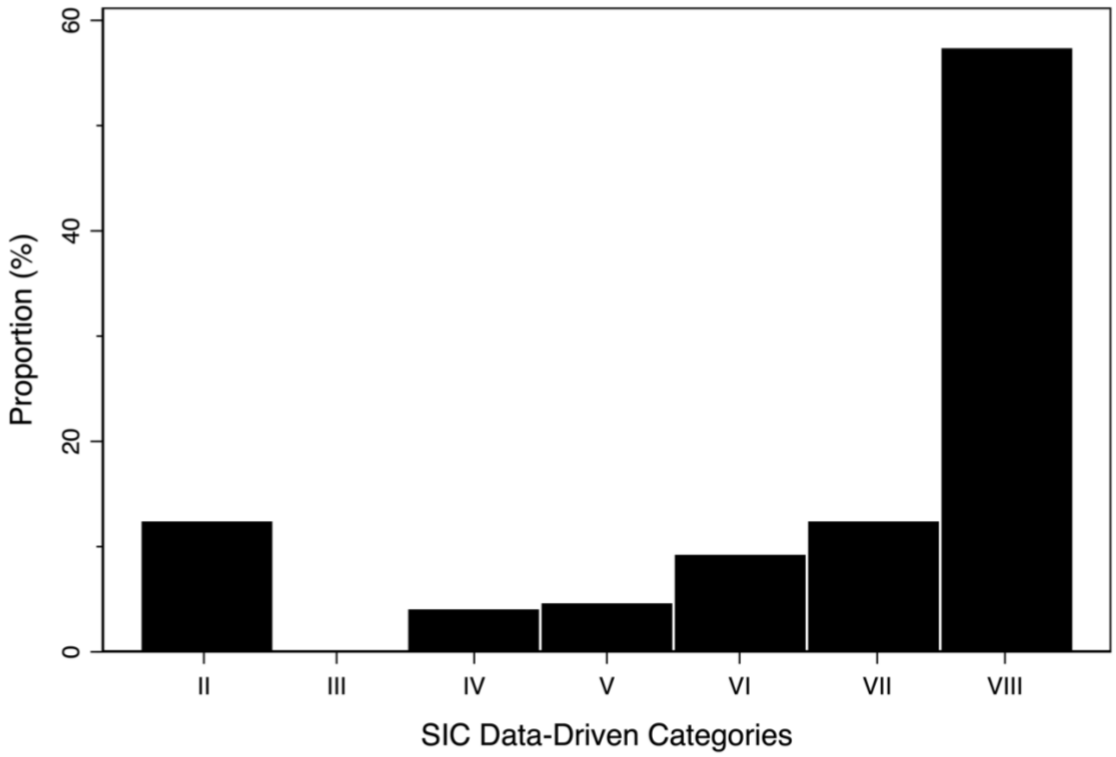


Figure 3.1 Distribution of categories as a proportion of allocated codes for each SIC-2.0 category▲ (n = 347).

SIC: subsequent injury categorisation;

▲SIC-2.0 data-driven categories (Table 2.4): II: Recurrent; III: Exacerbation; IV: Same site, same nature, same side, but of a different structure; V: Same site, same nature, but different side; VI: Same site but of a different nature; VII: Different site, but of the same nature; VIII: Different site and of a different nature.

Subsequent injuries that were of the same nature but at a different site (i.e. SIC category VII) represented 43 SIC codes (12.4% of subsequent injury codes, 95% CI [9.3, 16.4])) from 39 subsequent injuries. These subsequent injuries were commonly muscular in nature (n = 21, 53.9%; 95% CI [37.9, 69.1]). The relative risk of sustaining an injury of the same nature but at a different site increased when the index injury was a muscle injury compared to all other injuries (Table 3.1: RR = 2.76; 95% CI [1.34, 5.72], $p < 0.01$). Following a muscle index injury, there were 16 muscle injuries at different anatomical regions; of which, 8 were on the contralateral limb to the index and 8 were on the ipsilateral limb to the index.

Recurrent injuries (SIC II; same site and nature) represented 43 SIC codes (12.4% of subsequent injury codes, 95% CI [9.3, 16.4]) from 36 subsequent injuries. Muscle injuries (n = 12, 33.3%; 95% CI [19.6, 50.6]) and concussions (n = 8, 22.2%; 95% CI [11.2, 39.2]) were the most common nature of recurrent injuries. The relative risk of sustaining a recurrent injury increased when the index injury was a concussion compared to all other index injuries (Table 3.1: RR = 3.23; 95% CI [1.18, 8.87], $p = 0.02$).

Index Injury Nature *(n)*	Relative Risk [95%CI]			
	II Recurrent	VII Different site, same nature	VIII Different site, different nature	Any Subsequent Injury
Muscle *(84)*	1.49 [0.61, 3.61]	2.76 [1.34, 5.72] **	0.90 [0.62, 1.30]	1.06 [0.84, 1.34]
Joint *(101)*	0.55 [0.19, 1.60]	0.98 [0.44, 2.17]	1.08 [0.78, 1.51]	1.00 [0.80, 1.26]
Concussion *(23)*	3.23 [1.18, 8.87] *	n/a	0.91 [0.48, 1.73]	1.04 [0.69, 1.56]
Tendon *(13)*	1.24 [0.18, 8.59]	0.94 [0.14, 6.44]	1.67 [0.98, 2.83]	1.35 [0.93, 1.98]
Bone *(40)*	0.78 [0.19, 3.23]	0.58 [0.14, 2.37]	0.89 [0.54, 1.48]	0.90 [0.64, 1.28]
Unspecified *(40)*	0.80 [0.19, 3.32]	0.60 [0.15, 2.44]	1.28 [0.85, 1.94]	1.10 [0.82, 1.48]
Other *(19)*	n/a	n/a	0.30 [0.08, 1.14]	0.49 [0.23, 1.05] *
Total (n)§	20	26	106	166

Table 3.1 Relative risk of sustaining each subsequent injury type (i.e. II, VII, VIII, overall) ▲ following the specified index injury nature.

▲SIC-2.0 data-driven categories (Table 2.4): II: Recurrent; VII: Different site, but of the same nature; VIII: Different site and of a different nature; Any: irrespective of SIC-2.0 category.

*n/a: not applicable, where either exposed or cases was equivalent to 0; 95%CI: 95% confidence interval; Total §(n): sample of subsequent injuries allocated each code (column); *P < 0.05; **P < 0.01.*

3.6 Discussion

One third of AF players sustained multiple injuries in a single competitive season and most of these subsequent injuries were of different site and nature to the index injury. The nature of the index injury did not appear to influence the risk of sustaining a subsequent injury, with two important exceptions: [1] concussion was associated with a subsequent recurrence; and [2] an index muscle injury was associated with subsequent injury of the same nature but a different site. These findings are important to understand their impact on tertiary injury prevention in elite AF.

Consistent with prior research, subsequent injuries of a different nature and site to the index injury were the most prevalent subsequent injury (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Moore, Mount et al. 2018, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). However, the prevalence of this subsequent injury category in the current study was considerably lower compared to previous studies (57.1% compared to 69.7%-78.9% in previous studies) (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). This difference may be explained by the different sports investigated impacting the types of injuries that are most common. The generalisability of subsequent injury proportions is likely to be limited to the sport in which those findings were obtained (Moore, Mount et al. 2018).

The relative risk of sustaining a subsequent injury at a different site and of a different nature was not influenced by the nature of the index injury. Despite no association being identified in the present study, such relationships have been shown to exist in the literature (Green and Pizzari 2017, Toohey, Drew et al. 2017, Green, Bourne et al. 2020), with most establishing associations to an index concussion (Lynall, Mauntel et al. 2015, Pietrosimone, Golightly et al. 2015, Brooks, Peterson et al. 2016, Cross, Kemp et al. 2016). Previously concussed collegiate athletes, for example, are at an increased probability of sustaining a subsequent lower limb musculoskeletal injury compared to non-concussive athletes (Brooks, Peterson et al. 2016). This relationship is supported in multiple other sports (Lynall, Mauntel et al. 2015, Pietrosimone, Golightly et al. 2015, Hunzinger, Costantini et al. 2021) and is theorised to involve altered neurocognitive markers and gait performance, leading to an increased risk of subsequent lower limb musculoskeletal injury following concussion (Howell, Buckley et al. 2018, Howell, Lynall et al. 2018, Wood, Hsieh et al. 2019, Howell, Bonnette et al. 2020, Oldham, Howell et al. 2020). Despite not finding evidence of this relationship in the present study, evidence exists to suggest subsequent injuries of a different site and nature may be associated with previous injuries. These injuries are clinically distinct from previous injuries, however, are highly prevalent and require further investigation to better understand the aetiology of this injury type.

Injuries that were of the same nature as the index injury but to a different anatomical site were the second most common subsequent injury type. The proportion of these subsequent injuries was significantly greater than previous studies (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). We found that a muscle index injury was associated with a 2.76-fold increase in sustaining a subsequent injury of the same nature and different site compared to other index injuries. The aetiology of these potentially related injuries that occur at a different anatomical site has been theorised for many years. Recurrent muscle injuries have received considerable interest within the literature, especially in AF (Orchard 1998, Brukner, Nealon et al. 2014, Orchard, Chaker Jomaa et al. 2020). Yet, previous studies have also shown that an index hamstring injury may be associated with a subsequent calf injury (Orchard 2001, Hägglund, Waldén et al. 2012). While, Green, Bourne et al. (2020) observed the inverse association between hamstring and calf muscle injuries (i.e. previous calf injury was associated with subsequent hamstring injuries). Toohey, Drew et al. (2017) discussed that this association between muscle injuries at different locations may be due to sudden changes in limb biomechanics, training loads, and compensatory effects following an index injury. These findings highlight the need for clinicians to be aware of subsequent muscle injuries following an index muscle injury, both at the site of the index injury and at other sites.

Recurrent injuries comprised a total of 12.4%, considerably higher than previous studies, which range from 0.0 to 4.1% (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). Importantly, an index concussion was positively associated with a 3.23-fold increase in subsequent recurrence compared to other index injury natures. This finding is supported by previous work, with a meta-analysis of seven studies reporting that individuals with a history of concussion were ~4-times more likely to suffer a recurrent concussion (Reneker, Babl et al. 2019). While an index concussion was a risk factor in sustaining a recurrent injury, the overall prevalence of recurrent concussions was low in the current study. Of the 23 index concussion injuries, only 4 players (17.3%) sustained a recurrent concussion. This is likely to have been influenced by the injury definition adopted, in which only severe (match-loss) concussions were recorded. This may underreport the true prevalence of concussion, and possibly overreport recurrence rates (Hammond, Lilley et al. 2011). With the potential impact of multiple concussions on general health, understanding the factors that lead to a subsequent concussion may help improve post-concussion rehabilitation and prevention.

This study adds to the body of evidence by identifying that index concussion and muscle injury may alter the subsequent injury risk profile. Tertiary injury prevention strategies may be effective in targeting functional deficits following the index injury or ensuring an adequate preparation period prior to RTP. However, these approaches may not align with external pressures from the athlete and coaching staff, who often advocate for accelerated RTP timelines. Some athletes may have a higher intrinsic risk of certain index injuries, such as muscle injuries. Both muscle strength and muscle pennation angle have been associated with hamstring injury risk (Green, Bourne et al. 2020). Therefore, some factors for intrinsic injury risk remain unmodifiable. However, targeting modifiable factors in the injured muscle, as well as muscles throughout the body, may decrease the risk of subsequent muscle injuries throughout the body.

A limitation of this study is there is only one season of injury data that limits the injury sample, especially when investigating the impact of index injury nature on subsequent injury category. Most of the estimates of relative risk were accompanied by wide confidence intervals, which may impact the degree of certainty in the relative risk estimates. Further, relative risk does not consider the influence of exposure, therefore, censoring and temporality of the injury were not accounted for. It is also assumed that there is a history of injuries prior to the commencement of this study, which we were unable to account for. This is an inherent limitation of many epidemiological sports injury studies, because an athlete’s whole injury profile (i.e. from the beginning of their career) is often unattainable.

The match-loss injury definition used for the collection of injury data has limitations because less severe injuries are not well accounted for. This is likely the case for some head injuries and concussions as players are not always required to miss the following match. For this reason, exacerbations were also assumed to be underreported due to the observation that no SIC III codes were allocated in this dataset. However, the use of a match-loss injury definition is also a strength of the study as it provides a robust injury record with a medically diagnosed injury for each occurrence. Despite not including all clubs and players from the 2016 AFL season, a strength of this study was the large sample of football players. The majority of the players participated in this study and a wide range of characteristics were accounted for, including age, height and years of playing experience. Due to the sample size, these characteristics are likely representative of the same data at population level (i.e. elite AF players).

3.7 Conclusion

Most subsequent injuries were different in site and nature relative to the index injury. Recurrent injuries and those of the same nature but at a different anatomical site to the index were more prevalent compared to previous studies. Concussion was at increased risk of recurrence compared to other injuries, and subsequent muscle injuries were common following a muscle injury to a different anatomical site. Through the analysis of subsequent injuries and the relationships that exist between them, tertiary injury prevention programs that are tailored towards an athlete's individual injury profile may be informed with future research.

3.8 Practical implications

1. Most subsequent injuries were unrelated to the site and nature of previous injuries, despite being proportionately lower than in previous studies.
2. Recurrent concussion requires sustained monitoring and return-to-play should be cautiously approached where an index concussion has been sustained.
3. Rehabilitation from an index muscle injury must not only consider reducing muscle injury recurrence but also subsequent muscle injury on the other side, or a muscle proximal or distal to the index injury.

Chapter 4

Exploring the impact of subsequent injury definitions in elite Australian rugby union

4.1 Preface

4.1.1 Contributors

All authors contributed to the original concept and participated in the drafting and approval of the final manuscript. Mr Smith and Dr Toohey contributed to the categorisation (i.e. SIC-2.0) of the injury dataset. Mr Smith conducted all data cleaning, analyses and reporting. This work was completed by Mr Smith under the supervision of Dr Docking, Dr Fortington and Dr Rio as a component of his Master's thesis.

4.1.2 Publication status

This manuscript is in preparation for submission to the Journal of Science and Medicine in Sport (JSAMS) for October, 2021.

4.2 Abstract

Objectives: To investigate subsequent injury patterns using two methods of analysis in elite Australian rugby union players across two consecutive seasons.

Design: Descriptive epidemiological study

Methods: Prospectively collected injury data from the 2018 and 2019 Super Rugby seasons were obtained for all Australian Super Rugby teams. Medical attention injuries were categorised using the SIC-2.0 model to quantify subsequent injury relationships. Two categorisation methods were adopted, comparing subsequent injuries (1) relative to all previous injuries, and (2) relative to the immediately preceding injury only. The relative risk of sustaining a subsequent injury following each injury nature was calculated using chi-square test of independence.

Results: A total of 196 players sustained 1257 injuries, of which, 1061 injuries were subsequent to an index (84.4%). Most players sustained more than two injuries during the 2-year period (n=174, 88.8%). Most subsequent injuries were to a different site and of a different nature to all previous injuries (n=4,508 SIC-2.0 codes, 66.7%), however, this proportion reduced when categorised only to the immediately preceding injury (n=610, 58.9%). A higher proportion of recurrent injuries and exacerbations were observed relative to the immediately preceding injury (recurrent: n=65, 6.3%; exacerbation: n=130, 12.6%) compared to all previous injuries (recurrent: 211, 3.1%; exacerbation: 256, 3.8%). A strong association (i.e. observed for both categorisation methods) was observed between index muscle injuries and subsequent muscle injuries on the contralateral side (category V: RR = 2.8-3.0, $p < 0.005$) or of the same nature but at a different site (category VII: RR = 1.6-1.8, $p < 0.05$).

Conclusions: Subsequent injury patterns and relationships are different relative to the immediately preceding injury. Therefore, the dependency of subsequent injuries on previous injuries may change based on injury sequence or temporality. The role that this plays on subsequent injury risk should be further assessed for potential clinical implications.

4.3 Introduction

Rugby union is a high-intensity, intermittent, full-contact collision sport. Recent findings have highlighted that the overall injury rate is three times higher in rugby compared to American football (Willigenburg, Borchers et al. 2016). As such, strategies to prevent injuries are valued. To prevent injuries from occurring they must first be understood with far greater detail than currently reported (Finch and Marshall 2016, Fortington, van der Worp et al. 2017). Specifically, the longitudinal relationships between injuries sustained by an individual must be considered to accurately quantify injury prevalence and injury risk.

Application of the SIC model has been based on the same analysis approach since being introduced (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Moore, Mount et al. 2018, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). Each subsequent injury receives a SIC code (i.e. a data-driven category) that defines its relationship to a given injury that occurred before it. The initial procedure provided each subsequent injury an individual code comparing it to every injury preceding it. For example, the third injury would receive a SIC category comparing it to injuries one and two. Doing so quantifies subsequent injuries as they relate to all previous injuries, therefore, provides a holistic overview of the problem. However, one study has attempted the converse; an approach comparing only two chronologically adjacent injuries (Stares, Dawson et al. 2019). Despite adopting a method of categorisation to compare sequential injuries, the literature is yet to compare how this method of categorisation might impact the SIC distributions observed. Furthermore, it remains unclear if subsequent injury risk is related to the sequence in which injuries are sustained.

It is known that the nature (i.e. tissue type) of a previous injury may be associated with the type of subsequent injuries sustained by an athlete (Stares, Dawson et al. 2019, Green, Lin et al. 2020, Orchard, Chaker Jomaa et al. 2020). The previous chapter supports these findings by suggesting that multiple specific index injury natures are associated with a specific subsequent injury category (SIC-2.0) – making it clear that there exists an inherent relationship between the expected subsequent injuries and the index injury nature. However, in addition to the methods adopted in the previous chapter, the present study will compare the relationships between chronologically adjacent injuries. In doing so, it becomes possible to assess whether the preceding injury's nature may indicate increased risk for the immediately subsequent injury. Further, the types of subsequent injuries (according to SIC-2.0) expected to occur in the immediately successive injury are potentially predictable using the methods adopted in the previous chapter. This alteration to the typical methodology will illustrate how subsequent injuries relate to the previous injury and permit risk assessments between adjacent injury occurrences using diagnostic descriptors of the preceding injuries.

This study aimed to quantify the subsequent injury types that are most prevalent in Australian rugby union, and the relative risk of these relationships following common injury natures. We also aimed to compare subsequent injury types relative to the immediately preceding injury and to observe any similarities or differences to similar analyses in Australian football.

4.4 Methods

4.4.1 Ethics

With support of Rugby Australia for the project, a negligible Risk Human Research Ethics application was submitted and approved by La Trobe Human Research Ethics Committee (Appendix C, page 103, HEC20109). All Super Rugby athletes are required under contract to have their injury data recorded in Smartabase to assist in surveillance and the development of injury prevention measures for elite Australian rugby. For this reason, a waiver of consent was obtained for the recruitment of all participants. The identity of all athletes with health data to be analysed in this project remains anonymous, in accordance with the human ethics application.

4.4.2 Inclusion

Any player who participated in a Super Rugby match for an Australian franchise in 2018 or 2019 was eligible. From these players, those who sustained an injury in any competition (Super Rugby, International or National Rugby Championship) were included in the analysis. A total of 221 athletes from all four franchises were eligible, 196 of which sustained an injury and were included within the analysis; providing 8,955 individual observations.

4.4.3 Data collection

Smartabase is an online centralised database to support the prospective collection and recording of health data. Rugby Australia uses this system to record, store, and analyse health data for contracted players; collecting information relating to injuries, athlete wellbeing, performance and medical consultations. For the purposes of this study, information relating to athlete injuries and the treatment of these injuries was used.

Injury data were prospectively collected by the accredited medical personnel for each team, whom were either sports physiotherapists or sports physicians. Upon recording these data, the authorised medical staff are required to provide a minimum level of information to create a record of the event (Toohey 2019). For injury data, this includes the date of the injury, the date of treatment/assessment, a descriptive injury diagnosis, the OSICS-10.1 diagnostic code, the side of the injury, and the athlete's training status (no training, modified training, or full training) at the time of record (Toohey 2019). Time-loss injuries were defined as those resulting in missed participation from training or competition.

4.4.4 Data preparation

All datasets were obtained and prepared by Rugby Australia from Smartabase (Fusion Sport Pty Ltd, Brisbane, Australia).

Upon receiving this data, all identifying information was deleted in place of an ID to ensure the anonymity of the athletes while also permitting injury linkage within an individual. The injury dataset received contained details relating to the occurrence of each injury, with an observation for each treatment pertaining to the given injury.

Further steps were taken to ensure the injury record dataset contained information requisite for most sports' epidemiology studies (Bahr, Clarsen et al. 2020). The addition of the season, month, annual week, and number of days unavailable for training and in modified training was determined by the lead investigator based on the available data. Finally, duplicate records and those where the treatment date was earlier than the injury date were deleted from the dataset to eliminate inaccurate data entries.

4.4.5 Subsequent Injury Categorisation

The SIC-2.0 automatic syntax was used to categorise the subsequent injury relationships in this dataset. The automatic syntax was used due to its high reliability and the increased time efficiency compared to the manual coding method (Toohey, Drew et al. 2018). Each injury contained several records of the same injury at different treatment stages, therefore, the last observation for each unique injury was taken to represent the injury record; this would also identify the injuries that were ongoing at the time of data extraction. Injury exacerbations were considered a subsequent injury (SIC-2.0 category III), and accounted for by duplicating observations where rehabilitative progression had worsened (e.g. full training to modified training or unavailable). Where multiple injuries were sustained in the same event (e.g. simultaneous knee ligament and meniscal damage), the primary injury, as defined by the medical staff, was coded relative to previous injuries. Injuries sustained in the same event did not receive a SIC-2.0 category relative to each other because neither are subsequent to one another.

The remaining steps assigned each injury a SIC-2.0 code; where a series of programmable loops (i.e. a command to run a piece of code repeatedly; e.g. might ask program to rename variable looping over each variable in the dataset, therefore, the rename command does each variable sequentially until it has completed the command for all variables) would analyse the sub-string variables of the OSICS-10.1 code, the recovery date, and the side of injury; looping over each injury preceding the subsequent injury being coded.

4.4.6 Calculating relative risk using injury nature

The nature of the injury was also necessary for the computation of relative risk in the analysis. The injury nature categories relied on the OSICS-10.1 code to determine the broader category of the injury sustained, including muscle, joint, bruise/haematoma, tendon, bone, pain/unspecified nature, concussion and other. This variable was encoded from numbers, with the aforementioned categories listed in the numerical sequence with which they are represented in the dataset. Another variable representing the anatomical site of injury (i.e. first OSICS-10.1

character) was generated and encoded. Encoding is a process that labels each value of a variable with a specified string of letters, improving the readability of the dataset while maintaining an ability to include the variable in analyses relating to its contents. The final dataset included the diagnostic details of the injury, the severity metrics, the SIC-2.0 codes, and the injury nature for use in data analyses.

4.4.7 Data analyses

4.4.7.1 Descriptive injury statistics

Descriptive analyses looked at the number of players injured, number of total injuries, number of index and subsequent injuries, cumulative injuries per player, and the breakdown of anatomical site and nature. Prevalence measures were calculated as a percentage of the total number of injuries within the specified sample (n); excluding cumulative injury statistics, which were a percentage of the total number of players.

4.4.7.2 Subsequent injury distribution and comparison of categorisation methods.

Two approaches were used for the subsequent injury analyses. These were labelled:

1. All injuries approach: SIC codes relate to *all* injuries previous to the subsequent injury in the study.
2. Preceding injury approach: SIC codes relate only to the injury *immediately preceding* the subsequent injury.

It is important to note that there may be multiple SIC codes for each injury in the all injuries approach, while only one SIC code is possible for the previous injury approach because the subsequent injury is only being compared to one other injury: the previous injury.

Prevalence estimates of all subsequent injury analyses were calculated as a percentage of the total SIC codes in a specific sample. Confidence intervals (95% CI) of proportion (prevalence) represent the range within which the estimate is expected to be. Where these confidence intervals did not overlap between SIC-2.0 categories, prevalence estimates were considered to be different to one-another. Prevalence for analyses involving injury nature or site were calculated as a percentage of the number of injuries within the sample.

4.4.7.3 Relative risk of subsequent injury by injury nature categories

Subsequent injury risk was established using relative risk, 95% confidence intervals and the significance (alpha = 0.05) of the p-value (p).

$$Relative\ risk = \frac{exposed\ cases\ \div total\ exposed}{non\text{–}\ exposed\ cases\ \div total\ non\text{–}\ exposed}$$

Calculation of these statistics was undertaken using a Stata do file, which retrieved the relevant data and executed Stata's 'csi' command to run a Chi-squared test of independence using the values within each contingency table (Table 4.1). This process was performed within a programmable loop; therefore, the relevant data was retrieved and statistical analysis performed for every possible case and exposure combination. For all tests, the exposure was defined by the injury nature while the cases were defined by the SIC code.

For example, in looking at Table 4.1, the number of index muscle injuries was the number of exposed cases (n=61). The number of unexposed (i.e. did not sustain a muscle injury for their index) was equal to 135. The event occurring depends on whether the athlete sustained a recurrent injury (SIC-2.0 category II) relative to the index at some point throughout the season. With this in mind, a total of 13 sustained a recurrent injury as a subsequent injury relative to their index. Seven of these were following a muscle index injury, therefore, there were 7 exposed cases in which the event variable occurred.

The analysis was divided by the two methods of SIC-2.0 categorisation: the all injuries method and the preceding injuries method. Relationships between injury nature and SIC-2.0

categories that were statistically significant ($p < 0.05$) for both categorisation methods were considered strong relationships, thus described as 'consistent' findings. Relationships between injury nature and SIC-2.0 category that were only present for one of the categorisation methods were considered 'inconsistent' findings, given they differed by categorisation methods.

Table 4.1 Excerpt of output for the calculation of relative risk using the 'csi' command in Stata.

	Exposed	Unexposed	Total
Cases	7	6	13
Noncases	54	129	183
Total	61	135	196
Risk	.1147541	.0444444	.0663265

RR = 2.6

Note: an excerpt from real data describing the relative risk of sustaining SIC-2.0 category II following a muscle index injury.

The automation process of the relative risk procedures was logged as a Stata do file for reproducibility, as well as a compiled PDF with the results output, and a Stata log file containing all the commands that were executed. All data were prepared and analysed using Microsoft Excel (Version 16.36, Microsoft Office) and Stata statistical software (Stata®/IC 16.1, StataCorp, USA).

4.5 Results

4.5.1 Descriptive statistics

One hundred and ninety-six players from four Australian Super Rugby teams over the 2018 and 2019 seasons were included in the study. Over the 2-year data collection period, 1,257 injuries were recorded. These injuries were predominately time-loss injuries (n = 706, 56.2% of all injuries, 95% CI [53.4, 58.9]) with 551 non-time-loss injuries (43.8% of all injuries, 95% CI [41.1, 46.6]).

4.5.2 Cumulative injuries

The total number of injuries sustained per player ranged between 1 and 37 injuries (Figure 4.1; median 4.5, IQR 2.0-8.0). One-hundred and seventy-four players sustained two or more injuries throughout the two seasons (88.8% of injured players, 95% CI [83.5, 92.5]).

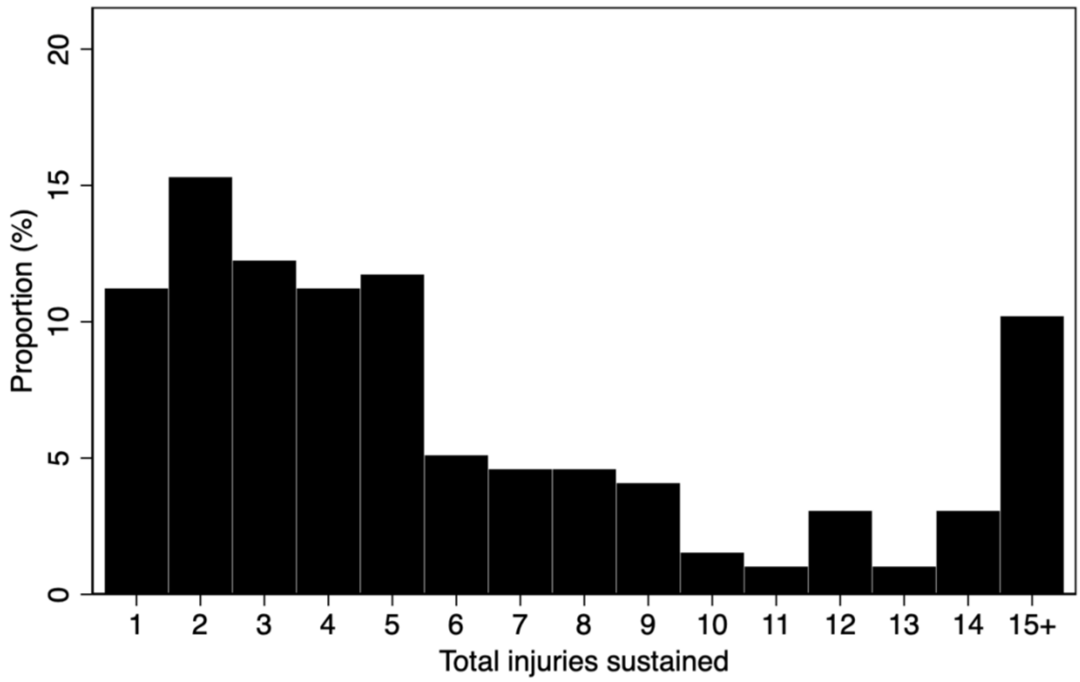


Figure 4.1 Proportion of total accumulated injuries sustained by individual players throughout the 2-year surveillance period (n=196).

4.5.3 Injury site and injury nature

Injuries to the thigh (n = 174, prevalence 13.8%), knee (n = 165, prevalence 13.1%), shoulder (n = 141, prevalence 11.2%) and head (n = 140, prevalence 11.1%) were the most commonly injured regions, accounting for nearly half (49.3%) of all injuries sustained (Figure 4.2).

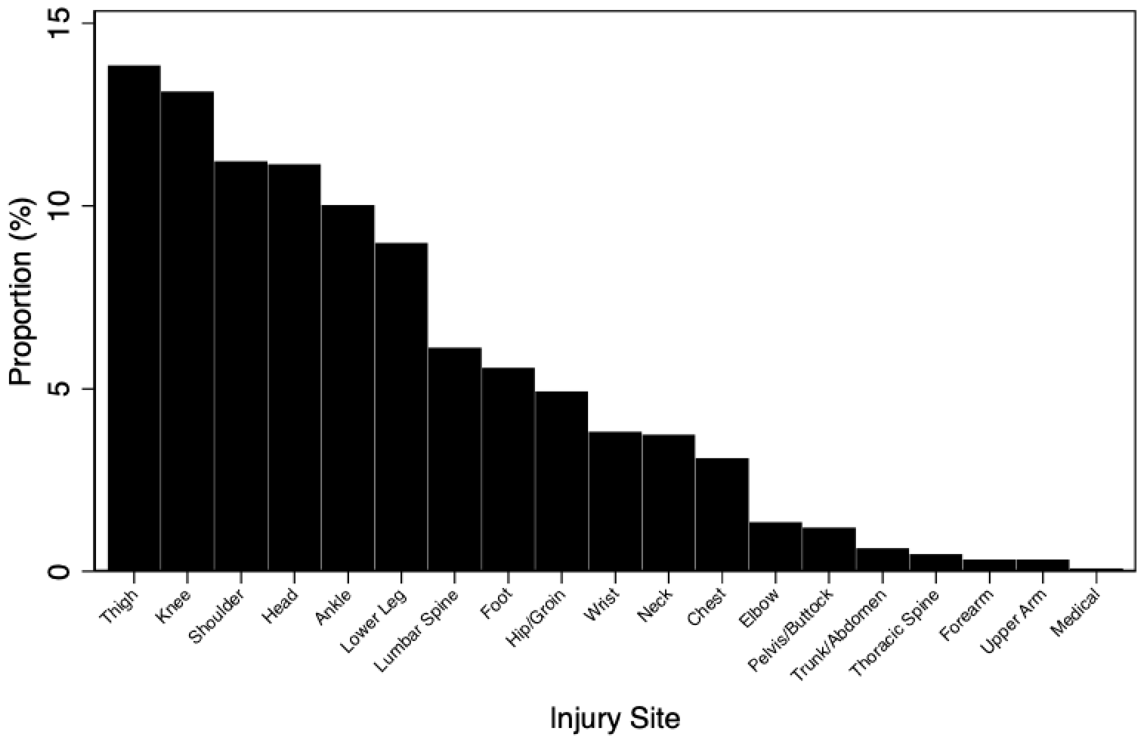


Figure 4.2 Proportion of the anatomical location of all injuries sustained throughout the 2-year surveillance period (n=1257).

Joint-related injury was the most common nature, accounting for 507 injuries in total (40.3% of all injuries; Figure 4.3). Muscle injuries comprised a high proportion of the remaining natures, accounting for 279 injuries (22.2% of all injuries). Concussion, the third most common injury nature, accounted for 115 injuries (9.2% of all injuries).

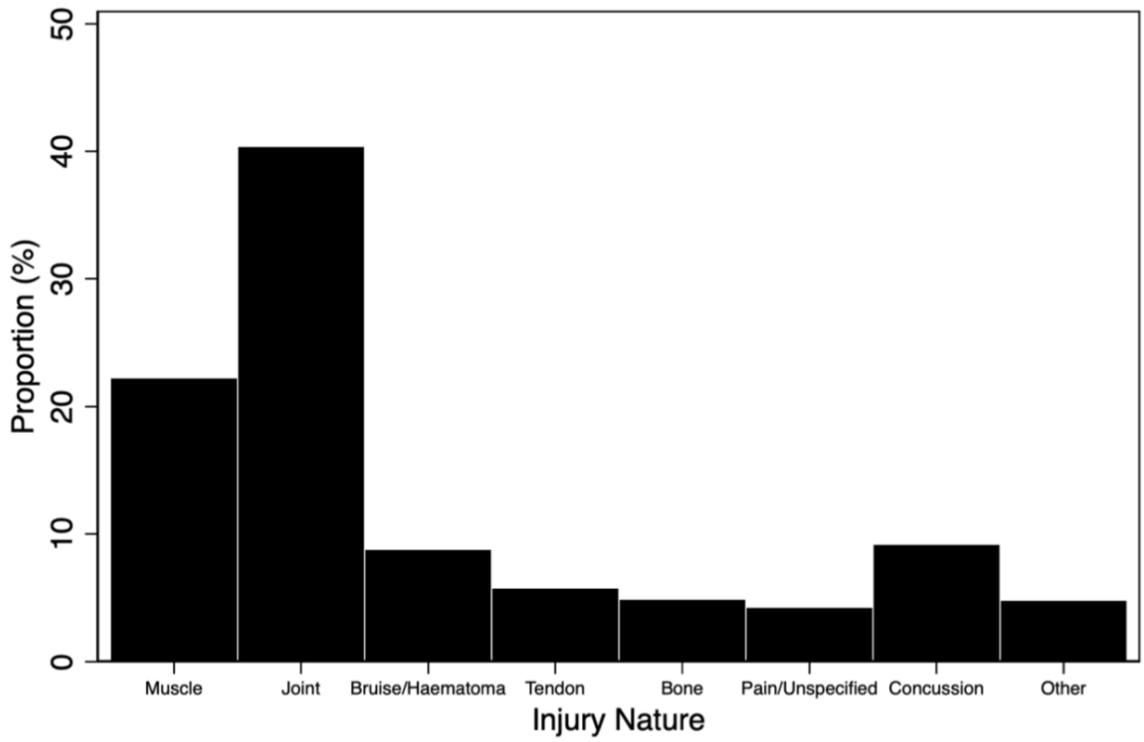


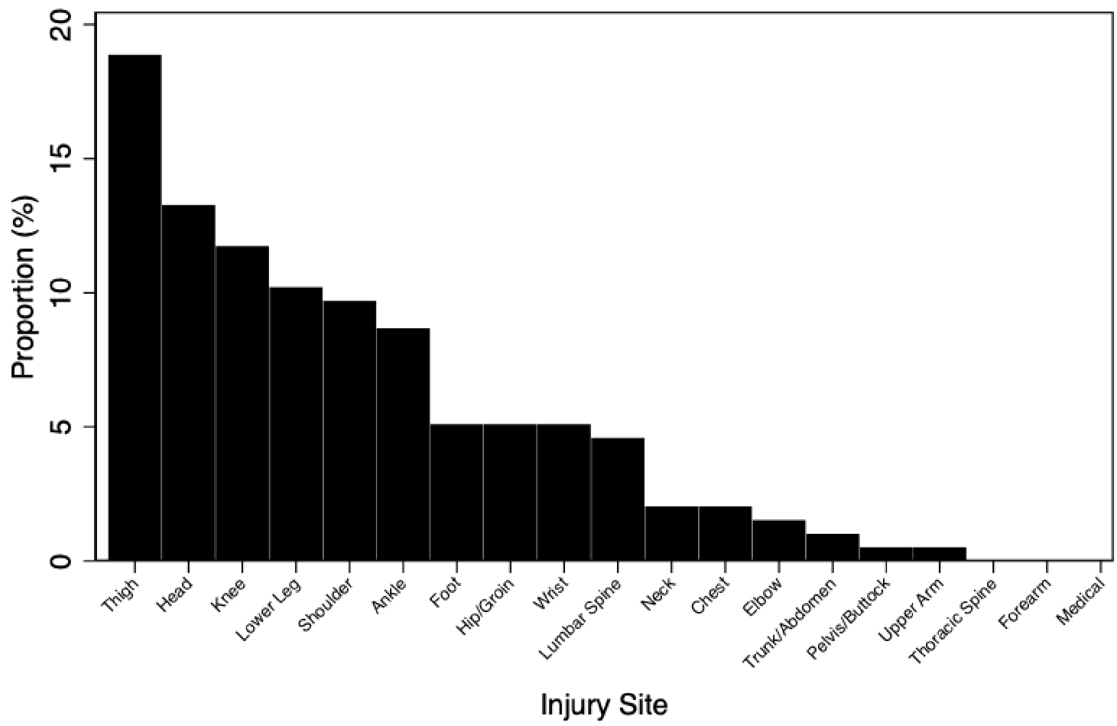
Figure 4.3 Distribution of the injury nature of all injuries during the 2-year surveillance period (n=1257).

4.5.4 Subsequent injury description, site and nature

From the 196 players that sustained at least one injury, 1,061 subsequent injuries were recorded (84.4% of all injuries, 95% CI [82.3, 86.3]). Index injuries most commonly occurred at the thigh (n = 37, prevalence 18.9%), head (n = 26, prevalence 13.3%), knee (n = 23, prevalence 11.7%) and lower leg (n = 20, prevalence 10.2%) regions, respectively (Figure 4.4a). Subsequent injuries were most commonly at the knee (n = 142, prevalence 13.4%), thigh (n = 137, prevalence 12.9%), shoulder (n = 122, prevalence 11.5%) and head (n = 114, prevalence 10.7%) regions, respectively (Figure 4.4b).

Index injuries most commonly impacted a joint (n = 67, prevalence 34.2%), muscle (n = 61, prevalence 31.1%), or were a concussion (n = 19, prevalence 9.7%) (Figure 4.5a). The nature of subsequent injuries was most commonly joint (n = 440, prevalence 41.5%), muscle (n = 218, prevalence 20.6%) or bruise/haematoma (n = 104, prevalence 9.8%) (Figure 4.5b).

(a) Index Injury Site



(b) Subsequent Injury Site

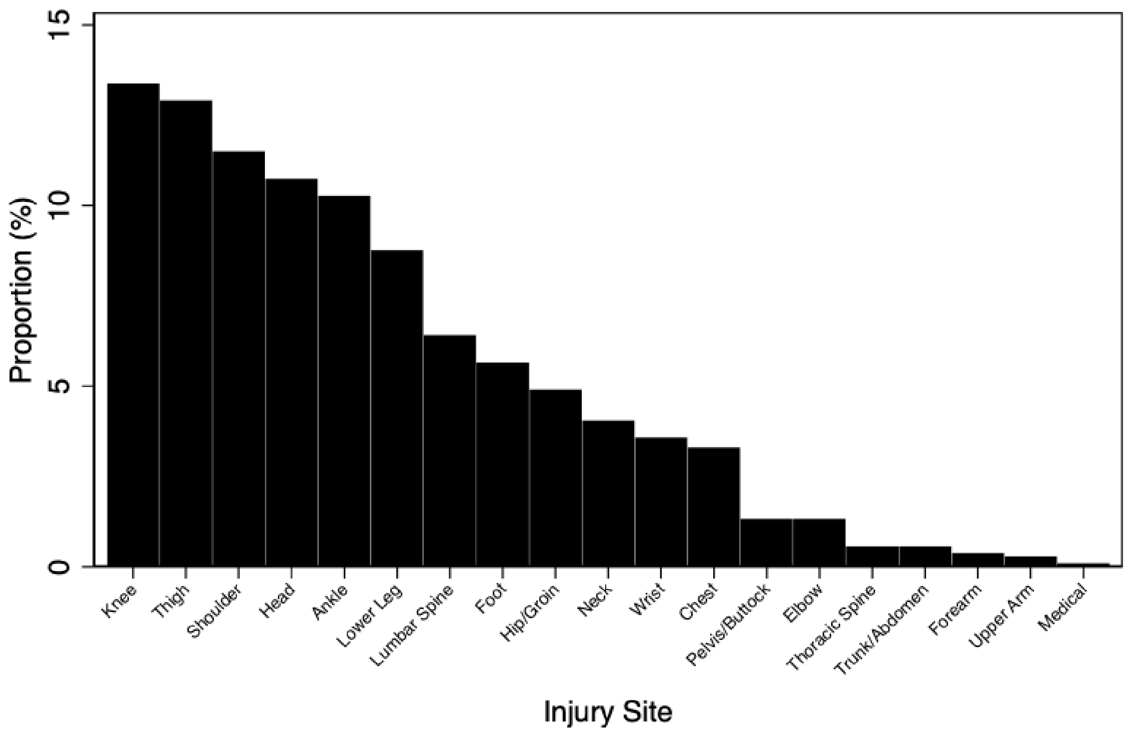
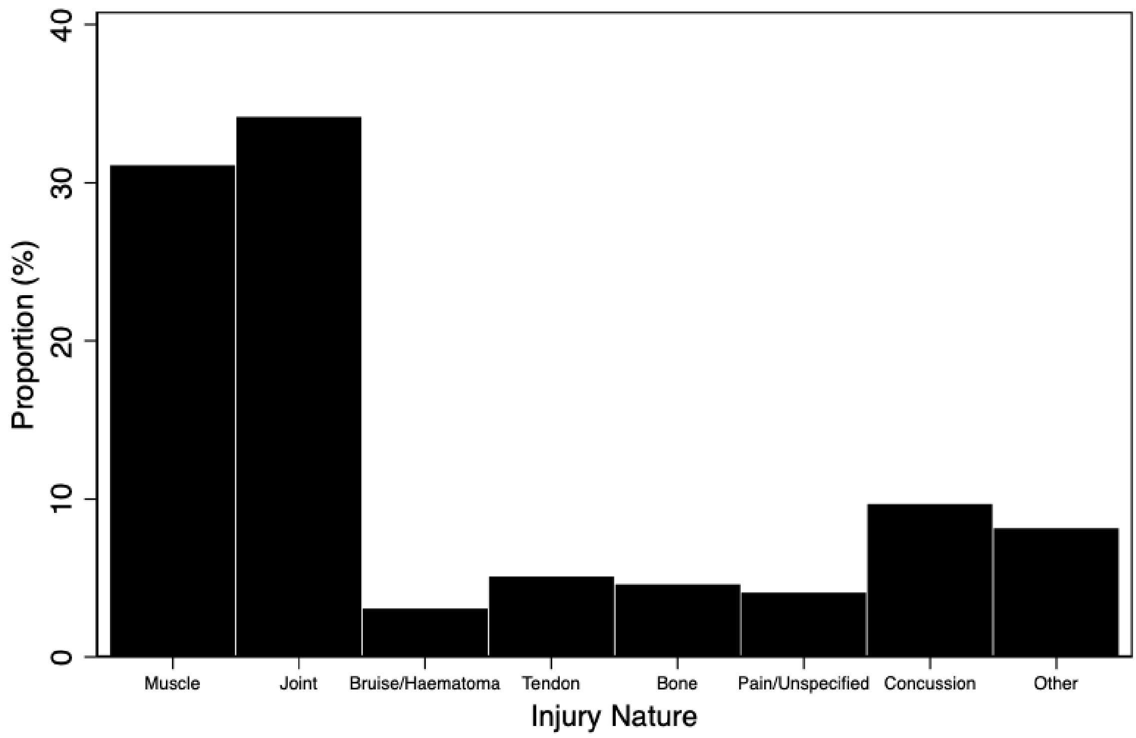


Figure 4.4 Distribution of the anatomical locations at which (a) index (n=196) and (b) subsequent injuries (n=1061) were sustained.

(a) Index Injury Nature



(b) Subsequent Injury nature

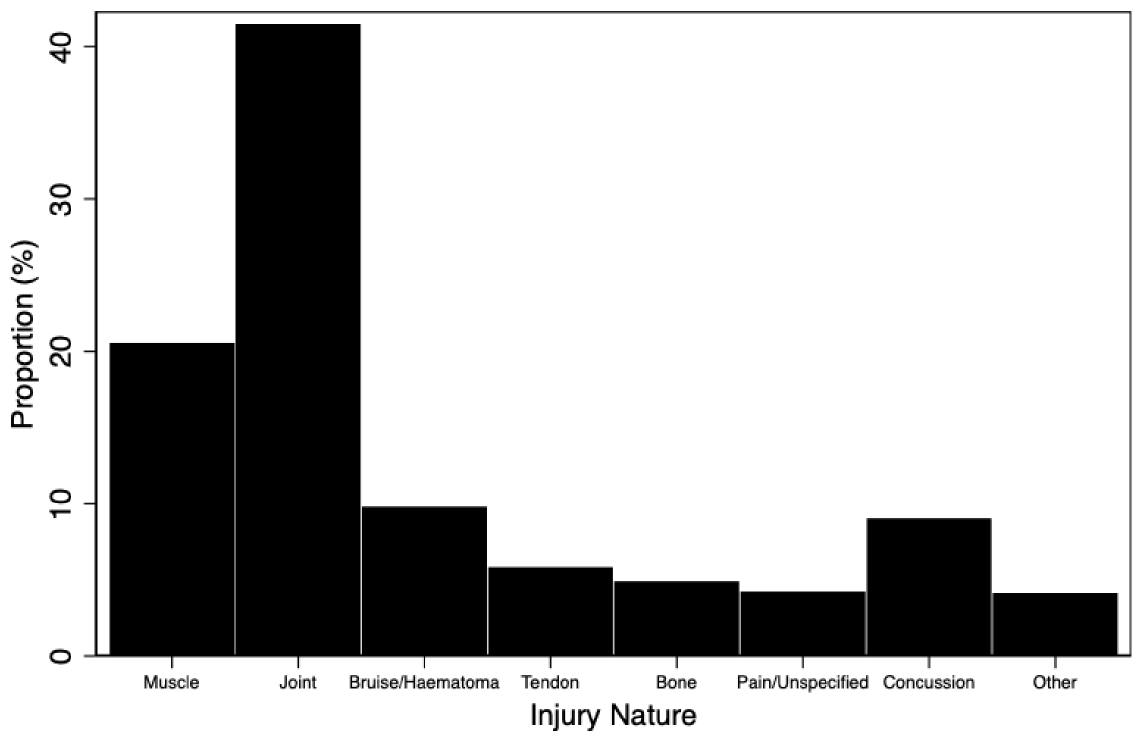


Figure 4.5 Distribution of the injury nature of (a) index (n=196) and (b) subsequent injuries (n=1061).

4.5.5 SIC-2.0 distribution

4.5.5.1 All injuries method

The SIC-2.0 classification system was applied to the 1,061 subsequent injuries in comparison to the index injury and all other injuries that preceded it, resulting in a total of 6,764 SIC codes. Subsequent injuries at a different site and nature were the most common code (category VIII) (Figure 4.6), accounting for 4,508 SIC-2.0 codes using the 'all injuries' method (66.7% of SIC-2.0 codes, 95% CI = 65.5 to 67.8). Injuries at a different site but the same nature (category VII) and at the same site but different nature (category VI) followed, accounting for 911 (13.5% of SIC-2.0 codes, 95% CI = 12.7 to 14.3) and 483 (7.1% of SIC-2.0 codes, 95% CI = 6.6 to 7.8) codes, respectively. Recurrent injuries (category II) and exacerbations (category III) were infrequent, accounting for 211 (3.1%, 95% CI = 2.7 to 3.6) and 256 (3.8%, 95% CI = 3.4 to 4.3) SIC-2.0 codes, respectively.

4.5.5.2 Previous injuries method

The 'previous injuries' method used the 1,036 codes relating to the immediately preceding injury. A further 25 codes were also unassigned where multiple injuries were sustained in the same event (22 multiple injury events, 48 distinct injuries sustained). Similar to the 'all injuries' method stated above, injuries of a different site and nature (SIC-2.0 category VIII) (Figure 4.6) were the most common subsequent injury type, accounting for 610 of the included SIC-2.0 codes (58.9% of SIC-2.0 codes, 95% CI = 55.9 to 61.8). The prevalence of category VIII was lower in this method compared to the 'all injuries' method, and the 95% confidence intervals did not overlap. Categories II and III in the preceding injuries method had a higher prevalence than the all injuries method, and confidence intervals did not overlap. Categories II and III accounted for 65 (6.3% of SIC-2.0 codes, 95% CI = 5.0 to 7.9) and 130 (12.6% of SIC-2.0

codes, 95% CI = 10.7 to 14.7) codes, respectively. The remaining categories did not show differences between the two methods used and confidence intervals were overlapping.

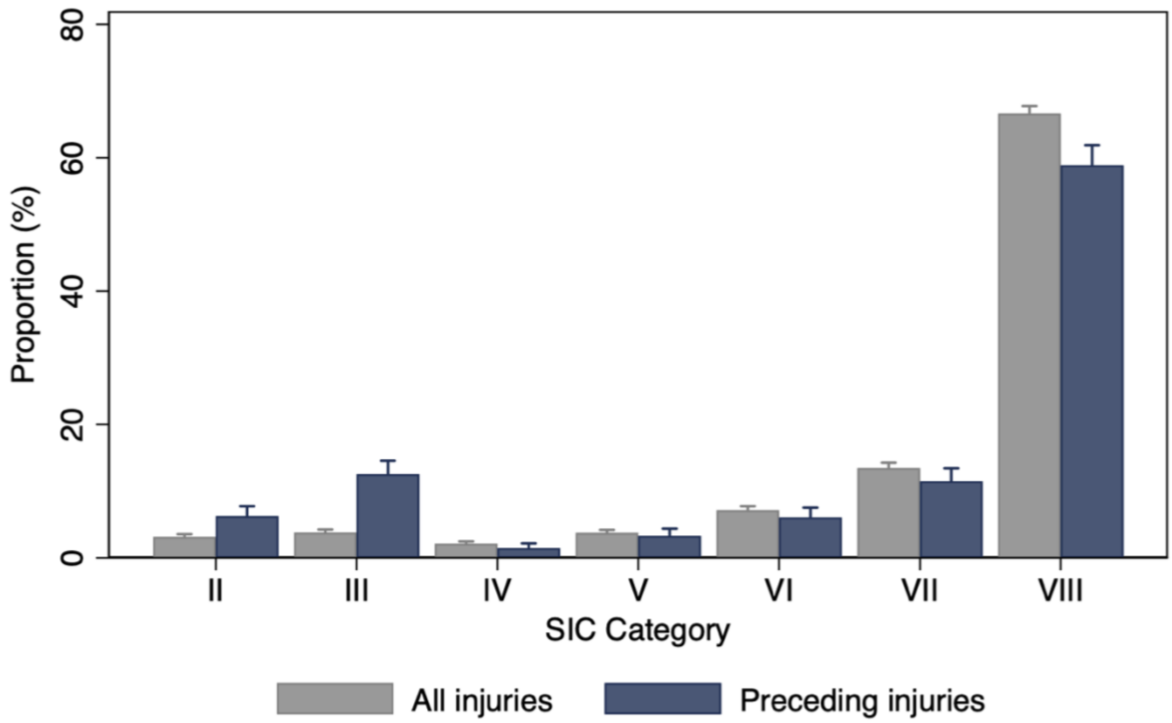


Figure 4.6 SIC-2.0 distribution relative to all injuries (grey; n=6764 SIC-2.0 codes) and only the immediately preceding injury (blue; n=1036 SIC-2.0 codes).▲

SIC: subsequent injury categorisation;

▲*SIC-2.0 data-driven categories (Table 2.4): II: Recurrent; III: Exacerbation; IV: Same site, same nature, same side, but of a different structure; V: Same site, same nature, but different side; VI: Same site but of a different nature; VII: Different site, but of the same nature; VIII: Different site and of a different nature.*

4.5.6 Subsequent injury relative risk

4.5.6.1 Muscle injury

The relative risk of sustaining the same injury on the contralateral side (SIC-2.0 category V) (e.g. contralateral calf muscle injury after a calf muscle injury) and injuries of the same nature but different site (SIC-2.0 category VII) (e.g. hamstring injury after calf muscle injury) was increased across both categorisation methods following a muscle injury ($p < 0.05$; Table 4.2). An exacerbation (SIC-2.0 category III) presented a lower relative risk for the preceding injuries method ($p = 0.02$).

4.5.6.2 Joint injury

The relative risk of sustaining the same injury on the contralateral side (SIC category V) was consistent for both categorisation methods, where joint injuries presented a lower risk of contralateral injuries ($p < 0.05$; Table 4.2). The relative risk of sustaining an injury of the same nature but at a different site (SIC-2.0 category VII) was increased where the preceding injury was a joint injury ($p = 0.02$) (e.g. knee injury immediately after an ankle injury). The relative risk of sustaining a clinically different injury (SIC-2.0 category VIII) was lower for the preceding injuries method ($p = 0.01$).

4.5.6.3 Bone Injury

Bone injuries may have included fractures or stress fractures. An increased relative risk of sustaining a subsequent injury at the same site but of a different nature (SIC category VI) was observed immediately after a bone injury ($p = 0.02$; Table 4.2) (e.g. femoral fracture followed immediately by quadriceps injury).

4.5.6.4 Pain or unspecified nature

There was an increase in the relative risk of sustaining an injury at the same site but of a different nature (SIC category VI) following an injury assigned the pain or unspecified nature code ($p = 0.01$; Table 4.2), however, only for the all injuries method (e.g. pain/unspecified knee as index injury followed by meniscal tear during season). There was also an increase in the relative risk of sustaining a different injury (SIC category VIII), however, only for the preceding injuries method ($p = 0.04$).

4.5.6.5 Concussion

There was a low relative risk of sustaining an exacerbation (SIC category III) following a concussion ($p = 0.03$; Table 4.2) for the preceding injuries method. The relative risk of sustaining an injury of the same nature but at a different site (SIC-2.0 category VII) and a clinically distinct injury (SIC-2.0 category VIII) was significantly increased for the preceding injuries method ($p < 0.05$).

Table 4.2 The relative risk of sustaining each subsequent injury type (SIC-2.0 category) following each index injury nature (white row) and the immediately preceding injury nature (grey row).

Injury Nature	Relative Risk (95% CI)						
	II	III	IV	V	VI	VII	VIII
Muscle	2.58 (0.91-7.36)	0.55 (0.24-1.28)	0.95 (0.25-3.54)	3.02** (1.47-6.18)	0.83 (0.41-1.68)	1.77* (1.07-2.93)	1.04 (0.90-1.19)
	1.07 (0.61-1.88)	0.56* (0.35-0.91)	1.75 (0.60-5.09)	2.77** (1.42-5.37)	1.1 (0.62-1.93)	1.58* (1.10-2.28)	1.02 (0.89-1.16)
Joint	0.35 (0.08-1.53)	1.28 (0.66-2.50)	2.98 (0.84-9.88)	0.25* (0.08-0.81)	1.42 (0.76-2.65)	1.06 (0.62-1.81)	0.9 (0.77-1.05)
	1.15 (0.71-1.86)	1.35 (0.97-1.87)	1.29 (0.47-3.55)	0.38* (0.17-0.87)	0.91 (0.55-1.49)	1.50* (1.07-2.12)	0.86* (0.76-0.97)
Bruise/Haematoma	0 (n/a)	1.09 (0.18-6.74)	3.52 (0.53-23.51)	0 (n/a)	0 (n/a)	1.47 (0.46-4.71)	1.02 (0.71-1.47)
	0.34 (0.08-1.36)	1.06 (0.61-1.86)	0 (n/a)	1.39 (0.50-3.87)	0.52 (0.17-1.63)	0.75 (0.38-1.50)	1.14 (0.95-1.36)
Tendon	0 (n/a)	2.07 (0.75-5.67)	0 (n/a)	2.43 (0.87-6.74)	1.86 (0.68-5.07)	0.42 (0.06-2.76)	1.11 (0.89-1.38)
	1.7 (0.76-3.81)	1.67 (0.97-2.88)	2.53 (0.58-11.01)	1.59 (0.50-5.09)	0.82 (0.26-2.56)	0.43 (0.14-1.31)	0.94 (0.73-1.22)

Injury Nature	Relative Risk (95% CI)						
	II	III	IV	V	VI	VII	VIII
Bone	1.73 (0.25-11.90)	0.72 (0.11-4.69)	0 (n/a)	0 (n/a)	0.65 (0.10-4.23)	0 (n/a)	0.81 (0.51-1.29)
	1.31 (0.49-3.48)	1.63 (0.90-2.95)	0 (n/a)	0 (n/a)	2.45* (1.17-5.15)	0* (n/a)	0.84 (0.62-1.14)
Pain/Unspecified	0 (n/a)	1.67 (0.48-5.85)	0 (n/a)	0 (n/a)	3.24* (1.50-7.00)	1.09 (0.32-3.73)	1.24 (1.15-1.33)
	0.73 (0.18-2.92)	0.72 (0.28-1.88)	0 (n/a)	1.42 (0.35-5.77)	1.96 (0.82-4.68)	0.79 (0.30-2.06)	1.30* (1.05-1.62)
Concussion	2.79 (0.84-9.28)	0.67 (0.17-2.58)	0 (n/a)	2.22 (0.95-5.20)	0.00* (n/a)	0.67 (0.23-1.94)	1.18 (1.04-1.34)
	0.84 (0.34-2.05)	0.40* (0.17-0.95)	0.71 (0.09-5.35)	0.96 (0.30-3.09)	0.33 (0.08-1.31)	0.35* (0.13-0.92)	1.23* (1.04-1.45)
Other	0 (n/a)	1.25 (0.43-3.67)	0 (n/a)	0 (n/a)	0.73 (0.19-2.76)	0.26 (0.04-1.74)	0.91 (0.68-1.22)
	0.64 (0.16-2.57)	1.14 (0.55-2.32)	0 (n/a)	0 (n/a)	1.35 (0.51-3.60)	0.52 (0.17-1.58)	1.07 (0.83-1.37)

n/a: not applicable, where either exposed or cases was equivalent to 0; 95%CI: 95% confidence interval

▲SIC-2.0 data-driven categories (Table 2.4): II: Recurrent; III: Exacerbation; IV: Same site, same nature, same side, but of a different structure; V: Same site, same nature, but different side; VI: Same site but of a different nature; VII: Different site, but of the same nature; VIII: Different site and of a different nature.

* $p < 0.05$

** $p < 0.005$

4.6 Discussion

4.6.1 Key findings

This study is the first to examine the impact of different categorisation methods on the findings inferred from SIC application in a sports injury dataset. We found there may be a sequential relationship between subsequent injuries, where previous or index injury nature may influence the relative risk of sustaining a particular subsequent injury type (i.e. SIC-2.0 category). Consistent findings between the all-injuries and preceding injuries methods may suggest a robust or non-sequential association. Inconsistent findings between the two categorisation methods may suggest either sequential associations, or clinically unimportant associations due to methodological limitations. Regardless, the roles that categorisation methods and injury definitions play in SIC analysis should be considered due to their influence on the SIC distribution and associations.

4.6.2 Categorisation methods impact subsequent injury

Subsequent injuries may have a temporal or sequential relationship (Ekstrand and Gillquist 1983), yet little is understood about the mechanisms responsible for such an association. Temporality, in the context of this research, may be defined as the time between injuries. Sequential relationships, on the other hand, describe the relationships between injuries that occur one after another. Temporality is often included in sports injury epidemiology studies. One of the most common applications of temporality may be found in recurrent injury literature, where consensus statements recommend that early recurrence (within 2 months), late recurrence (between 2-12 months), and delayed recurrence (greater than 12 months) be recognised explicitly (Fuller, Ekstrand et al. 2006, Fuller, Molloy et al. 2007). However, subsequent injuries have not been reported in the same way. In recognition of this, the two methods of categorisation adopted in this study accounted for different inter-injury relationships: (1) the all injuries methods representing a broad definition of subsequent injury investigating associations between all injuries within a specified period ; and (2) the preceding injuries methods representing a narrow definition of subsequent injury and focusing on the associations of sequential injuries. Therefore, the inter-injury relationships consistent between both methods suggest an association irrespective of the time-between, or sequence of, subsequent injuries. Conversely, associations that are inconsistent between the two methods may suggest either a specific relationship related to the sequence or timing of injuries, or may be a result of methodological limitations. The impact that each categorisation method has on the SIC distribution, the relative risk relationships, and the implications of these findings are discussed in detail below.

4.6.2.1 Clinically distinct injuries are the most common subsequent injury type

Similar to previous studies using SIC methods and irrespective of the sport, subsequent injuries of a different site and nature (i.e. SIC-2.0 category VIII) accounted for an overwhelming majority of the SIC distribution for both categorisation methods (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Moore, Mount et al. 2018, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019). The only other study investigating subsequent injury in rugby union (Moore, Mount et al. 2018) applied a previous version of the SIC model (SIC-1.0), which relied on clinical judgement for category allocation and contained different category criterion (e.g. injury nature) (Toohey, Drew et al. 2018). Therefore, no direct comparison of our study with this earlier work is possible. This study does, however, present similarities to previous studies that have applied the updated model. These similarities are: injuries of a different site and nature were the most common (SIC-2.0 category VIII), followed by injuries at a different site but of the same nature (SIC-2.0 category VII), and finally, injuries at the same site but of a different nature (SIC-2.0 category VI), respectively (Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019, Toohey, Drew et al. 2019).

Recent literature has begun to highlight the relationships between clinically distinct injuries (SIC-2.0 category VIII), which was explored in-depth in **Chapter 3.6**. These injury relationships represent the most common subsequent injury type across all sports that have applied the SIC models, thus should be regarded as important as recurrent injuries.

4.6.2.2 Categorisation methods influence SIC distribution

The distribution of SIC categories between the two methods revealed most categories had similar proportions, as indicated by overlapping confidence intervals. However, recurrent injuries (SIC-2.0 category II), exacerbations (SIC-2.0 category III) and clinically distinct injuries (SIC-2.0 category VIII) did not have overlapping confidence intervals thus differed in prevalence. Clinically distinct injuries represented 66.7% (95% CI = 65.5 to 67.8) using the all injuries method and 58.9% (95% CI = 55.9 to 61.8) using the preceding injuries method. Recurrent injuries represented 6.3% (95% CI = 5.0 to 7.9) of subsequent injuries using the preceding injuries method, double that of the all injuries method which represented 3.1% (95% CI = 2.7 to 3.6). Finally, exacerbations represented 12.6% (95% CI = 10.7 to 14.7) of the distribution using the preceding injuries method, which increased three-fold compared to the all injuries method (3.8%, 95% CI = 3.4 to 4.3). These findings show that the choice between a broad or narrow definition of subsequent injury is important as outcomes between the two methods differ.

Subsequent injuries that are temporally or sequentially closer to the previous injury may be more likely to be a recurrent injury. This idea has not been directly addressed in the literature but may be recognised through previous work looking into recurrent injury. This is evident for recurrent muscle injuries, for which a *non-recent* (i.e. longer than eight weeks prior) history of the same injury is a strong risk factor for a future muscle injury (Orchard, Chaker Jomaa et al. 2020). This risk factor is only superseded by that of a *recent* (i.e. within the previous eight weeks) history of the same injury (Orchard, Chaker Jomaa et al. 2020). For example, the odds of sustaining a recurrent quadriceps muscle strain is 5-times higher in the presence of a recent quadriceps strain compared to a non-recent quadriceps strain (Orchard, Chaker Jomaa et al. 2020). Similar findings have been observed for recurrent hamstring injuries, whereby half of all hamstring injuries occur within 4-weeks of RTP from a previous hamstring injury (Wangensteen, Tol et al. 2016). Stretching this timeline out to 100-days after RTP and 70% of all hamstring reinjuries have been sustained (Wangensteen, Tol et al. 2016). This is true for calf strains too; roughly 70% of which occur within 100-days of the index calf injury (Green, Lin et al. 2020). Therefore, the increased proportion of recurrent injuries using the narrow categorisation method may be due to a heightened risk of recurrent injury upon RTP. The notion that sequential injuries are more similar than non-sequential injuries is logically plausible and encourages more research to examine the potential relationships between these injuries.

The differences reported between categorisation methods may also be a function of the coding procedure, which relies on the OSICS diagnostic codes to categorise subsequent injury. For an injury to receive the SIC-2.0 category II (i.e. recurrent injury), it must have an almost identical OSICS code, matching the first three OSICS characters with the previous injury. However, for an injury to receive the SIC-2.0 category VIII (i.e. clinically distinct), it must have zero matching OSICS characters with the previous injury. For example, there are 1,368 musculoskeletal codes in the OSICS-10.1 spreadsheet (Orchard, Rae et al. 2010). One-hundred and fifteen of these codes are knee injuries. Therefore, if an athlete was to sustain a knee injury of any nature, there are still 1,253 diagnostic codes that would yield a SIC-2.0 category VIII. However, amongst all knee injuries, there are between one and six possible diagnostic codes that a subsequent injury must be assigned to be considered recurrent. Therefore, there is an unequal likelihood for each SIC-2.0 category to arise. Comparing subsequent injuries to all previous injuries (i.e. broad subsequent injury definition) only compounds this problem, given the natural probability of SIC-2.0 category VIII is greater for each subsequent injury. Therefore, by comparing subsequent injuries to a higher number of previous injuries further increases the likelihood of SIC-2.0 category VIII representing an overwhelming majority of SIC-2.0 codes. The impact of this phenomenon on subsequent injury coding remains unknown, however, statistical weighting of the categories should be considered for future validation.

4.6.3 Consistent associations suggests a strong non-temporal relationship

Findings observed across both methods of categorisation provide empirical evidence for an association between injuries sustained by a single player. Our analyses of these associations are defined using two key factors: (1) the index or previous injury nature and (2) the subsequent injury type (SIC-2.0 category). Finding significance between these factors provides a basis for future research to investigate whether a particular injury nature is at a greater risk of being followed by a specific subsequent injury type for the immediate subsequent injury (preceding injuries method) or for any future subsequent injury (all injuries method). As discussed above, findings found to be associated for both methods suggest that a non-temporal relationship may exist — linking injuries that are potentially a full-season away, or as close as the following injury.

4.6.3.1 Muscle injuries at different sites are associated

The results suggest an association between muscle injuries on a contralateral limb; athletes were at an increased risk of a muscle injury on the contralateral side (SIC-2.0 category V) following an index or preceding muscle injury. The mechanisms of this relationship are unknown at present, although contralateral injuries of the same site and nature to the previous (SIC-2.0 category V) have been statistically associated in the past. Fulton, Wright et al. (2014) found that a previous Achilles tendon rupture is a risk factor for a subsequent contralateral

Achilles tendon injury. This study provides rationale for the investigation of analogous muscle injury on the contralateral side. This may provide more opportunity for targeted injury prevention of the most prevalent injury nature – muscle injury.

Another consistent finding between the two categorisation methods was an increased risk of sustaining an injury of the same nature but at a different anatomical site (SIC-2.0 category VII) following muscle injury. This is the same association observed in the previous study of AF players (**Chapter 3.5**). A common clinical presentation is observed between calf and hamstring strains; a recent meta-analysis of five studies found previous calf strain injury increased the risk of subsequent hamstring injury by 50% compared to those without a history of calf strain (Green, Bourne et al. 2020). Green, Bourne et al. (2020) hypothesised that the period of reduced exposure during rehabilitation had a role in reducing the capacity of the hamstring muscles to tolerate high-speed running. This mechanism is not sport-specific, as periods of reduced exposure during rehabilitation is common after many muscle injuries — which will ultimately reduce exposure and potentially predispose an athlete to a subsequent muscle injury. Therefore, studies investigating the rehabilitation of muscular injuries should carefully consider the potential deficit in injury tolerance at different anatomical locations that may be a result of the altered training loads prior to RTP.

4.6.3.2 Previous or index joint injury had a low risk of subsequent contralateral injury

Joint injuries were at a lower risk of occurring than other injury natures on the contralateral side (SIC-2.0 category V). The significant association between contralateral muscle injuries (**Chapter 4.5.6.1**) may have influenced this, which was far more likely to be followed by SIC-2.0 category V than joint injuries were. This may have caused all other relative risks to be low for SIC-2.0 category V. However, some joint injuries are known to be linked with similar joint injuries on the contralateral side (SIC-2.0 category V), such as ACL ruptures, which are at higher risk of reinjury on the contralateral side than they are of occurring for the first time (Swärd, Kostogiannis et al. 2010). Further, a meta-analysis found the pooled contralateral ACL injury rate (7 studies) to be higher than that of the pooled ipsilateral ACL reinjury rate (14 studies), although with high heterogeneity for both analyses (Wiggins, Grandhi et al. 2016). Our findings do not refute this relationship, but suggest a lower relative risk compared to contralateral injury following other injury natures. It is also possible that the severity of joint injuries may influence the short-term risk of sustaining a subsequent injury. An extended period spent injured results in less time exposed to injury because the injured athlete cannot participate in training or competition – thereby decreasing the relative risk of sustaining another injury for the remainder of the season. The reasons for which a previous and index joint injury had a low relative risk for subsequent contralateral (SIC-2.0 category V) injury remain elusive, however are likely complex and multifactorial.

4.6.4 Inconsistent associations represent a potential limitation or a short-term relationship

Inconsistent findings between the two methods may provide insight specific to the broad or narrow definitions of subsequent injury. This is because the findings inferred from only the preceding injuries method are only true for injuries that are chronologically adjacent, or sequential. In contrast, findings inferred from only the all injuries method are suggestive of a broader association, linking not only adjacent injuries but also those distant in sequence. This is because the exposure variable is *index* injury nature, therefore, a significant association is indicative of a relationship that may exist between the index and second injury, or even index and thirty-seventh injury. For the forthcoming paragraph, these considerations are important in determining what implications a result may have.

A total of 11 significant findings were inconsistent between categorisation methods. Two of these findings had a relative risk equal to 0 because they had no exposed cases, likely due to low injury case number within these contingency tables. Eight inconsistent findings were observed using a narrow subsequent injury definition (i.e. preceding injuries method), which had a low number of injuries. One of the inconsistent findings was observed for the broad subsequent injury definition. Due to the small number of injuries in some cells, the inconsistent findings reported cannot be affirmed with confidence, given we are unaware whether an actual association exists, or the associations observed are a function of our analysis. Nonetheless, some inconsistent findings may warrant further investigation, which would likely benefit from having a greater number of seasons to increase the statistical power of these analyses.

Amongst the findings that were inconsistent between the two methods, one was observed only for the all injuries method. Players who sustained an index injury denoted the pain/unspecified injury nature were associated with a subsequent injury at the same anatomical site, but of different nature. For example, an athlete presenting with knee pain at the start of the season who goes on to sustain a meniscal tear in the knee. This may be reflective of the evolving diagnostic process for injuries that originally present as diffuse pain. It is possible that original consultations aiming to address an area of pain cannot be accurately diagnosed due to a diffuse onset, however, the specific nature of this pain becomes apparent in future consultations. Once recognised, the SIC-2.0 code would account for this ‘new’ injury by recognising the site is the same while the nature is no longer unspecified, thus yielding the SIC-2.0 category VI. The role of undiagnosed/unspecified injuries on subsequent injury risk have not been investigated in previous literature. Therefore, this finding may warrant further investigation, with a greater sample size for more confident conclusions of their implications.

Many findings were observed for only the preceding injuries method; representing associations due to their sequence, as stated earlier. One finding suggests a 50% increase in the risk of sustaining an injury of the same nature but at a different site (SIC-2.0 category VII) immediately after a joint injury. This association between joint injuries at different locations is not explored in the literature, however, might suggest potential relationships between two sequential, but completely different joints. Further investigation is required to make any clinical implications of this finding.

We found preceding bone injury was at 145% higher risk of being immediately followed by an injury in the same site but of a different nature (SIC-2.0 category VI) (e.g. femoral fracture immediately followed by quadriceps injury). This is another relationship that is yet to receive attention in the literature, but may be logically plausible. As a hypothetical clinical example, this may mean that sustaining a femoral fracture predisposes the athlete to a non-bone injury at the thigh for the next injury they sustain (e.g. quadriceps injury). Further research is required to support or refute both these findings, however, they highlight the strengths of SIC-2.0 in establishing potential injury relationships for further investigation.

4.6.5 Non-time-loss injuries are an important consideration for injury surveillance

A secondary aim of this study was to account for non-time-loss injuries, which was a limitation of Study 1 (**Chapter 3**). In doing so, injuries that were not severe enough to cause time-loss were recorded and included in subsequent injury analyses. A primary benefit of this is the ability to accurately reflect an athlete's injury profile; an important consideration given 44% of all injuries in this study did not result in time-loss. Previous work has established that the prevalence of Achilles and patellar tendinopathy is nearly 10-times greater when including non-time-loss injuries rather than just match-loss injuries (Docking, Rio et al. 2018).

Additionally, due to the inclusion of non-time-loss injuries, this was the first study to report the prevalence of exacerbations (SIC-2.0 category III). Exacerbations were more common than recurrent injuries, accounting for 3.8% of subsequent injuries. These injuries represented a greater problem using a narrow definition (i.e. preceding injuries method), representing 12.6% of subsequent injury codes. Reporting subsequent exacerbations using the SIC-2.0 model allows investigators to recognise whether these injuries are a problem and what factors influence athletes returning to sport. Future work should aim to distinguish between TL and non-time-loss injuries in subsequent injury analyses to determine the impact that one might have on the other, and whether any directional relationships exist between this injury dichotomy.

4.6.6 Strengths and limitations

Accounting for non-time-loss injuries addressed previous limitations that inhibited our ability to recognise the large proportion of the injuries not causing time-loss, providing more data for the analysis of subsequent injuries and their relationships with the prior.

Extending beyond a single season is important as athletes' are likely to sustain multiple injuries over multiple seasons, and subsequent injuries may be related across seasons (Finch and Cook 2014, Finch, Cook et al. 2015). This analysis included two years of injury data that were collected prospectively by the same data entrants. Accounting for the injury relationships that may extend across multiple seasons is important to inform future research and injury prevention programs.

The novelty of this study is recognised in the new categorisation methods, which has not been explored in prior literature. Stares, Dawson et al. (2019) recently found that a players' risk of subsequent injury is greatest in the week of RTP, therefore, we wanted to establish whether the subsequent injury distribution is altered in the short-term as compared to the typical all previous injuries method. The new method considering subsequent injury distribution relative only to the immediately preceding injury adds to the constantly evolving ways in which SIC-2.0 may be used. Determining how chronologically adjacent injuries relate to one-another is an important aspect of secondary injury prevention. Future work must endeavour to explore more ways in which to apply the model to sports injury datasets to inform research for the prevention of subsequent injury.

We did not account for any exposure measures, such as individual match and training participation or running workloads. Quantifying athlete participation is an important consideration for longitudinal injury analysis because it affects an athlete's risk of injury (Finch 1997). Particular caution must be taken when interpreting the links between injury nature and subsequent injury types, for which exposure – and other modifiable and nonmodifiable factors – are expected to have some confounding effects.

An inherent limitation of all subsequent injury research remains an inability to obtain injuries prior to the surveillance period. Just as injuries across the 2-year surveillance period are potentially related, injuries from the prior seasons may impact an individual's injury risk. This is to say that the index injury is only an index injury within the surveillance obtained, but was in fact preceded by many injuries and is likely influenced by the injury profile preceding the injury surveillance period. Accounting for multiple-season injury data should be a priority for this reason, as future work may find ways in which to mitigate the confounding effects this may have on subsequent injury analyses. Without multiple seasons of data, the potential confounders cannot be determined. However, it remains important to perform isolated analyses of each season included, and to compare the observations between these seasons. Doing so ensures that potential variations between seasonal factors are accounted for, such as cohort injury rates, match density and external pressures.

4.7 Conclusion

Subsequent injury distributions and inter-injury associations varied between the narrow and broad definition of subsequent injury in a 2-year analysis of rugby players. Some injuries were found to be consistently associated regardless of the order in which they were sustained. In particular, previous or index muscle injuries, which were associated with subsequent muscle injuries whether they were on the contralateral side or at a different anatomical site. It is likely that the relationships between injuries may be somewhat dependent upon the sequence within which they occur. However, this excludes strongly correlated injuries such as muscle injuries, which may increase the risk of sustaining subsequent muscle injuries at all times throughout the season. The relationship between muscle injuries at different locations must be greater understood in order to inform injury prevention strategies. Further, a better understanding of the role that previous injury nature or the sequence of injury plays in subsequent injury risk may assist clinicians in understanding *what* injury is likely to occur and *when* it is likely to occur. This targeted approach exemplifies the aims of subsequent injury analyses, which are primarily to reveal previously unthought relationships that may be mechanistic in subsequent injury aetiology.

Chapter 5

General Discussion

The aim of this thesis was to explore methods of subsequent injury analysis to improve longitudinal injury surveillance in professional men's AF and Australian rugby union. Through a series of studies establishing the methods, patterns, and relationships between subsequent injuries, the research in this thesis provides empirical evidence that demonstrates how subsequent injury definitions and methodology impact the epidemiological findings. The continued exploration of new and modified methods of injury analysis is recommended to further understand these relationships between injuries sustained by a single athlete (i.e. inter-injury relationships). Inter-injury relationships may then be used to encourage future research and inform effective tertiary injury prevention strategies.

5.1 The prevalence of subsequent injury in elite sport.

5.1.1 Subsequent injuries are common

Subsequent injuries are common in professional football and rugby players, representing a substantial problem for sports injury prevention. **Chapters 3** and **4** found that 37% and 89% of all players sustained subsequent injuries throughout their respective surveillance periods, supporting previous findings that more players sustain subsequent injuries than those who sustain either one or zero injuries (Finch, Cook et al. 2017, Toohey, Drew et al. 2018, Toohey, Drew et al. 2019). To address the problem that subsequent injuries represent to team and individual performance (Eirale, Tol et al. 2013, Hagglund, Walden et al. 2013), player availability (Williams, Trewartha et al. 2013), and as a financial burden (Brooks, Fuller et al. 2006), the trends between inter-injury relationships must be investigated.

In the context of sports injury research, subsequent injury models are relatively young. Despite van Mechelen, Hlobil et al. (1992) proposing a sports injury prevention model as early as 1992, it was not until 2011 that non-recurrent subsequent injuries received explicit categorisation (Hamilton, Meeuwisse et al. 2011). However, this model was limited by a lack of clinical relevance and statistical robustness (Finch and Cook 2014). Finch and Cook (2014) introduced the SIC model in 2014 to provide a model suitable for clinical and research applications. The original SIC model was soon updated by Toohey, Drew et al. (2018) to remove the need for clinical adjudication during category allocation. This removed the need for subjective interpretation and reduced the influence of rater biases that may affect reliability and validity. Clearly, subsequent injury analysis is relatively new to sports injury epidemiology and may be improved with further applications. For example, there remains little recognition of how methodological factors may implicate the findings extracted from SIC application – despite the importance of these decisions for subsequent injury research (Finch and Marshall

2016). The literature requires further application of SIC-2.0 to explore the methods of categorisation and reporting that are most suitable for various research aims.

5.1.2 Most subsequent injuries are different to the previous or index injury

In both **Chapters 3** and **4**, where the SIC-2.0 model was applied to an elite sports injury dataset, clinically distinct injuries (SIC-2.0 category VIII) accounted for an overwhelming majority of the subsequent injuries sustained. **Chapter 4** provides novel insight using a new method of categorisation, which finds that clinically distinct injuries remain an overwhelming problem when limiting comparisons only to the immediately preceding injury. Despite the overwhelming evidence that clinically distinct injuries represent a significant burden (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Moore, Mount et al. 2018, Toohey, Drew et al. 2018, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019, Toohey, Drew et al. 2019), recurrent injuries remain of high interest within the literature and within individual sporting teams (Matheson, Shultz et al. 2011). Clearly, there is a need to re-focus sports injury research and prevention, with recurrent injuries representing between 3.1% and 12.4% of subsequent injuries in rugby union and Australian football – only a fraction of the problem. Therefore, subsequent injuries remain mostly unreported unless they are identical to the previous, highlighting our lack of understanding of the risk or causal factors preceding clinically distinct subsequent injuries (i.e. SIC-2.0 category VIII).

To date, the SIC models have been applied in rugby sevens (Toohey, Drew et al. 2018, Toohey, Drew et al. 2019), rugby union (Moore, Mount et al. 2018), AF (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Stares, Dawson et al. 2019), cricket (Moore, Mount et al. 2018), water polo (Toohey, Drew et al. 2019), and sprint kayak (Toohey, Drew et al. 2019). All of these studies reported clinically distinct injuries as the most common subsequent injury type. It is clear that subsequent injuries different to previous injuries represent a challenge for sports injury prevention. **Chapter 4** established this subsequent injury type is also highly prevalent relative to the immediately preceding injury, therefore, determining if these injuries are truly random or occur with a predictable pattern is critical for future research. Risk-factor analysis accounting for the multifactorial nature of these injuries is required to elucidate the aetiology of these injuries. It remains plausible that most of these clinically distinct injuries are in fact random, however, until statistical analyses are performed that account for the large degree of confounding factors associated with injury risk, no conclusions can be made. It is not until the final step of establishing causality that clinically distinct subsequent injuries (SIC-2.0 category VIII) can be prevented.

5.2 Understanding the risk-factors for subsequent injury

The potential risk factors for subsequent injury are discussed in **Chapter 2.4.3.5**. However, the previous literature remains scarce of risk factors that are linked to subsequent injury, whether that be specific subsequent injury types (i.e. SIC-2.0 categories) or simply the occurrence of any subsequent injury (irrespective of type/SIC-2.0 category). At present, these risk-factors include previous injury history (Fulton, Wright et al. 2014), session availability (Ruddy, Pietsch et al. 2019), acute:chronic workload ratios (Blanch and Gabbett 2016) and running workloads (Stares, Dawson et al. 2017, Stares, Dawson et al. 2018). Understanding the risk factors of subsequent injury permits more complex analyses of the mechanisms responsible for such events, in hope that they may ultimately be prevented.

5.2.1 Injury nature alters subsequent injury risk profile

This thesis found that an index or previous injury's nature is associated with the risk of some subsequent injury types. This concept has been indirectly explored in prior work, typically being examined in multi-pathology studies, which explore the relationships between multiple pre-defined injuries of choice. A meta-analysis and systemic review found that index hamstring, quadriceps, adductor, and calf injuries are associated with muscle injuries at different locations (Toohey, Drew et al. 2017). This review, as it pertains to the findings of our thesis, has been discussed in previous chapters. This discussion focuses on the methodological approach of these studies and its potential to inform tertiary injury prevention.

5.2.1.1 Muscle injuries at different locations are linked

Muscle injuries increase the risk of a subsequent muscle injury at a different location in elite team ball sports. This finding was consistent in both AF (**Chapter 3**) and rugby union (**Chapter 4**), and is supported by previous work in soccer and AF (Orchard 2001, Hägglund, Waldén et al. 2012). **Chapter 4** adds to this body of evidence, where an association was observed in rugby union over two consecutive playing seasons. Supporting our findings in rugby union, a recent systemic review and meta-analysis of five studies found previous calf strain injury increased the risk of a subsequent hamstring strain injury (Green, Bourne et al. 2020). Furthermore, a similar systemic review found previous adductor, hamstring and quadriceps injuries increased the risk of future calf strain injury (Green and Pizzari 2017). However, our findings are the first to include an element of injury sequence in these analyses and suggest that an inter-injury relationship exists in multiple sports and irrespective of the sequence of these injuries. This thesis increases our understanding of a complex relationship, highlighting that an *index* or *previous* muscle injury increases the risk of a subsequent muscle injury at a different location (SIC-2.0 category VII) by 77% and 58%, respectively. Therefore, it may be theorised that the risk of a subsequent muscle injury at a different location remains high following any muscle injury — made clear by the associations observed between adjacent subsequent injuries (**Chapter 4**), a subsequent injury within one season (**Chapter 3**), and also a subsequent injury within two seasons (**Chapter 4**). The mechanisms remain contentious, however, are hypothesised to involve biomechanical alterations or spikes in workload upon RTP (Orchard 2001, Blanch and Gabbett 2016) — which increase the risk of sustaining any subsequent injury, not just a subsequent muscle injury (Stares, Dawson et al. 2018). There are strong relationships between muscle injuries at different locations throughout this thesis, which must be understood to inform subsequent injury prevention strategies based on a specific inter-injury relationship.

5.2.1.2 Concussion may be associated with clinically distinct injuries

Clinically distinct injuries and the potential clinical manifestations have been discussed extensively throughout the thesis. To date, no clinically distinct injury relationship (SIC-2.0 category VIII) has received more attention in previous literature than an index concussion and a different subsequent injury. There is growing evidence to suggest subsequent injury risk is increased following a concussion (Brooks, Peterson et al. 2016, McPherson, Nagai et al. 2019, Reneker, Babl et al. 2019). Primary investigations examining potential causality remains most concerned with the clinical tests that athletes are passing prior to RTP; due to assumed residual neurological deficits that are not detected following concussive events (Kamins, Bigler et al. 2017). One such deficit has been recognised in dual-task gait performance, which has been found to alter subsequent injury risk in concussed athletes (Howell, Buckley et al. 2018, Wood, Hsieh et al. 2019, Howell, Bonnette et al. 2020, Oldham, Howell et al. 2020). Dual-task gait assessment tests an ability to complete motor and cognitive tasks simultaneously — a common feature of sports participation —yet is infrequently featured in RTP protocols (Baugh, Kroshus et al. 2016). Given neuromuscular and attention deficits are known risk factors for future injury (Howell, Lynall et al. 2018), there is evidence to support dual-task gait performance as a risk-modulator for subsequent injury following concussion. The implementation of dual-task gait assessment as an RTP milestone following concussion may help prevent clinically distinct subsequent injuries following concussion.

This thesis found some evidence of a relationship between concussion and clinically distinct injuries (i.e. SIC-2.0 category VIII). A previous concussion significantly increased the relative risk of sustaining a clinically distinct injury for the immediately subsequent injury (RR = 1.23, 95% CI = 1.04-1.45). Although this finding was not observed when the *index* injury was a concussion. The most recent study found concussed athletes are 2.3 times more likely (OR = 2.299, 95% CI = 1.45-3.65) to sustain a subsequent musculoskeletal injury than non-concussed athletes (Hunzinger, Costantini et al. 2021); a finding that is becoming increasingly common in recent literature (McPherson, Nagai et al. 2019). Recent studies applying time stratification methods to subsequent injury risk assessments highlight the risk of subsequent injury is greatest in the first week of RTP and remains elevated for 12 or even 15-weeks following RTP (Stares, Dawson et al. 2019, Orchard, Chaker Jomaa et al. 2020). Future studies should examine how the risk of subsequent injury fluctuates over a period of time following a concussion. Establishing whether a temporal window of increased risk exists following concussion may implicate clinical intervention strategies.

5.2.2 Accounting for dependency within an individual to accurately quantify subsequent injury risk

An important distinction between previous findings and those of this thesis is the epidemiological approach by which injury nature was associated with subsequent injury type. Methods undertaken in this thesis were not selective of particular injury subgroups, therefore, all potential inter-injury relationships were considered important for the analysis. This is important because the nature of subsequent injuries represent competing risks, therefore, they should be analysed simultaneously rather than separately (Nielsen, Bertelsen et al. 2019). Excluding particular types of injuries is strongly discouraged by recent literature because it is known that athletes' sustain multiple and different injuries, which are inherently linked because they occur in the same person (Finch and Cook 2014, Finch, Cook et al. 2015, Brooks, Peterson et al. 2016, Cross, Kemp et al. 2016, Finch, Cook et al. 2017, Toohey, Drew et al. 2017, Moore, Mount et al. 2018, Toohey, Drew et al. 2018, Reneker, Babl et al. 2019, Stares, Dawson et al. 2019, Toohey, Drew et al. 2019, Toohey, Drew et al. 2019). When examining the inter-injury relationships within any sporting cohort, the investigator should strongly consider accounting for dependency within an individual to gain accurate understanding of the outcome they are investigating. By doing so, some inter-injury relationships have been observed in **Chapters 3** and **4** which corroborate previous findings.

A method to establish suitable statistical models was explored in **Chapter 4**, focussing on using the preceding injury method to link injuries – where the only outcome is a single subsequent injury rather than multiple. This may simplify the analysis and assist investigators in determining the best way to account for time-varying exposures since there is only one outcome. A specific recommendation to account for the dependency of injuries is to use an Aalen-Johansen estimator (Nielsen, Bertelsen et al. 2019). This statistical model is similar to the Kaplan-Meier estimator, which produces a curve describing cumulative risk against a continuous variable (e.g. the cumulative risk of sustaining a SIC-2.0 category against time), while still accounting for covariates such as exposure. However, if modelling injury nature, the impact that repeated measures may have on the findings should be considered given one athlete may sustain multiple injuries of the same nature and appear exposed multiple times. Clearly, the statistical models most appropriate to analyse inter-injury relationships require more investigation and discussion. There is little consensus on the best statistical methods to use in sports injury epidemiology (Nielsen, Bertelsen et al. 2019), thus future work should aim to explore all possible methods; discussing the advantages and disadvantages in the context of one's research aims.

5.2.3 Subsequent injury associations may depend upon their chronological sequence.

The notion that a subsequent injury's risk fluctuates over time is a relatively new concept, however, provides plausibility for inter-injury relationships having some dependence on time. Proof of concept exists in many forms, including time-to-event analyses and logistic regression, which have been used in previous work to describe how subsequent injury risk changes over time (Stares, Dawson et al. 2019, Orchard, Chaker Jomaa et al. 2020). This work differs from previous studies in that injury sequence, rather than time between injuries, is used to distinguish two methods of SIC-2.0 categorisation. Therefore, findings that are only observed using the preceding injuries method will only associate with an injury that is chronologically adjacent to the previous. Such findings are discussed throughout this thesis, where inferences are made about this potential relationship that exists only between adjacent injuries in sequence.

5.2.3.1 Subsequent injury risk may be regulated by time-varying aetiological factors

Sports injury is a time-varying outcome because an athlete may transition between 'healthy' and 'injured' states over the given surveillance period (Nielsen, Bertelsen et al. 2019). Due to this fact, it should be acknowledged that the aetiological factors contributing to subsequent injury risk may change over time and regulate fluctuations in injury risk as a season, or surveillance period, progresses (Nielsen, Bertelsen et al. 2019).

The dependence of subsequent injury risk over time has been established only recently; where a subsequent injury, regardless of the type, is shown to be most probable in the first week of RTP, yet steadily declining (but not returning to baseline) for the entirety of a 12-week follow-up (Stares, Dawson et al. 2019). In corroboration of this finding, although more inferential than directly comparable, we found that certain subsequent injury types are at an increased risk following the nature of the immediately *preceding* injury only (potentially suggesting a sequential dependence). For example, a concussion (an injury nature category) increased the risk of a clinically distinct injury (i.e. SIC-2.0 category VIII) only if the concussion was immediately prior to the subsequent injury; this increased risk was not observed if concussion was the index injury. The observation is not causal, but rather, suggestive of an increase in the risk of sustaining a clinically distinct injury only for the next injury in sequence. Therefore, plausibility exists for the notion that a previous or index injury's nature is a constituent of the time-varying exposures mediating subsequent injury risk.

A study conducted by Orchard, Chaker Jomaa et al. (2020), who examined the risk of recurrent injury (i.e. SIC-2.0 category II) following hamstring, quadriceps, calf and groin strain, attempted to identify a temporal window of increased subsequent injury risk. These findings show that the risk recurrence following each of these injuries followed a similar pattern to that observed by Stares, Dawson et al. (2019) — highest in the first week of RTP; steadily declining over the surveillance window. However, the time at which athletes' remained at an increased risk differed between the muscle groups; hamstring and quadriceps remaining at an increased risk of recurrence for 15-weeks, whilst calf strains and groin strains were at an elevated risk of recurrent injury for 18- and 19-weeks following RTP, respectively (Orchard, Chaker Jomaa et al. 2020). Therefore, the characteristics (i.e. injury site or nature) of an athlete's previous injury (or injuries) potentially influence the time at which they remain at risk of a subsequent injury.

It appears that the inter-injury relationships throughout the season may also be temporally or sequentially dependant; where a subsequent injury type (SIC-2.0 category) is more likely to occur within a temporal window, *or*, a subsequent injury type is only more likely to occur in the next chronological injury. The former of these theories is more feasible due to the findings that a temporal window of increased subsequent injury risk does in fact exist (Stares, Dawson et al. 2019, Orchard, Chaker Jomaa et al. 2020). It is possible that once the next chronological injury is sustained, the time-varying exposures contributing to subsequent injury aetiology change as a result of the new injury (Nielsen, Bertelsen et al. 2019). The role that temporality or the sequence of injuries play in inter-injury relationships has not received extensive attention and requires further investigation. This may inform rehabilitation programs and subsequent injury prevention, especially if we understood the period of increased risk of subsequent injury following RTP.

It should be acknowledged that the findings suggestive of temporal or sequential inter-injury relationships in this thesis are inconclusive due to the limitations in sample size and unaccounted variables of exposure. While it is hypothesised that these relationships may exist, it is also possible that the limitations had profound effect on the observed outcomes. However, the limited evidence in this thesis coupled with the previous literature provide a foundation for future investigation of the potential temporal or sequential dependence for particular inter-injury relationships.

5.2.3.2 Improved understanding of time-varying risks may have substantial implications for clinical intervention strategies

It is known that subsequent injury risk varies over time and specific index injuries increase the risk of a recurrence (SIC-2.0 category II) for a specific temporal window following RTP (Stares, Dawson et al. 2019, Orchard, Chaker Jomaa et al. 2020). It is possible that these temporal windows of increased susceptibility to subsequent injury may be incorporated into post-rehabilitation programs, where an athlete is managed, and individual loads are adjusted for a number of weeks following RTP. Incorporation of temporality and injury sequence for inter-injury analyses provides a new dimension for injury prevention strategies that has not yet been explored. The implications these findings could have on preventing subsequent injury by predicting *what* is most likely to happen and *when* it is most likely to happen are substantial and could be a powerful tool for clinical application.

5.3 Improving subsequent injury analysis to better understand the mechanisms responsible

Sports injury surveillance is constantly evolving to accurately represent the numerous factors involved in sports injury aetiology. In order to do so, the literature must continue to investigate the impact of various methodological decisions on the epidemiological patterns observed in sport. This thesis conducted two studies with different injury surveillance systems and durations of surveillance. Given these studies were also different sports, many direct comparisons cannot be made. However, some of the findings are likely to have differed due to the methodological variations. These are discussed below.

5.3.1 Subsequent injury research must consider accounting for non-time-loss injuries

The definition used to delineate a recordable injury event implicates the analysis, reporting and interpretation of sports injury data (Brooks and Fuller 2006). Typically, this methodological variation is mediated by the sport-specific consensus statements for the respective sport under investigation (Fuller, Ekstrand et al. 2006, Fuller, Molloy et al. 2007, Pluim, Fuller et al. 2009, Timpka, Alonso et al. 2014, Mountjoy, Junge et al. 2016, Orchard, Ranson et al. 2016, Bahr, Clarsen et al. 2020). However, regardless of these recommendations, variations in sports injury surveillance systems remain a barrier for consistency in epidemiological research. The possible reasons for these discrepancies between sports are discussed in **Chapter 2.2**, however, mostly relate to limitations in accessibility, therefore are not likely to be a limitation within elite sporting environments. This discrepancy is best exemplified comparing the data obtained for this thesis. The AFL uses a match-loss definition, requiring an athlete to have missed an entire match due to injury to be recorded as an injury in the dataset (Orchard and Seward 2002), whereas Rugby Union Australia (organisation) require an athlete to consult with a team physician or physiotherapist to be recorded as injured, which is in line with the consensus recommendations for rugby union (Fuller, Molloy et al. 2007). Both methods have advantages and disadvantages, however, the injury definition adopted should be made a choice of the investigator. This is an advantage of the injury surveillance system adopted by Australian rugby union organisations, given medical attention and match-loss are not mutually exclusive. Excluding non-time-loss injuries from injury surveillance in AF provides consistency within the literature but limits the methodological variability that may inform progression in the techniques used for capturing and reporting subsequent injuries. Doing so also substantially reduces the number of injuries captured in the dataset, therefore, may alter the SIC-2.0 distribution.

5.3.1.1 Non-time-loss injuries are common and potentially linked to severe subsequent injuries

The proportion of time-loss injuries varies within the literature, representing as few as 20.9% in rugby sevens and up to 85% in rugby league (Gissane, Hodgson et al. 2012, Toohey, Drew et al. 2019). Present literature lacks any report of non-time-loss injury prevalence in elite rugby union. Our findings from **Chapter 4** suggest that these injuries represent a substantial proportion of the total injuries sustained by elite rugby union players (43.8% of all injuries). Accounting for this proportion of injuries enables an accurate quantification of an athlete's injury profile (Snyder Valier, Kellie et al. 2020), which is particularly important for the analysis of inter-injury relationships (Finch and Marshall 2016). Recent work has also revealed that non-time-loss index injuries, just like time-loss index injuries, elevate the absolute risk of a more severe subsequent injury for the 12-weeks post-RTP (Stares, Dawson et al. 2019). Evidently, non-time-loss injuries are highly prevalent and statistically related to subsequent injuries, therefore, may provide insight into the aetiological factors that are commonly ignored.

5.3.1.2 Adopting a medical attention injury definition accurately quantifies injury exacerbations

The role of non-time-loss injuries in **Chapter 4** was not investigated in isolation, however, is theorised to have had an impact on the reported outcomes. One of the tangible impacts that non-time-loss injuries had on the reported results was the accurate representation of exacerbated subsequent injury (briefly discussed in **Chapter 4.6.5**). This subsequent injury type is often unrecognised using a match-loss injury definition, given it is typical to use return-to-competition as a proxy for recovery. Rather, the severity of the injury is falsely inflated since the injury symptoms re-emerged and the athlete remained in their 'injured' state without returning to competition. This is an important scenario to account for since many athletes are not afforded the time to completely heal. Accounting for exacerbations quantifies the impact of these accelerated rehabilitation programs, where pattern recognition in future studies may help clinicians and athletes decide on the right time to resume competition. Further, it is important for studies to report exacerbations to avoid over-representing severity metrics and provide potential feedback for the rehabilitative progression of the injured athlete (Toohey 2019). Exacerbations should be considered preventable, thus should be quantified relative to the previous injury to better understand how and why they occur.

5.3.1.3 Non-time-loss injuries have a role in subsequent injury research and prevention

Accounting for non-time-loss injuries when describing subsequent injury is essential because they impact subsequent injury risk (Stares, Dawson et al. 2019). Time-loss injuries are major events throughout the season and are likely to have a substantial impact on the risk profile of an individual athlete. By definition, non-time-loss injuries are less severe than time-loss injuries and if established to be indicative of a subsequent time-loss injury, they could provide a marker for clinical intervention before any match-time is lost. Not only would this decrease the number of subsequent injuries sustained, it would also impact the player and team performance due to increased availability (Eirale, Tol et al. 2013, Hagglund, Walden et al. 2013, Williams, Trewartha et al. 2016).

The prevalence of non-time-loss injuries in AF is rarely reported. Some single pathology studies have revealed that certain injuries are substantially underreported using a time-loss only definition, particularly when adopting a specific match-loss only definition (Docking, Rio et al. 2018). This underreporting may influence subsequent injury analyses because non-time-loss injury events have been shown to impact subsequent injury risk (Stares, Dawson et al. 2019). Future work should establish the influence of non-time-loss injury on the risk of subsequent injury. The establishment of a statistical relationship may lead to renewed prevention aimed at reducing the likelihood of severe injuries throughout the season.

5.3.2 Study duration implicates subsequent injury outcomes

An important consideration to better understand inter-injury relationships is surveillance duration (Finch, Cook et al. 2015). Restricting the surveillance period to one playing season (or year) underestimates subsequent injury risk (Hamilton, Meeuwisse et al. 2011). Further, of the few studies that have extended follow-up over multiple consecutive seasons, most have analysed each season independently (Fortington, van der Worp et al. 2017). This is especially important for AF, which currently has the highest use of the SIC models (Finch and Cook 2014, Finch, Cook et al. 2015, Finch, Cook et al. 2017, Stares, Dawson et al. 2019). Only one of these studies has extended beyond a single season (Stares, Dawson et al. 2019), but this study was limited to one AFL club (Stares, Dawson et al. 2019). Other sports, including rugby union (**Chapter 4**) show that the burden of subsequent injury over multiple seasons is elevated, thus there is a need for future work to incorporate more than one season of injury data.

Our inability to account for an athlete's entire injury history (i.e. injuries prior to the surveillance period) has implications on the subsequent injury relationships extrapolated (Orchard, Ranson et al. 2016). Analysing multiple season injury data may lead to a greater understanding of how injuries relate across seasons, and potentially provide the best estimate of the impact that injury history may have on injury risk during surveillance. At the time of writing, there are too few studies that encourage accounting for injury history or beginning discussions for future literature to consider. However, surveillance period clearly has some impact on subsequent injury analyses because it increases the athlete's exposure to injury, which is statistically linked to subsequent injuries (Finch and Cook 2014, Ullah, Gabbett et al. 2014, Finch and Marshall 2016). Future work should establish what impact this methodological decision has on SIC-2.0 outputs, subsequent injury risk, and the relationships that are observed as a result.

5.4 Thesis strengths

The strengths of this thesis are discussed in detail below. These include study design, data collection and surveillance period, multiple sporting populations and novel insights relating to each of the studies conducted.

5.4.1 Injury surveillance and data collection

The use of strong injury surveillance systems for the collection of injury data in **Chapters 3** and **4** were strengths of the thesis. AF and rugby union organisations maintain an ongoing injury surveillance system that records all injurious events defined by the respective injury definitions. These events are prospectively collected by club physiotherapists and physicians involved in the typical care and treatment of each athlete, creating a clinically adjudicated injury record consisting of robust data collection. On top of the typical in-season injury records provided for most sports' epidemiology studies, **Chapter 3** included pre-season injury data, while **Chapter 4** included all pre-season and off-season injury throughout the respective surveillance period for an accurate reflection of injury occurrence. The analysis of two separate injury surveillance systems also allowed for comparisons between the methodology adopted by each system, an infrequent comparison within the literature.

Chapter 4 included multiple seasons of injury data, which provides a thorough reflection of the inter-injury relationships that exist across consecutive seasons. Accounting for multiple seasons remains a limitation of many sports epidemiology studies (Fortington, van der Worp et al. 2017), which limits individual injury history and the longitudinal patterns that exist between subsequent injuries. Using multiple consecutive seasons of injury data provides insight into the subsequent injury patterns that may extend beyond a single season.

5.4.2 Multiple sporting populations

Conducting multiple studies of similar design across two different sporting populations adds novel insights into the sport-specific subsequent injury patterns. **Chapter 3** adds to the literature further application of SIC-2.0 in AF, largely concurring with previous findings. **Chapter 4** provides the first application of SIC-2.0 to a rugby union population, providing a means for comparison with **Chapter 3** and the other sporting populations examined. Examining multiple populations also allowed an investigation comparing the subsequent injury distributions of each sport, which were found to be very similar. The continued application of SIC-2.0 to various sports with different risk-factors provides valuable external use and exposure of the relatively novel categorisation model. This thesis adds another sporting population to the SIC-2.0 literature.

5.5 Thesis limitations

This thesis was limited by several factors that were considered and are documented below. Limitations specific to a chapter were discussed within the respective chapter.

5.5.1 Limitations of the injury surveillance systems

An inherent limitation in all sports' epidemiology research is the inability to account for an athlete's entire injury history. Since subsequent injuries are related to previous injuries, it is likely that the individual's injury history impacts their risk of injury throughout the season, and that all players enter the surveillance period with varied risks and exposure to injury. Establishment of how best to account for an athlete's injury history remains a challenge, with self-reported data collection remaining the only suggestion to date (Toohey 2019). These methods are of limited use in sports injury epidemiology, given the provided information is subject to recall bias and becomes increasingly complex with greater levels of diagnostic details (Gabbe, Finch et al. 2003, Toohey 2019). It might be useful to examine whether only the most recent injury prior to the surveillance period has an impact on an athlete's risk of injury during surveillance. This may provide some measure of individual risk that could be accounted for whilst still maintaining robust data with limited recall bias. Continued research is required within the sports injury literature to examine how individual injury history can be properly accounted for.

Sports injury surveillance systems may be negatively impacted by having multiple people with differing health professions and clubs, each with their own subjectivity. This subjectivity may limit the consistency across the dataset, particularly when a non-time-loss injury definition is used (as in **Chapter 4**). Various influences on the data collected, such as the date of injury and recovery, or the level of detail provided in diagnostic coding, may differ due to the various perspectives and experience throughout their careers. Further, the level of clinical training received by the data entrant may influence the accuracy of diagnostic codes where a non-clinical professional is recruited for this task. There are multiple potential influences on the data collected where different individuals are responsible for data entry. To account for this, sports organisations such as Rugby Australia and the AFL should incorporate routine training and recommendations to promote consistency between clubs. However, this remains a limitation in many sporting organisations and should be considered by many to improve injury surveillance systems.

Another important limitation in the surveillance system used for **Chapter 3** was the injury definition, which recorded only injuries resulting in match-loss. It is recognised that recording only the severe injuries limits comprehensiveness of each athlete's injury profile, potentially ignoring important risk-factors exposing athletes to injury. This is particularly important when establishing subsequent injury patterns, which assess the relatedness between injuries, therefore, require high sensitivity to accurately represent the aetiological factors contributing the subsequent injury. This is likely to have limited the clinical accuracy of outputs recorded in **Chapter 3**.

Injury surveillance systems that adopt the non-time-loss injury definition (as in **Chapter 4**) may be limited by the underreporting of injuries by athletes. Unlike the match-loss definition, a medical attention definition relies on athlete self-report or comprehensive medical examinations to recognise an injury. Therefore, there is likely to be a number of injuries that contained inaccurate severity metrics or were not recorded at all. Athletes may avoid reporting an injury or consulting with the medical practitioner because they are in fear of losing game-time (Long, Ambegaonkar et al. 2011, Toohey 2019). They may also avoid reporting injury because they believe they are adequately equipped to manage the injury themselves (Toohey 2019). This is particularly important to consider with recurrent or exacerbation injuries, which the athlete has already received a treatment plan for and may not feel it is necessary to hold a consultation again (Toohey 2019). These factors may impact the findings reported and are inherent parts of sports injury epidemiology. It is hoped that future research may reveal how best to account for this and improve athlete injury reporting.

5.5.2 Lack of exposure data

An important limitation of this thesis was the lack of exposure data available for the participating cohorts. It is important to account for variables such as exposure and workload because such factors may play a role in mediating subsequent injury risk. The greater period of time an athlete is competing in training or match-play, the more time they spend in an environment where they are at risk of injury. Sufficiently accounting for this fact requires a high degree of compliance to provide individual data that describes the time spent training or competing and an analysis that takes into account this data. Previous work has established that athlete exposure (minutes of sporting participation) and workload (total distance run and high-speed running distance) decreased between successive injuries (Toohey, Drew et al. 2019). Therefore, it is plausible that athletes become less tolerable of the workload and exposure parameters they typically encounter with each cumulative injury sustained. It is likely that a number of the associations observed are confounded by the amount of exposure and the workload that each athlete accumulated before sustaining the subsequent injury. The statistical analyses should therefore be interpreted with caution.

It should be noted that measuring exposure remains contentious within the literature due to the wide range of measures available. For exposure data to provide meaningful insight it must be relating to each individual or the specific injury of interest, which is often unattainable due to accessibility issues. Given this thesis focussed on a wide variety of injuries, specific exposure measures relating to particular injuries (e.g. total jump count for patellar tendon injury) would have provided no benefit for the research aims. Individual exposure data would have provided accountability of individual injury risk throughout the season, however, was not feasible within the time-constrains of this thesis. Finally, assuming athletes are subject to the same exposure each week effectively negates the rationale for including generalised exposure measures because this is not a valid assumption. For this reason, avoiding unnecessary complication to this aspect of the research may have afforded more time to conduct complex analyses in other areas.

5.5.3 Limited sample for categorical injury characteristics

Categorical subdivision of the injuries into groups defined by their nature limited some analyses in sample size. In cases where sample size is low and likely to have impacted the statistical findings reported, there was little discussion of the potential implications. This is because we could not confidently endorse the findings which were likely to be substantially limited. For analyses of a similar nature to take place, it is necessary to have a very large sample to ensure robust statistical analyses. This highlights a major challenge within sports' injury epidemiology, where even large sample studies (such as those within this thesis) cannot ensure all subgroups maintain statistical power.

5.5.4 Limitations of the statistical analyses

The relative risk was used as the primary statistical method used to establish associations between injury nature and subsequent injury type. Many of the confidence intervals were quite wide, even when findings were considered significant ($p < 0.05$). This is likely representative of low sample sizes, given sub-groups of injury nature with high sample sizes often presented a narrow confidence interval. In all findings, whether significant or not, the confidence intervals should be considered alongside the p-value and relative risk when interpreting the potential effect size of the result.

Another limitation of this statistical test is the difficulty of accounting for potentially confounding covariates (Simon 2001). It is important to understand the effect of covariates because the increase in risk of sustaining a particular subsequent injury type may be, at least partially, due to subjective demographical variables associated with the exposed groups. For example, it is possible that the cumulative number of injuries sustained or the exposure of the athletes who sustained index muscle injuries was different to those who were in the index joint injuries group. This would confound the findings, especially given the risk of subsequent injury types are calculated relative to the risk of other injury nature groups sustaining the same subsequent injury type. This ratio needs to account for covariates that differ between groups because the index injury nature is likely to be one of many variables that impacts the risk of sustaining a subsequent injury type. It is advised to readers to interpret all relative risk findings with caution, taking into account the confidence interval and potential impact that covariates had on these analyses.

5.6 Conclusion

Injury definitions and reporting methods were evaluated to present new findings on subsequent injury patterns in elite male athletes. In both Australian football and rugby union, most subsequent injuries were clinically distinct from the previous injuries, irrespective of their chronological sequence. The nature of previous injuries was associated with several subsequent injury types and should be investigated for its potential to inform targeted injury prevention strategies. The sequence in which injuries are sustained alters subsequent injury patterns and relationships, therefore, may further increase the specificity of injury prevention strategies. The cumulative findings from this thesis provide rationale for the continued research of subsequent injury in sport. Clearly, sports injury prevention must extend beyond simple recurrences because they represent only a small portion of the problem. Future investigation of subsequent injuries needs to include exposure to reveal the inter-injury relationships that contribute to subsequent injury aetiology. The substantial impact of subsequent injuries may be mitigated through the development and implementation of tertiary injury prevention programs based on an individual's injury profile.

Chapter 6

Appendices

Appendix A. List of consensus statments

International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sport 2020 (including STROBE Extension for Sport Injury and Illness Surveillance (STROBE-SIIS)).

Sport: all

Bahr, R., B. Clarsen, W. Derman, J. Dvorak, C. A. Emery, C. F. Finch, M. Hägglund, A. Junge, S. Kemp, K. M. Khan, S. W. Marshall, W. Meeuwisse, M. Mountjoy, J. W. Orchard, B. Pluim, K. L. Quarrie, B. Reider, M. Schwellnus, T. Soligard, K. A. Stokes, T. Timpka, E. Verhagen, A. Bindra, R. Budgett, L. Engebretsen, U. Erdener and K. Chamari (2020). "International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sport 2020 (including STROBE Extension for Sport Injury and Illness Surveillance (STROBE-SIIS))." Br J Sports Med 54(7): 372-389.

Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries.

Sport: soccer

Fuller, C. W., J. Ekstrand, A. Junge, T. E. Andersen, R. Bahr, J. Dvorak, M. Hägglund, P. McCrory and W. H. Meeuwisse (2006). "Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries." British Journal of Sports Medicine 40(3): 193.

Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union.

Sport: rugby union

Fuller, C. W., M. G. Molloy, C. Bagate, R. Bahr, J. H. M. Brooks, H. Donson, S. P. T. Kemp, P. McCrory, A. S. McIntosh, W. H. Meeuwisse, K. L. Quarrie, M. Raftery and P. Wiley (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.

Consensus statement on the methodology of injury and illness surveillance in FINA (aquatic sports).

Sport: aquatic sports

Mountjoy, M., A. Junge, J. M. Alonso, B. Clarsen, B. M. Pluim, I. Shrier, C. van den Hoogenband, S. Marks, D. Gerrard, P. Heyns, K. Kaneoka, H. P. Dijkstra and K. M. Khan (2016). "Consensus statement on the methodology of injury and illness surveillance in FINA (aquatic sports)." British Journal of Sports Medicine 50(10): 590.

International consensus statement: methods for recording and reporting of epidemiological data on injuries and illnesses in golf.

Sport: golf

Murray, A., A. Junge, P. G. Robinson, M. Bizzini, A. Bossert, B. Clarsen, D. Coughlan, C. Cunningham, T. Drobny, F. Gazzano, L. Gill, R. Hawkes, T. Hospel, R. Neal, J. Lavelle, A. Scanlon, P. Schamash, B. Thomas, M. Voight, M. Wotherspoon and J. Dvorak (2020). "International consensus statement: methods for recording and reporting of epidemiological data on injuries and illnesses in golf." Br J Sports Med 54(19): 1136-1141.

Methods for injury surveillance in international cricket.

Sport: cricket

Orchard, J. W., D. Newman, R. Stretch, W. Frost, A. Mansingh and A. Leipus (2005). "Methods for injury surveillance in international cricket." British Journal of Sports Medicine 39(4): e22.

International consensus statement on injury surveillance in cricket: a 2016 update.

Sport: cricket

Orchard, J. W., C. Ranson, B. Olivier, M. Dhillon, J. Gray, B. Langley, A. Mansingh, I. S. Moore, I. Murphy, J. Patricios, T. Alwar, C. J. Clark, B. Harrop, H. I. Khan, A. Kountouris, M. Macphail, S. Mount, A. Mupotaringa, D. Newman, K. O'Reilly, N. Peirce, S. Saleem, D. Shackel, R. Stretch and C. F. Finch (2016). "International consensus statement on injury surveillance in cricket: a 2016 update." Br J Sports Med 50(20): 1245-1251.

Consensus statement on epidemiological studies of medical conditions in tennis, April 2009.

Sport: tennis

Pluim, B. M., C. W. Fuller, M. E. Batt, L. Chase, B. Hainline, S. Miller, B. Montalvan, P. Renstrom, K. A. Stroia, K. Weber and T. O. Wood (2009). "Consensus statement on epidemiological studies of medical conditions in tennis, April 2009." Clin J Sport Med 19(6): 445-450.

Injury and illness definitions and data collection procedures for use in epidemiological studies in Athletics (track and field): consensus statement.

Sport: athletics

Timpka, T., J. M. Alonso, J. Jacobsson, A. Junge, P. Branco, B. Clarsen, J. Kowalski, M. Mountjoy, S. Nilsson, B. Pluim, P. Renstrom, O. Ronsen, K. Steffen and P. Edouard (2014). "Injury and illness definitions and data collection procedures for use in epidemiological studies in Athletics (track and field): consensus statement." Br J Sports Med 48(7): 483-490.

Tennis-specific extension of the International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sport 2020.

Sport: tennis

Verhagen, E., B. Clarsen, J. Capel-Davies, C. Collins, W. Derman, D. de Winter, N. Dunn, T. S. Ellenbecker, R. Forde, B. Hainline, J. Larkin, M. Reid, P. A. Renstrom, K. Stroia, S. Wolstenholme and B. M. Pluim (2021). "Tennis-specific extension of the International Olympic Committee consensus statement: methods for recording and reporting of epidemiological data on injury and illness in sport 2020." Br J Sports Med 55(1): 9-13.

Appendix B. Letter of ethical approval for Study One

Dear Sean Docking,

The following project has been assessed as complying with the National Statement on Ethical Conduct in Human Research. I am pleased to advise that your project has been granted ethics approval and you may commence the study.

Application ID: HEC19109
Application Status/Committee: Science, Health & Engineering College Human Ethics Sub-Committee

Project Title: Impact of Achilles and Patellar tendinopathy on subsequent injuries in Australian Football League players

Chief Investigator: Sean Docking

Other Investigators: Joel Smith, Ebonie Rio

Date of Approval: 08/05/2019
Date of Ethics Approval Expiry: 08/05/2024

The following standard conditions apply to your project:

- Limit of Approval. Approval is limited strictly to the research proposal as submitted in your application.

- Variation to Project. Any subsequent variations or modifications you wish to make to your project must be formally notified for approval in advance of these modifications being introduced into the project.

- Adverse Events. If any unforeseen or adverse events occur the Chief Investigator must notify the UHEC immediately. Any complaints about the project received by the researchers must also be referred immediately to the UHEC.

- Withdrawal of Project. If you decide to discontinue your research before its planned completion, you must inform the relevant committee and complete a Final Report form.

- Monitoring. All projects are subject to monitoring at any time by the University Human Ethics Committee.

- Annual Progress Reports. If your project continues for more than 12 months, you are required to submit a Progress Report annually, on or just prior to 12 February. The form is available on the Research Office website. Failure to submit a Progress Report will mean approval for this project will lapse.

- Auditing. An audit of the project may be conducted by members of the UHEC.

- Final Report. A Final Report (see above address) is required within six months of the completion of the project.

You may log in to ResearchMaster (https://rmenet.latrobe.edu.au) to view your application.

Should you require any further information, please contact the Human Research Ethics Team on:
T: +61 3 9479 1443| E: humanethics@latrobe.edu.au.

Warm regards,

Human Research Ethics Team
Ethics, Integrity & Biosafety, Research Office

Appendix C. Letter of ethical approval for Study Two

LA TROBE UNIVERSITY

Research Office

From	University Human Research Ethics Committee
HEC Number	HEC20109
Project title	Understanding the impact of non-time loss injuries on subsequent injury epidemiology in elite Australian sport
Principal Investigator	Sean Docking
Co-Investigators	Ebonie Rio, Joel Smith, Liam Toohey, Lauren Fortington
Approval Period	28th April 2020 – 28th April 2025
Date	28 April 2020

I am pleased to advise you that the University Human Research Ethics Committee has granted ethical approval of the project listed above, subject to the following conditions being met:

Conditions of Approval – All projects

- This research project was approved during COVID-19 restrictions. The conduct of the research during this period should reflect any changes in relation to COVID-19 mandates in the relevant jurisdictions. To accommodate these mandates a modification request must be submitted for any changes prior to their implementation.
- Approval is limited to the research project and associated documents as outlined in this ethics approval letter.
- The Principal Investigator will immediately report anything that might warrant review of ethical approval of the project.
- **Modifications to an Approved Project:** Any changes to the project application, project description/protocol and/or other project documents must be submitted for review and approval in accordance with the instructions outlined on the Human Research Ethics website. Modifications can be implemented once written approval has been received.
- **Annual Report:** If your project continues for more than 12 months, you are required to submit an Annual Report by the due date outlined in the annual report reminder. The form is available on the Human Research Ethics website. Failure to submit a Progress Report will mean approval for this project will be suspended and no further research activities can be carried out until the annual report is received.
- **Final Report or Withdrawal of Project:** At the conclusion of your project you must submit a final report within 6 months via the process outlined on the Human Research Ethics website.
- **Safety Reporting:** If a significant safety issue arises from the conduct of the project, it must be

reported via the process outlined on the Human Research Ethics website.

- **Monitoring:** All projects are subject to monitoring at any time and will be monitored in accordance with the University's Research Monitoring Policy.

The Human Research Ethics Committee (HREC) Terms of Reference, membership and standard forms are available from http://www.latrobe.edu.au/researchers/research-office/ethics/human-ethics.

Should you require any further information, please contact the Human Research Ethics Team on:
T: +61 3 9479 1443| E: humanethics@latrobe.edu.au.

Warm regards,

David Finlay
Chair, University Human Research Ethics Committee

Appendix D. Support from Rugby Australia for request of data

RUGBY AU

Secretariat
Edith Cowan University HREC

BY EMAIL: l.fortington@ecu.edu.au

10 March 2020

Dear Sir/Madam

Re: Joel Smith – request for use of Super Rugby injury surveillance data

We write in response to a request by Joel Smith (Master of Science Candidate, La Trobe University) for access to de-identified Super Rugby injury surveillance data to assist with a postgraduate research project, under the joint supervision of Dr. Sean Docking (La Trobe University), Dr. Ebonie Rio (La Trobe University) and Dr. Lauren Fortington (ECU and adjunct at La Trobe University).

We have carefully considered this matter and agree to share de-identified injury surveillance data i.e. no personal identifiable information relating to any player or healthcare professional will be provided to the Candidate or those supervising.

All data requests[1] will, following review by Dr. Fortington and Mr. Eduardo Rubio del Castillo, be considered and the relevant information extracted from the Athlete Management System by David Williams (Rugby Australia Sports Performance Scientist).

[1] data collected by club physicians and allied healthcare professionals pertaining to injuries, their treatment and details of matches/training sessions missed as reported in the Athlete Management System.

QANTAS Spirit of Australia asics

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T +61 2 8005 5555 | E info@rugby.com.au | W www.rugbyaustralia.com.au
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RUGBY AU

We also understand that the research findings will be reported back to Rugby Australia in due course.
We look forward to hearing from Joel in due course and in the meantime wish him all the best with this very interesting rugby-related research project.

Yours sincerely,

Ben Whitaker
General Manager, Professional Rugby Services

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Figure 2.2 Flowchart for manual application of the SIC-2.0 model.

Table 2.4 Description of the SIC-2.0 categories and comparison to SIC-1.0 model

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Chapter 7

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