Injury epidemiology in male professional Rugby Union: player-specific injury analysis and its application to starter and replacement players

by

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A thesis presented for the degree of Doctor of Philosophy

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4th November 2021

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This thesis was undertaken under the auspices of Cardiff Metropolitan University.

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Publications from the Thesis

Bitchell, C.L., Mathema, P. & Moore, I.S. Four-year match injury surveillance in male Welsh professional Rugby Union teams. *Phys Ther Sport*. 2020; 42:26-32.

Bitchell, C.L., Varley-Campbell, J., Robinson, G., Stiles, V., Mathema, P., & Moore, I.S. Recurrent and Subsequent Injuries in Professional and Elite Sport: a Systematic Review. *Sports Med – Open*. 2020; 6(58):1-16.

Bitchell, L., Stiles, V.H., Robinson, G., Mathema, P., & Moore, I.S. Is team-level injury analysis giving us the full story? Exploring a player-specific approach to analysing injuries. *Under review.*

Conference abstracts

Reporting recurrent and subsequent injuries in professional sport: A systematic review. Pan Wales Sport and Exercise Sciences PhD Conference. May 2019.

The probability of injury in professional Rugby Union. BASES Student Conference. April 2021.

Team vs Individual Estimates of Injury Rates in Professional Rugby Union. July 2021.

Industry partner collaboration

WRU

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To whom it may concern,

The WRU established a collaboration with Cardiff Metropolitan University at the inception of the Welsh Rugby Union injury surveillance project in 2012. Since its commencement, biannual reports and injury surveillance analysis have been provided to each of the four professional regional teams. Producing research from the injury surveillance project has been an important aspect of the collaboration. Additionally, exploring the epidemiology and potential areas for improving player welfare has been key a key factor in the partnership.

Within Leah's PhD research, we were keen to explore the regulations associated with using replacements within matches and whether this influences match injuries. Due to the scarcity of research exploring the impact of replacement players, it was essential that appropriate analysis methods were developed to analyse this impact. This research helps to inform practice within the Welsh Rugby Union and contributes to the global research associated with the impact of replacement players, an area that Rugby's global governing body, World Rugby, are focusing upon within their research.

Yours sincerely

Mr Prabhat Mathema
WRU National Medical Manger

Acknowledgements

I would firstly like to thank Dr Izzy Moore, Dr Vicky Stiles and Dr Gemma Robinson for their continuous support and guidance throughout this process. Firstly, to Dr Izzy Moore, I will be forever grateful for the opportunities she has provided me with, her support and belief in my ability has pushed me further than I believed possible. My gratitude also goes to both Dr Vicky Stiles and Dr Gemma Robinson who have provided valuable insights throughout the completion of this thesis, from how to write the most eye-catching introduction to developing new skills in performance analysis. They have also endured the struggles of a Ph.D. in a pandemic but have ensured that the level of banter has remained at its peak throughout the process.

Secondly, I would like to thank Mr. Prabhat Mathema who has provided invaluable insight in the completion of this thesis. My thanks must also go to the Knowledge Economy Skills Scholarship (KESS), who in collaboration with the Welsh Rugby Union, provided financial support throughout. A thanks to Ryan Chambers and Rhodri Bown for their assistance with GPS and video analysis data. I am also extremely grateful to the medical personnel at each of the regional teams, specifically Matthew Rees, Ben Stirling, Dan Jones and Chris Towers, who have provided the injury surveillance data throughout the Ph.D. A thanks must also go to Mrs. Jo Varley-Campbell who provided essential guidance for writing a systematic review.

I would also like to thank my family – Mum, Dad and Adam – who have always supported me in my life choices, even the questionable ones. Though they have no idea what a Ph.D. means or what I've been doing for the past three years, they have always provided an ear to listen and a shoulder to cry (and a house to live in during the most stressful Ph.D. period). My Ph.D. peers have also provided essential support throughout this process.

Finally, a special thanks must go to my boyfriend Harry, who has provided me with endless support, encouragement and essential Ph.D. tips and tricks throughout this process. His passion for coding has introduced me to a skill I never thought I would be able to accomplish, and he has maintained a sense of calm even in my most rage inducing moments.

Abstract

This thesis investigated the epidemiology of injuries in professional Rugby Union and the methods in which they are analysed and reported. Furthermore, the thesis explored the development and application of a player-specific method of analysing injuries. Chapter 3 investigated match injuries within the Welsh regional professional Rugby Union teams, demonstrating a higher incidence than previously reported in professional Rugby Union (99.1 injuries/1000 match hours). In addition, the highest proportion of injuries in matches were sustained during the tackle event (50-63%). Whilst this study followed the recommendations of the consensus statement, Chapter 4 aimed to identify whether research in elite or professional sports with published consensus statements also follow their respective recommendations. Chapter 4 demonstrated that there remain inconsistencies with regards to reporting injuries, identifying that the pooling of injury data across individuals remains a common issue within research. As this method is recommended by the consensus statement on data collection and analysis procedures within Rugby Union, Chapter 5 explored a player-specific approach to analysing and reporting injuries. The consensus statement method of calculating team-level exposure, using the standard number of players in a team and standard match length, was compared against the use of global positioning systems (GPS) to identify if the consensus statement provides an adequate method of analysing injury incidence. Interestingly, there were differences between the injury incidence calculated using standard match length and the injury incidence using GPS-derived exposure hours (59.5 vs 95.7 injuries/1000 match hours, respectively). While the team-level injury incidence was influenced by the number of players providing consent, the study demonstrated that team-level injury incidence does not reflect the variation in injury rates at a player-specific level, with 94% of players falling outside of the 95% confidence intervals for the team-level injury incidence. In addition, an alternative to injury incidence statistic was explored through analysing the probability of injury. This identified that when players at the same incidence are exposed to higher match hours, they have a higher probability of incurring multiple injuries. The player-specific methods of analysis from this Chapter were applied in Chapter 6, where the injury rates and mechanisms of starter and replacement players were analysed. Chapter 6 identified that starters had a higher injury incidence than replacement players (80.8 vs 57.2 injuries/1000 match hours, respectively). When accounting for the number of replacements used in a match, the injury rate per player exposure did

not change for each number of replacements used. However, the number of replacement players had a significant effect on the number of match injuries, where injuries increased by 12% per replacement used (p = 0.037). This increase may, in part, be due to a small number of matches using less than seven replacements (20%). Therefore, further analysis accounting for the replacement time-in-game was also implemented, showing a non-significant 1% increase in injury for every 10 minutes of replacement player time-in-game (p = 0.099). Chapter 6 also identified that the tackle event was the mechanism responsible for the highest proportion of injuries for both starter and replacement players. The propensity for injury was similar for tackles involving two starters or two replacements, with a higher injury propensity only shown when an injured starter was tackling a replacement ball carrier. Starter and replacement players exhibited different characteristics during an injury inciting tackle, specifically when the injured player was making a tackle. Replacement players maintained a lower body position, predominantly using a shoulder tackle and contacting the upper leg of the ball carrier. In contrast, starters demonstrated a higher body position, contacting the ball carriers head whilst in an upright position. This thesis demonstrated that whilst consensus statements are important for the consistent definition and data collection associated with injury surveillance, there remains inaccuracies and inconsistencies with the way data is analysed and reported. The lack of research reporting the subsequent injuries fails to consider the potential for multiple injury occurrence at a player specific level. Furthermore, the continued pooling of data across individuals within a team (team-level injury incidence) fails to account for the variation in injury rates at a player-specific level. This is emphasised further when player-specific analysis is applied to starter and replacement players. The application of a player-specific analysis demonstrated that current regulations associated with the use of replacement players within matches is appropriate. Importantly, however, the analysis of tackle characteristics at a player-specific level demonstrated differences in injury inciting tackle characteristics between players. Where possible, methods such as GPS-derived exposure and probability analysis should be incorporated within injury surveillance to provide a more comprehensive player-specific analysis of injury that can aid in injury management and improve player welfare. In addition, injury risk mitigation strategies associated with the tackle should incorporate a player-specific approach, specifically considering the type of player (i.e. starter or replacement player) used within matches.

Chapter 1: Introduction

Introduction

Rugby Union is a highly physical sport, encompassing a range of movement demands and collisions (Austin et al., 2011; Roberts et al., 2008). A Rugby Union match is 80 minutes long, where two teams of 15 players, eight forwards and seven backs, compete for the ball. Given the nature of the sport, match injury rates are among the highest within team sport, with men's international level Rugby Union showing the highest rates (180 injuries/1000 match-hours; Moore et al., 2015), closely followed by the men's professional level (87 injuries/1000 match-hours; West, Starling, et al., 2020). In order to establish the extent of the injury problem within the sport, research has implemented injury surveillance, which constitutes the first stage in developing appropriate injury risk mitigation strategies (Finch, 2006; Roe et al., 2017; van Mechelen et al., 1992). As one of the main priorities for any medical team involved in professional Rugby Union is the reduction of injury rates through effective injury management, a consensus statement was published to provide researchers with guidelines on data collection and analysis procedures to implement when conducting injury surveillance research (Fuller, Molloy, et al., 2007). Since its publication in 2007, epidemiological research within Rugby Union has extensively explored the injuries sustained by players, where factors such as the type, mechanism and timing of injuries have been reported (Bitchell et al., 2020; Brooks & Kemp, 2008, 2011; Fuller et al., 2020; Moore et al., 2015; Ranson et al., 2018; West, Starling, et al., 2020; Williams et al., 2013; Williams, Trewartha, Kemp, Brooks, et al., 2017).

Since the professionalisation of Rugby Union in 1995, match injury rates have shown an increasing trend, from 74 injuries/1000 hours in 2002 to 88.0 injuries/1000 hours in 2020 (Bathgate et al., 2002; England Professional Rugby Injury Surveillance Project Steering Group, 2020). Though limitations exist within the methods of studies published before 2007, these rates are consistently reported at a team-level, with little indication of the potential for individual players to sustain multiple injuries across a number of seasons (Moore et al., 2015). The pooling (summing) of data across individuals is a common approach, advocated within the consensus statement, where the total number of injuries sustained by individuals and estimated match exposure (based on 15 players exposed for 80 minutes) is utilised to calculate the injury incidence rate (Fuller, Molloy, et al., 2007). Investigations into the factors responsible for the high match injury rates have suggested that player position, the time within the match and the introduction of tactical replacements influence the injury rate (Bathgate et al., 2002; Brooks et al., 2005b; Williams et al., 2013). Furthermore, differences in match demands experienced by players have been suggested to influence the injury mechanisms and types of injury sustained (Brooks et al., 2005b; Owen et al., 2015). This includes differing involvement in close contact events such as the tackle; a contact event that has consistently shown to be responsible for the highest proportion of match injuries (Fuller et al., 2020; West, Starling, et al., 2020).

Fuller and colleagues (2007) emphasised the importance of the tackle event in association with injuries, demonstrating that although collisions and scrums carried a higher risk for injury, the high frequency of tackles within a match contributes to the highest number of injuries. As a result, research has implemented performance analysis techniques to establish the types of tackles that lead to injuries (Burger et al., 2016; Hendricks et al., 2015; Hopkinson et al., 2021; Tucker, Raftery, Kemp, et al., 2017). Findings associated with the tackle height and technique consequently resulted in the implementation of law changes within matches, with the aim of reducing injury rates across a team (Tucker, Raftery, Kemp, et al., 2017; World Rugby, 2019a). However, a factor that remains consistent with regards to match injuries is the analysis and interpretation of results at a team-level. Consequently, there is a lack of consideration for the injuries sustained at a player-specific level, a factor which could influence both the injury rate and the mechanisms leading to injury as well as the efficiency of injury risk mitigation strategies.

In an attempt to establish injury management strategies that encompass player-specific characteristics, Roe and colleagues (2017) outlined a six-stage framework. This framework builds upon the traditionally group-based interventions, by determining the extent of the injury problem and understanding the demands at a player-specific level. However, the first stage of the framework remains focused on outlining team-level injury rates, before then considering the individual characteristics (Roe et al., 2017). This method of analysis is supported in the consensus statement, where injury rates are calculated using the entire cohort of players (Fuller, Molloy, et al., 2007). Though strategies to investigate the relationship between injuries at a more individual level have been published, that is the subsequent injury categorisation model (SIC 1.0 and 2.0; Finch & Cook, 2014; Toohey et al., 2018), it is unknown how often this strategy of analysing injuries is implemented within research. Perhaps not surprisingly, therefore, research primarily focuses on the analysis and interpretation of team-level injury rates. However, the recommendation to use the standard match length as the measure of match exposure (i.e., 15 players exposed for 80 minutes) is unlikely to account for differences in match exposure between players within a team. Despite this, there is yet to be a method of analysis that can account for player-specific differences in match exposure. Further, methods that consider the potential for differing injury rates between players due to varying exposure are limited, with research previously only investigating the risk associated with the number of games participated in throughout a season (Williams, Trewartha, Kemp, Brooks, et al., 2017). The development and application of a player-specific method of analysis therefore may provide an opportunity to investigate match injury rates further. Specifically, the differing exposures and potential for different injurious situations experienced by starter and replacement players within matches.

Purpose of the Thesis

The purpose of this thesis was to investigate current methods of analysis in injury surveillance research and explore the development and application of a player-specific approach to injury analysis. Specifically, this thesis aimed to: -

a) Investigate the injury rates and mechanisms within Welsh professional Rugby Union
b) Identify whether the subsequent injury categorisation model is implemented within professional or elite sports injury research
c) Identify whether team-level injury rates account for player-specific differences and explore a player-specific method of analysing injuries
d) Apply the player-specific method of analysis to investigate injuries sustained by starter and replacement players.

Chapter 2: Literature Review

Outline

This chapter will provide a review of the literature surrounding injury epidemiology, with specific reference to injury epidemiology within Rugby Union. Having outlined principles and definitions associated with injury surveillance, the chapter will then outline the key data collection, analysis and reporting techniques implemented within epidemiology, before further reviewing the types and mechanisms of injuries within Rugby Union. This review will draw on the findings from current research within Rugby Union to establish the importance of the aims addressed in the current thesis.

Injury aetiology frameworks and models

Participation in sport is known to carry a risk of injury (Bahr & Holme, 2003b), and previous research has identified that the associated injury risk varies depending on the type of sport and level of play (Brooks et al., 2005b; Fuller et al., 2017; Gabbett, 2004). Within professional Rugby Union, the collaboration of stakeholders such as medical personnel, coaches and sport scientists in the risk mitigation, management and rehabilitation of injuries is essential in attempting to reduce the number of injuries sustained. In order to develop adequate injury management protocols, understanding the injury problem is crucial, including details on how and why injuries are sustained. To enable researchers and clinicians to gather accurate information regarding the injury problem, injury frameworks have been created that outline the steps required to develop appropriate injury management protocols. One of the first frameworks to be developed for its application to sports injury was the van Mechelen et al. framework in 1992. The four stages outlined by van Mechelen et al. (1992) included establishing the extent of the injury, establishing the aetiology, introducing preventative measures and assessing their effectiveness by repeating the first step. Since its inception, the van Mechelen et al. (1992) framework has been widely used to understand the injury problem and implement preventative measures within a sport environment (Van Tiggelen et al., 2008). The first two stages of the framework are of importance in any injury surveillance project, and contribute essential knowledge on the incidence, severity and the mechanisms leading to injury. This has been demonstrated across research within Rugby Union, with injury surveillance conducted within amateur, professional, and international levels, establishing the injury incidences and priority injury problems within the sport (Fuller et al., 2020; Haseler et al., 2010; Moore et al., 2015; Ranson et al., 2018; Roberts et al., 2013; West, Starling, et al., 2020). Although the van Mechelen et al. (1992) framework introduces the assessment of the effectiveness of preventative measures, primarily based on their consequences on injury incidence and mechanisms, limitations have been identified in research with regards to the implementation of the preventative measures identified in the framework (Finch, 2006).

In 2006, Finch provided a development of the van Mechelen et al. (1992) framework that aimed to consider the uptake of the prevention methods identified through injury research (Finch, 2006). The translating research into prevention practice (TRIPP) framework developed by Finch (2006) provides six steps that are required to build an evidence base for the development of prevention protocols within sport. The TRIPP framework is demonstrated in Figure 1, where injury surveillance constitutes the first step and is an essential aspect of research identifying the injury trends to quantify the injury problem within sport. In contrast to the van Mechelen et al. (1992) framework, Finch (2006) highlights the importance of both developing *and* assessing the effectiveness of a prevention protocol in reducing the problem identified in stages one and two. Within Rugby Union, research analysing injuries sustained within matches have demonstrated the usefulness of this stage within the framework, with the scrum event specifically analysed. Research identified that injury rates from a collapsed scrum were substantially higher than scrums that did not collapse (Taylor et al., 2014). Consequently, interventions were introduced to amend the scrum technique within matches, substantially reducing the injury risk (Brooks & Kemp, 2008; World Rugby, 2019b).

Figure 1 The Translating Research into Injury Prevention Practice (TRIPP) framework outlined by Finch in 2006 (Finch, 2006).

However, one disadvantage associated with the frameworks outlined by van Mechelen et al. (1992) and Finch (2006) is the focus on identifying injuries within a group, or at a team-level in relation to Rugby Union, in order to develop and apply prevention measures. Whilst the stage-by-stage guide within these frameworks has encouraged consistency within injury surveillance research, the emphasis on team-level understanding of the aetiology of injury reduces the potential for individual differences to be identified and addressed. Though establishing the injury rate within the sport is key, understanding how external factors such as exposure to sport, and internal factors such as injury history, can influence the individual injury risk is also important.

The individual influence is however considered in models outlined by Meeuwisse et al. (2007) and Bittencourt et al. (2016), who take a multi-disciplinary approach in considering the aetiology of injuries to an *individual* athlete (Figure 2). Specifically, the model outlined by Meeuwisse et al. (2007) is associated with the intrinsic and extrinsic injury risks of an athlete, taking a dynamic approach towards injury. However, Bittencourt et al. (2016) suggest that the model outlined by Meeuwisse et al. (2007) is not sufficient in addressing the interactions between multiple factors associated with injury. Consequently, Bittencourt et al. (2016) proposes a complex systems approach that can address the aetiology of sports injuries in a dynamic way. Examples proposed within the study by Bittencourt et al. (2016) include a 'web of determinants' for ACL injuries to basketball players and ballet dancers, which includes previous risk, fatigue and muscle weakness. Whilst this can demonstrate the varying factors that relate to a specific injury, unlike the frameworks from van Mechelen et al. (1992) and Finch (2006), both the dynamic approach by Meeuwisse et al. (2007) and the complex system outlined by Bittencourt et al. (2016) exclude the element of injury risk management strategies. In addition, the passive nature of the repeat participation and adaptation aspects of the models from Meeuwisse et al. (2007) and Bittencourt et al. (2016) may not be appropriate in a practical setting, where clinicians actively look to improve injury management strategies and adaptations of individual athletes.

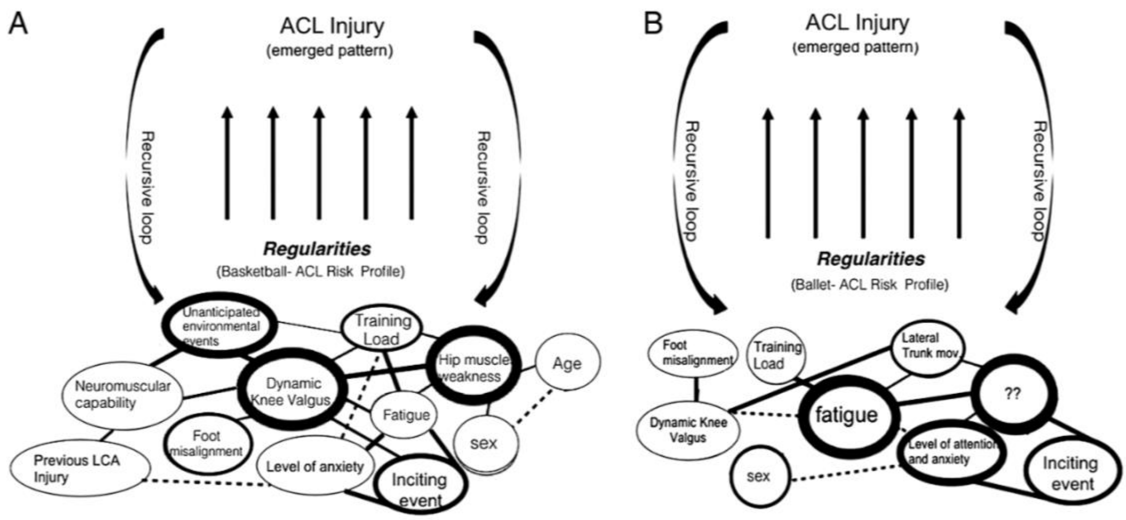


Figure 2 The web of determinants for ACL injury in basketball and ballet dancers outlined by Bittencourt et al. (2016).

In 2017, Roe and colleagues (2017) combined the frameworks outlining injury surveillance and risk management with the individual approaches from the aetiology models to develop a six-stage operational framework, emphasising the importance of considering the potential for diversity within a team (Figure 3). The individualised approach proposes that injury risk management has the potential to be improved by incorporating more tailored prevention and interventions for individual athletes. Similar to the TRIPP framework, the first stage of the model identifies injury trends, with emphasis on the importance of avoiding relying on a single risk factor and considering the multidisciplinary nature associated with injury risk factors (Roe et al., 2017). The incorporation of individual sporting demands and athlete profiling improves upon the framework outlined by Finch (2006), and incorporates the implementation of assessments to establish whether athletes present with the characteristics associated with increased injury risk outlined in stage one. Individualising the injury framework can help identify the unique profile of athletes within a team and provide a more individualised approach to designing appropriate interventions. With this in mind, the following project will be conducting injury surveillance using the model outlined by Roe and colleagues (2017), where individual influences on injury rates will be investigated following the identification of injury rates across a team.

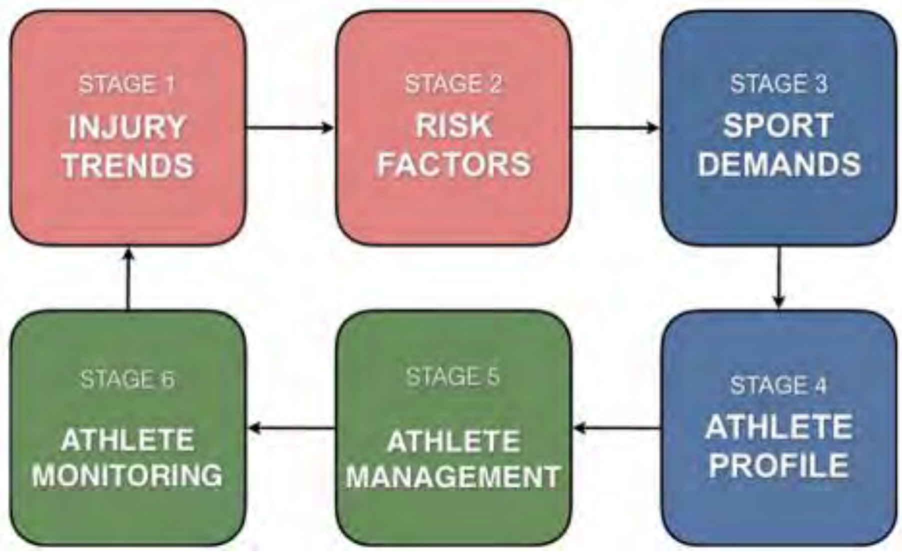


Figure 3 A six stage framework for individualising the management of injury risk in sport by Roe et al. (2017).

Epidemiology injury definitions

As one of the first stages in the framework for injury management is injury surveillance, consensus statements outlining injury definitions and data collection procedures have been published. The consensus statements include recommendations within Athletics, Association Football, Aquatic sports, Cricket, Horseracing, Rugby Union, and Tennis, as well as a recently published consensus statement from the International Olympic Committee (IOC) that encompasses all sport (Bahr et al., 2020; Fuller et al., 2006; Fuller, Molloy, et al., 2007; Junge et al., 2008; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Ranson, et al., 2016; Pluim et al., 2009; Timpka et al., 2014; Turner et al., 2012). These statements include definitions for injury and the exposure to the sport, and provides researchers with an outline of which details associated with injury should be reported including the type, location and injury mechanism (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Orchard et al., 2005). However, the definition of an injury can differ according to the setting that the injury data was collected in, such as community or professional level sport (Badenhorst et al., 2017; Chalmers et al., 2011; West, Starling, et al., 2020). Epidemiological research published within amateur or community level sport often relies on self-reported injury data collected through telephone or web sources (Badenhorst et al., 2017; Malisoux et al., 2013; Palmer-Green et al., 2013). However, self-reported data can be prone to underreporting and inaccurate diagnosis of injuries, resulting in an underestimation of actual injury rates (Badenhorst et al., 2017). In contrast, within professional sport it is often the responsibility of medical personnel to monitor and collect injury surveillance data. This consequently results in a more accurate diagnosis of injuries and improved consistency with regards to collecting and reporting injuries sustained by players. Differences between the methods of injury data collection and diagnosis potentially results in inconsistencies between research within the same sport, with differences in playing level further contributing to the complexity between research, making comparisons between injury rates challenging (Badenhorst et al., 2017; Bathgate et al., 2002; Rafferty et al., 2018).

Injury definition

The first consensus statement to be published was within Cricket in 2005, where injury was defined as an injury or medical condition that prevented a player from being selected for a match, or meant a player was unable to bat, bowl or keep wicket, typically considered a time-loss injury (Orchard et al., 2005). Following this, Association Football and Rugby Union published consensus statements that included a definition of injury that considered the time-lost from sport, for more than 24 hours following the day of injury (Fuller et al., 2006; Fuller, Molloy, et al., 2007). Although the Association Football and Rugby Union consensus statements were published within different sports, the definition of injury remains similar, making it easier to compare the injury rates in research. However, the publication of consensus statements in Athletics, Aquatic sports, Horseracing and Tennis, required an adapted definition of injury due to the individual nature of the sports, where there is often a lack of consistent injury surveillance support, making reliable injury reporting more challenging (Alonso et al., 2012; Prien et al., 2017). Within these consensus statements, injury definitions include a non-time-loss injury, where injuries are recorded regardless of whether the injury resulted in an athlete missing training or competition. In accordance with the consensus statements for individual sports, the Cricket consensus statement was updated in 2016 to include both a 'time-loss' *and* a 'non-time-loss' definition that included injuries requiring medical attention and player reported injuries that could result in no time-lost from match or training (Orchard, Ranson, et al., 2016). In addition to the updated consensus statement published by Orchard and colleagues (2016), the International Olympic Committee (IOC) recently published a consensus statement for recording and reporting injuries in sports (Bahr et al., 2020). The IOC consensus statement was published in order to provide generic guidance for researchers across all sports and defines an injury as "tissue damage or other derangement from physical function as a result of participation in sport" (Bahr et al., 2020). Where differences exist between the definitions outlined for generic, individual and team sports, consistency should be encouraged within research, using the sport specific definitions and data collection procedures where possible when conducting injury surveillance, in order to allow comparisons between injury rates (Bahr et al., 2020; Fuller et al., 2006; Fuller, Molloy, et al., 2007; Junge et al., 2008; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Sims, et al., 2016; Pluim et al., 2009).

New, recurrent, and subsequent injury

Though injury definitions can differ between the consensus statements, injuries are typically dichotomised into a 'new' or a 'recurrent' injury. All recorded injuries within injury surveillance are considered 'new' injuries, unless they are an injury of the same type and to the same site as a previous injury, which are consequently categorised as recurrent injuries (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Junge et al., 2008; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Ranson, et al., 2016; Pluim et al., 2009; Timpka et al., 2014; Turner et al., 2012). Within Rugby Union, recurrent injuries typically contribute to less than a quarter of the overall injuries, with studies reporting that between seven to 24% of injuries were recurrences (Fuller et al., 2013, 2017; Kenneally-Dabrowski et al., 2019; Moore et al., 2015). Injuries that are categorised as 'new' occur more frequently than recurrent injuries, with a study by Williams and colleagues (2013) identifying a ratio of 7:1 new injuries to recurrent injuries. However, the increased severity of recurrent injuries, which are reported to be significantly higher than new injuries (99 vs 28, respectively; Pearce et al., 2011) highlight the importance of identifying these types of injuries within research (Kemp et al., 2008; Pearce et al., 2011; Williams et al., 2013).

Clinical experience and injury frameworks, however, suggest that injuries are not dichotomous, and that an injury occurrence can affect subsequent injury occurrence. Therefore, in 2011, Hamilton et al. (2011) suggested the use of a broader categorisation that encompassed injuries to different sites and of different types, as well as recurrent injuries. This subsequent injury categorisation included an index injury, which was the first recordable injury, followed by subsequent injuries that were either new (different location), local (same location, different type) or recurrent. In 2013, Finch and Cook (2014) updated the subsequent injury categorisation to provide a broader range of definitions for subsequent injuries (SIC 1.0). The updated model by Finch and Cook (2014) included 10 different definitions of a subsequent injury, with the potential to apply to large data sets in a more statistically orientated diagnosis. Following this, Toohey and colleagues (2018) provided a further update to the SIC model to include two levels; a higher-order data driven level and a clinical level (SIC 2.0). Eight categories were established at the data-driven level and accommodated for the diagnosis of subsequent injuries from a research/statistical approach, without requiring previous clinical knowledge. In addition, six new clinical categories were added to the 10 outlined in the SIC 1.0 model, associated with the relatedness between the previous injury and subsequent injury (Toohey et al., 2018). Though the definition of a subsequent injury has been outlined since 2011, and the SIC 1.0 and 2.0 provide the opportunity for post-hoc diagnosis of subsequent injuries in large injury surveillance data sets, there is yet to be a consistent uptake of these methods of reporting injuries in epidemiological research. Chapter 4 reviews the current use of recurrent and subsequent injury definitions and SIC models within research at a professional and elite level and outlines recommendations for future research.

Injury severity

Within Rugby Union research, a time-loss definition for injury is widely adopted. This has consequently resulted in the development of severity categories that can be applied within sport to allow the severity of injuries to be determined based on the number of days unavailable (Table 1; Fuller, Molloy, et al., 2007). However, a major limitation with the categorisation of injury severity by Fuller and colleagues (2007) is the advocation of a time-loss injury definition, which mitigates injuries of slight severity outlined in Table 1 being reported. Although the time-loss definition of injury allows a consistent comparison between studies, it could lead to less severe injuries such as bruising or lacerations being excluded from analysis (Meeuwisse & Love, 1997). Whilst minor injuries such as abrasions and bruising do not always lead to time-lost from sport, these injuries remain an important consideration for medical personnel within sport due to the potential for subsequent injury (Ekstrand et al., 2006).

Table 1 The categorisation of injury severity from Fuller and colleagues (2007).

Severity Category	**Severity (days)**
Slight	0-1
Minimal	2-3
Mild	4-7
Moderate	8-28
Severe	>28
Career-ending / Non-fatal Catastrophic injuries	No return to play

Although these categories allow injuries to be grouped for comparison across research, the categorisation is not widely adopted, with research often representing the severity simply as the mean and median number of days lost to a specific injury (Beijsterveldt et al., 2015; Fuller et al., 2010; Junge et al., 2009; Ma et al., 2016; Williams, Trewartha, Kemp, Brooks, et al., 2017). Presenting the severity as a continuous variable rather than a severity category provides insight into the potential for variation between injuries, specifically across large cohorts of players such as within epidemiological research. Within studies that have specified the number of days lost from sport, severities often differ between sports (Alonso et al., 2012; López-Valenciano et al., 2019; Williams et al., 2013). However, the severity of injuries in Rugby Union is often higher than other sports such as Association Football and Athletics (Williams et al., 2013). Injury surveillance within both Association Football and Athletics have often reported that the majority of time-loss injuries are considered to be of a minor severity, with between one to seven days lost from training or competitions within Athletics (Alonso et al., 2010, 2012; López-Valenciano et al., 2019). In contrast, Rugby Union has identified that injuries are primarily of a moderate severity, resulting in between 8-28 days lost from sport (Williams et al., 2013).

Whilst reporting the mean or median days lost due to injury provides a single numerical value for the injury severity, it is often more useful to present the severity in a contextual way that helps researchers understand the relationship between the exposure to sport and the severity of injuries (Bahr et al., 2017). Consequently, the calculation of injury burden has been proposed as a method of analysis that incorporates the days lost to sport in relation to the exposure to sport. As demonstrated in Figure 4, injuries of high severity but low incidence, such as the foot, are considered medium risk, falling between the 25th and 75th percentile for injury burden. However, injuries to the shoulder and the posterior thigh demonstrate that when the severity and incidence is considered together as the burden of injury, they are considered high risk and are above the 75th percentile for injury burden.

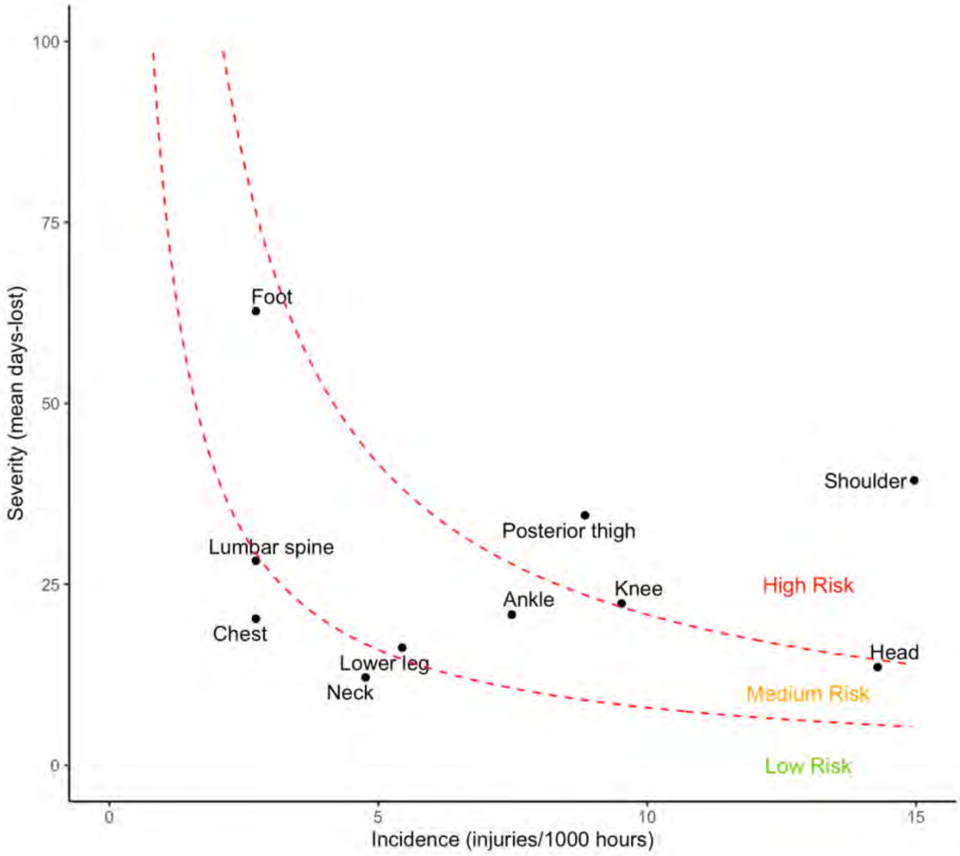


Figure 4 The body areas with the top ten injury burden (days-lost/1000 hours) of the four Welsh regional teams within the PRO14 league in the 2018/19 season.

Although the concept of injury burden has been adopted in healthcare research (Weijermars et al., 2018), analysis of injury burden is yet to be widely implemented within sports epidemiological research (Bahr et al., 2017). However, recent research within Association Football and Rugby Union have analysed injury burden alongside injury incidence and severity (Cosgrave & Williams, 2019; Ekstrand, Waldén, et al., 2016; Hägglund et al., 2013; Whalan et al., 2019; Williams et al., 2016). Within Association Football, an 11 year follow up showed a burden of 130 days-lost/1000 hours across 24 teams (Hägglund et al., 2013). Studies within Association Football have also anaylsed the burden of specific injuries, with hamstring injuries showing a burden of 19.7 days-lost per 1000 hours (Ekstrand, Waldén, et al., 2016), and ankle injuries showing a burden of 16.3 days-lost per 1000 hours (Waldén et al., 2013). However, when comparing the burden across 13 seasons in professional Association Football to a study of a similar length of time in Rugby Union (16 seasons), the burden of injuries in Rugby Union is substantially higher, at 2178 days-lost per 1000 hours (West, Starling, et al., 2020). The use of a similar method of calculating injury burden across sport therefore demonstrates that injuries within Rugby Union remain a problem within the sport and provides rationale for the continued investigation of injury rates and mechanisms. Whilst the use of injury burden is yet to be widely implemented within sports epidemiology, the practical use of burden within a clinical environment indicates the benefits of reporting this metric within research. Specifically, the identification of injuries considered 'high risk' in Figure 4 allow medical personnel to identify priority injury risk mitigation strategies and understand the demands on medical resources and player availability throughout a season (Fuller, 2018).

Exposure to sport

Rugby Union match exposure

Rugby Union is a physically demanding contact sport that involves high intensity movements and repetitive impacts, often requiring players to execute complex skills under fatiguing situations (Austin et al., 2011; Duthie et al., 2003; Roberts et al., 2008; Roe et al., 2016). A Rugby Union match consists of two teams made up of 15 players each, split into 8 forwards and 7 backs. Though research has identified that Rugby Union has high physical demands through contact events, players also require high levels of fitness in order to cope with the high intensity running activities and high sprint frequency throughout a match (Cunningham et al., 2016). The complex nature of the sport has warranted substantial research into the injury rates and mechanisms, though accurately calculating the exposure and the consequent injury incidence can present a challenge.

Exposure and injury

Injuries within epidemiological research have primarily been reported as the number or proportion of injuries sustained and the injury incidence rate (Ekstrand et al., 2012; Larruskain, Lekue, et al., 2018; Waldén et al., 2013). Although reporting the number or proportion of injuries gives a simplistic overview, utilising the exposure to calculate the injury incidence rate, as proposed in consensus statements, provide context to the injuries sustained within a given time-period. Injury incidence can be interpreted in different ways depending on the injury setting. Epidemiologic incidence proportions represent the average risk of injury per athlete, incidence rates represent the injury per unit of athlete time and clinical incidence represents a measure of resource utilisation (Knowles et al., 2006). Within injury surveillance research, the epidemiologic incidence proportion or the incidence rate is the primary method for reporting injury incidence, depending on the availability for calculating the exposure. However, challenges arise when calculating the exposure to sport.

Similar to the injury definitions, consensus statements outline different methods of capturing and analysing exposure within different sports (Fuller, Molloy, et al., 2007; Orchard et al., 2005; Timpka et al., 2014). The different denominators for exposure outlined in the consensus statements aims to provide researchers with the most accurate calculation of exposure in order to represent the injury rates within the respective sport. Where team sports are concerned, the time of exposure based on match or training hours can be calculated, and is often monitored using exposure report forms or global positioning systems (GPS; Cummins et al., 2019; Fuller, Molloy, et al., 2007; Williams, Trewartha, Kemp, Brooks, et al., 2017). Though GPS can provide a player-specific overview of training demands, utilising exposure report forms involves the estimation of training exposure based solely on the number of players training and the average training exposure hours across the entire team. This method consequently fails to consider the individual variation in training exposure, further complicating the analysis of exposure within team sport. Furthermore, within sports such as Athletics where individuals are often exposed to different amounts of training and competition, using hours of exposure becomes challenging to monitor and interpret. In this circumstance, consensus statements within individual sport have proposed different methods of presenting exposure, using the number of registered athletes or number of competing athletes (Mountjoy et al., 2016; Timpka et al., 2014). Furthermore, when calculating exposure within Cricket, the different phases of play need to be considered, where exposure can be interpreted as either the number of overs played, the number of overs bowled or the number of balls faced when batting (Orchard et al., 2005). Although ensuring a method for calculating exposure is established according to the sport and injury setting, the inconsistency between the exposure calculations utilised within these sports further complicates the understanding of injury rates, and lacks consistency for comparisons across research involving different sports (Alonso et al., 2012; Beijsterveldt et al., 2015; Moore et al., 2015; Ranson et al., 2013).

A factor that further complicates the consistency of analysis and comparisons is the use of estimated exposure within sports. Within both Association Football and Rugby Union, match exposure hours are estimated based on the number of matches, number of players and the total match duration in order to calculate the match injury rate (Fuller et al., 2006; Fuller, Molloy, et al., 2007). While estimating the match exposure provides context for the number of injuries sustained and allows researchers to understand the injury rates, there is potential for injury rates to be inaccurately represented. The potential for inaccuracies associated with the estimated exposure is emphasised when considering the differences between individual player exposure. For example, within Rugby Union match exposure is calculated using 15 players exposed for 80 minutes. However, this estimation fails to consider replacement players who often play for less than 80 minutes and any additional time-lost within a match for head injury assessments (HIA) or foul play (Lacome et al., 2016; Williams, Trewartha, Kemp, Brooks, et al., 2017). Furthermore, a temporary replacement can be made during matches where a player is removed due to circumstances such as the HIA, adding to the complex nature of exposure within a team. Therefore, due to the potential for varying demands between players, quantifying the physiological demands can be challenging.

Positional demands

In an attempt to quantify these complex match demands, research has utilised GPS and video analysis during matches, and has demonstrated that the type of impacts and running activities differ between positional groups (Cahill et al., 2013; Portillo et al., 2014; Roberts et al., 2008). In addition to the use of GPS, accelerometers that quantify impacts during matches have shown that all players within a team are involved in a high number of collisions (Roe et al., 2016). As Rugby Union is a full contact sport, this is not surprising, but interestingly Owen and colleagues (2015) showed that forwards experienced a higher number of impacts than backs throughout a match. It was suggested that the demands placed on the forwards from contact events outweigh the demands placed upon the backs, who spend more time in running activities (Owen et al., 2015). This is supported in many studies looking at differences between positional groups, showing that forwards spend a larger amount of time doing high-intensity static exertions, whilst the backs perform higher intensity movements during running (Roberts et al., 2008). Furthermore, Portillo et al. (2014) showed that backs performed both a greater number of very-high intensity runs and covered a greater mean distance per high-intensity run than forwards. The increased high-intensity running experienced by backs is emphasised in studies by Cahill et al. (2013) and Roberts et al. (2008), showing that forwards spend more time jogging and performed more discrete bouts of high-intensity activity than the backs.

Research has taken the positional analysis further by breaking down the forwards and back positions into more specific positional groups including front row, second row, back row, scrum half, inside back and outside backs (Cahill et al., 2013; Grainger et al., 2018). This more specific positional analysis showed similar patterns to the overarching forwards and backs positional differences, with scrum halves covering the furthest distance and hookers experiencing the highest relative frequency of impacts (Cahill et al., 2013; Grainger et al., 2018). The higher exposure to high intensity running in the backs was supported in the more specific studies, where it was shown that outside backs attained the highest peak speeds and covered twice as much distance whilst sprinting than the inside backs (Cahill et al., 2013). The findings in these studies indicate the various demands placed upon players during a professional Rugby Union match, specifically demonstrating that demands can vary considerably between positional groups.

Starter vs replacement demands

Interestingly, a finding highlighted in a study by Grainger et al. (2018) was that there were also differences between positions where replacement players are concerned, with forwards more likely to be replaced for tactical reasons, often ending up not playing the full duration of the match. This has been supported in studies investigating differences between the performance of starter and replacement players, with forwards often replaced sooner in the game for tactical reasons, in order to have more of an impact on the match (Lacome et al., 2016; Michael et al., 2019). Studies within both Rugby 7's and Rugby Union have identified that differences in performance during matches exist between starter and replacement players (Higham et al., 2012; Lacome et al., 2016; Michael et al., 2019; Murray & Varley, 2015). Replacements in Rugby 7's are often only made in the second half, however as the time period for each half of a game are only eight minutes, there is only a short timeframe for the differences between starter and replacement players to be analysed (Higham et al., 2012; Murray & Varley, 2015). Though the time for replacement players to be analysed in a Rugby 7's match is short, replacement players have still demonstrated an increased work rate compared to those who started a game, performing greater high-speed running and covering more distance at higher velocities (Higham et al., 2012; Murray & Varley, 2015).

Similar findings have been demonstrated in international Rugby Union, where substitutions for forwards and backs have been analysed separately (Lacome et al., 2016; Michael et al., 2019). In the study by Lacome et al. (2016), replacements for forwards were made earlier than the backs, with forwards typically replaced between 50-55 and 60-65 minutes. The majority of the replacements were attributed to tactical purposes, with forward position replacements showing an increase in running performance in comparison to the starter forwards. In addition, replacement players for both forwards and backs performed higher total distance and more running at high intensities. Whilst the study by Lacome et al. (2016) investigated match performance measures associated with running, a study by Michael et al. (2019) analysed the short term impact in attacking and defensive movements of replacements within a 10 minute time period. Similar to Lacome et al. (2016) the replacement players for forward positions demonstrated improved performance in comparison to the forwards who started a match. When comparing the first 10 minutes of the replacement player against the final 10 minutes of the starter, forwards replacements were involved in a higher number of match events. However, in contrast to findings by Lacome et al. (2016) there were no significant differences in the performance of starter and replacement backs (Michael et al., 2019). The differences between players were identified by using both GPS and video analysis methods, with GPS consistently implemented as a method of measuring match exposure within previous research analysing match demands (Cahill et al., 2013; Lacome et al., 2016; Portillo et al., 2014; Roberts et al., 2008). Though match demands have been identified, the corresponding injury rates continue to be calculated utilising estimated exposure calculations outlined in consensus statements (Fuller et al., 2020; Moore et al., 2015; Ranson et al., 2018; West, Starling, et al., 2020). Studies implementing GPS as a method of measuring exposure therefore provide an opportunity for a different method of exposure analysis to be used in conjunction with epidemiological research, providing an alternative for the analysis of exposure traditionally used in calculating injury incidence.

Reporting injuries

Injury incidence in sport

Epidemiological research within individual sports, including Athletics, Swimming and Tennis have consistently reported relatively low injury rates in comparison to team sports, with an injury incidence of 1.2 injuries per 1000 hours of exposure reported in Tennis (Pluim et al., 2016). However, when attempting to compare with other individual sport, the different denominator for exposure used within Athletics and Swimming mean that differences in incidence become harder to interpret (Alonso et al., 2009; Edouard et al., 2013; Prien et al., 2017). Furthermore, comparing incidence rates within Athletics and Swimming demonstrates the inconsistency between reporting incidence, even when consensus statements have outlined a similar denominator. For example, research across three Swimming World Championships showed an incidence rate of 12.9 injuries per 100 athletes (Prien et al., 2017), whereas research within Athletics Championships have shown incidence rates between 47.5 and 135.4 injuries per 1000 registered athletes (Alonso et al., 2010; Edouard et al., 2013). Whilst the incidence within Athletics seems to show a higher value, the different denominator utilised between studies renders comparisons impractical and unreliable.

Although the exposure denominator is different in individual sports compared to team sport, where hours of exposure are traditionally utilised, the incidence rates within team sport is often substantially higher (Fuller et al., 2017; Moore et al., 2015; Rafferty et al., 2018). One of the reasons behind the differences in incidence rates could be due to the inconsistent medical support within individual sport, with consistent support often only provided within competition or championship environments where response rates from athletes and physicians are often low (Edouard et al., 2013, 2014). In contrast, research published in team sport often involve medical personnel that have been working closely with the athletes within the team across a number of seasons. It is hypothesised that this enables consistent reporting of injuries and may provide a more accurate injury dataset than temporary surveillance within Championship environments (A. Jones et al., 2019; Moore et al., 2015; Williams et al., 2016).

Research within team sports such as Association Football and Rugby has previously investigated match injury rates within youth, amateur, professional, and international levels, with different incidence rates shown between levels of play (Table 2). Comparisons between Rugby and other team sports often show that Rugby has a consistently higher incidence of injuries (López-Valenciano et al., 2019; Williams et al., 2013; Willigenburg et al., 2016). Within Rugby, there are often differences in injury rates reported between Rugby 7's, Rugby League and Rugby Union (Table 2; Fitzpatrick et al., 2018; Gissane et al., 2012; Ma et al., 2016; Moore et al., 2015; Toohey et al., 2019; Viviers et al., 2018; Williams et al., 2013). However, within Rugby 7's and Rugby League studies, often both time-loss and non-time-loss injuries are considered in analysis, with incidence rates for time-loss injuries showing consistently lower values than Rugby Union (Fitzpatrick et al., 2018; Gissane et al., 2012). Whilst Rugby 7's and Rugby League capture both time-loss and non-time-loss injuries, Rugby Union primarily reports the incidence of time-loss injuries only. When comparing time-loss injury incidence within Rugby Union to Association Football and Rugby League, Rugby Union has consistently shown higher injury rates (Viviers et al., 2018; Williams et al., 2013). A recent review of Rugby Union injury epidemiology demonstrated that men's international Rugby Union showed the highest incidence rates, followed by men's professional Rugby Union (Viviers et al., 2018). Research within male professional Rugby Union has consistently followed the definitions in the consensus statement since its publication in 2007 (Fuller, Molloy, et al., 2007).

Following this, the injury rates within the male professional game, reported solely across a team, have continued to increase. Research has often focused on the analysis of match injuries, primarily due to the high number of injuries sustained during matches (Ranson et al., 2018; West, Starling, et al., 2020; Williams et al., 2013). Though changes in player physiques, style of play and improved collection of injury data may contribute to the increases in incidence, the continued investigation of team-level injury rates fail to consider the influence of individual players (West, Starling, et al., 2020; Williams et al., 2013). Thus, the six-stage model outlined by Roe and colleagues (Roe et al., 2017) provides the opportunity to consider the characteristics of each athlete, in order to reduce injury rates within a team. Consequently, investigating injury rates at a player-specific level may provide further insight into the continued reporting of high team-level injury incidence.

Table 2 The injury incidence across matches and all activities within Association Football, Rugby 7's, Rugby League and Rugby Union.

Sport	Level	Injury Definition	Incidence (injuries/1000 match hours)
Association Football (Dvorak et al., 2011)	International	All encompassing	61.1
Association Football (Ergün et al., 2013)	Elite Youth	Time-loss	30.4
Rugby Sevens (Cruz-Ferreira et al., 2018)	Elite	Time-loss	133.9
Rugby League (Gissane et al., 2012)	All	Time-loss	30.0
Rugby Union (West, Starling, et al., 2020)	Professional	Time-loss	87.0 (62-103)
Rugby Union (Moore et al., 2015)	International	Time-loss	180.0 (178.6-262.5)

Rugby Union match injuries

Considering the high physicality of Rugby Union matches, it is unsurprising that injury rates are consistently high. Interestingly, studies by Bathgate and colleagues (2002) and Garraway and colleagues (2000) demonstrated that injury incidence changed when Rugby Union became professional, with rates increasing after the introduction of professional level play. This is supported by the continued reporting of high incidence rates at the professional level (Ranson et al., 2018; West, Starling, et al., 2020; Williams, Trewartha, Kemp, Brooks, et al., 2017). The introduction of the consensus statement in 2007 (Fuller, Molloy, et al., 2007) has allowed research to remain consistent in the way injuries are collected, analysed and reported, meaning that comparisons between research utilising the methods outlined in the consensus statement can be more reliable. Though methods have remained consistent since the publication of the consensus statement, research published before 2007 has showed similar patterns to those published more recently (Bathgate et al., 2002; Best et al., 2005; Brooks et al., 2005b; Holtzhausen et al., 2006).

When considering the types of injuries sustained during matches, professional and international level Rugby Union have reported similar findings, with the most common body locations reported as injuries to the head, thigh, knee and ankle (Bathgate et al., 2002; Best et al., 2005; Brooks et al., 2005b; Brooks & Kemp, 2008, 2011; Fuller et al., 2020; Moore et al., 2015; Ranson et al., 2018; West, Starling, et al., 2020). Lower limb injuries have consistently shown the highest injury incidence, with thigh haematomas, hamstring muscle injuries and knee and ankle ligament injuries occurring most frequently (Brooks et al., 2005b; Fuller et al., 2008, 2020; Williams et al., 2013). In addition to the lower limb often showing the highest incidence, lower limb injuries have also shown high severities (Brooks et al., 2005b; Fuller et al., 2008, 2013, 2020). Specifically, the knee and the posterior thigh often constitute the most severe injuries, where knee ligament and posterior thigh muscle injuries result in the highest number of days unavailable (Fuller et al., 2008, 2020). Whilst lower limb injuries have previously shown high injury incidence, recent trends within epidemiological research has shown that head injuries are the most prominent match injury (Fuller et al., 2020; Moore et al., 2015; West, Starling, et al., 2020).

Though the lower limb has been reported as a consistent injury within Rugby Union, recent research has identified concussions as a priority injury within matches, showing an increasing trend in injury incidence recent years (Cosgrave & Williams, 2019; Fuller et al., 2020; Moore et al., 2015; West, Starling, et al., 2020). Concussion is now often the most common type of injury reported during matches, suggested to be due to improvements in concussion recognition and in turn, improved reporting during injury surveillance (Moore et al., 2015). However, a recent study by West and colleagues

(2020) suggested the increased recognition may not influence the increasing concussion incidence shown in professional English Rugby Union, instead suggesting that the increasing trend may be due to increased occurrence of concussive injuries within the match. This increase is hardly surprising when considering the demands placed upon players within a match, with high numbers of contact events and high-intensity running experienced by players (Cahill et al., 2013; Portillo et al., 2014; Roberts et al., 2008; G. Roe et al., 2016). Though extensive research has quantified the rates of injuries within Rugby Union, the continued reporting of substantially higher injury rates within the male professional game warrants further investigation.

Injury risk analysis

An important area of consideration in injury analysis is the terminology and method of analysis implemented. The terms injury rates and injury risk are often used interchangeably to describe the number of injuries sustained within a team or group of individual athletes. However, they do not represent the same thing. Injury rates describe the number of injuries sustained within a given time of exposure, whereas injury risk is the average probability of an injury per athlete, and considers the number of athletes injured rather than the total number of injuries sustained within a period of time (Knowles et al., 2006). Whilst Knowles and colleagues (2006) emphasise the differences between injury risk and rates, consensus statements consider the injury incidence as an appropriate measure of injury risk (Bahr et al., 2020; Fuller, Molloy, et al., 2007). Though the calculation of incidence rates can be useful when comparing between sports, expressing injuries as a number per 1000 hours of exposure can be counterintuitive when attempting to understand the injury trends and athletes risk for injury (Chalmers et al., 2011; Fuller et al., 2010; Moore et al., 2015; Rogalski et al., 2013). The interpretation of injury risk is consequently a simpler expression of injury that can be widely understood, describing the probability that an athlete will sustain an injury. Where the main aim of the research is to report the trends and risk of injury in order to provide feedback to coaches or clinicians in the professional environment, injury risk could be considered the most comprehensible method of analysis. In addition, policy changes brought about by research often needs to be disseminated to the wider public, requiring a method of reporting injury risk that is easily understandable and can be communicated to non-scientific audiences.

Previous research has explored risk analysis through looking at the effects of exposure to sport on injury (Colby et al., 2018; Hagglund et al., 2003; Hulin et al., 2014; Malone et al., 2017; Ruddy et al., 2018; Williams, Trewartha, Kemp, Brooks, et al., 2017). Studies looking at the acute and cumulative loads from Cricket, Australian Football League and Rugby Union have used different methods of analysis to calculate whether exposure influences the risk of sustaining an injury. These methods of analysis have primarily included hazard or odds ratios, calculated using generalized estimating equations or logistic regressions (Cross, Williams, et al., 2016; Cummins et al., 2019; Hulin et al., 2014; Malone et al., 2017; Rogalski et al., 2013; Stares et al., 2018; Williams, Trewartha, Kemp, Brooks, et al., 2017; Windt et al., 2017). Within Rugby Union and Rugby League, the association between training load and injury risk were investigated in order to understand the influence of training on the likelihood of sustaining an injury (Cross, Williams, et al., 2016; Windt et al., 2017). Furthermore, Williams and colleagues (Williams, Trewartha, Kemp, Brooks, et al., 2017) investigated match specific loads, using hazard ratios to assess the injury risk associated with the exposure in the preceding 30 days and preceding 12 months in professional Rugby Union.

Within the studies utilising hazard ratios, the entire cohort of players within the team throughout a season are analysed. This provides a control population in order to identify the high-risk exposures associated with the injured population (Cummins et al., 2019; Windt et al., 2017). However, research implementing injury surveillance primarily analyses the injury rates of the cohort of injured players only, which negates the use of hazard ratios for injury risk analysis. Furthermore, the hazard ratio method of analysis is challenging to easily implement within a clinical environment, primarily due to the relatively complex statistical analysis required to calculate the injury risk. Though an increase above one for a hazard ratio demonstrates increased risk, this analysis does not demonstrate the probability that an athlete will sustain an injury within a given time-period. With this in mind, Parekh and colleagues (2012) suggested a different method of analysing injury risk using the Poisson probability, a standard approach for risk analysis in statistics. Using an example of schoolboy rugby, Parekh and colleagues (2012) implemented the Poisson probability method using the individual player incidence and an example exposure to matches (i.e. 15 matches calculated as 17.5 hours) in order to establish the probability of sustaining a given number of injuries. For example, if a player had an incidence of 43.3 injuries per 1000 hours and was exposed to 17.5 hours of match play, there was a 46.9% probability of sustaining 0 injuries, a 35.5% probability of sustaining 1 injury and so on until there was a 0.1% probability of sustaining 5 injuries (Table 3). The method of transforming injury rates into the probability of injury for an athlete could be seen as a more suitable method to communicate the risk of injury in a practical setting (Parekh et al., 2012). The practical implications associated with analysing injury risk emphasise that a simpler, more communicable method of injury risk should be implemented. However, this method of calculating injury risk is yet to be utilised across a larger cohort of players, specifically at a professional level. Consequently, exploring this method of injury analysis and its application in a professional setting as an alternative method within sports injury epidemiology may provide greater insight into injuries within professional Rugby Union.

Table 3 The probability of sustaining between 0 to 5 injuries in an example player from schoolboy rugby, adapted from Parekh et al. (2012).

Number of injuries from 17.5 h playing exposure	**Probability (injury incidence of 43.3/1000 player hours)**
0	46.9%
1	35.5%
2	13.5%
3	3.4%
4	0.6%
5	0.1%

Rugby Union injury mechanisms

Positional injuries

In agreement with studies analysing the demands of the match, different positions have been reported to experience differing injury rates based on the activities they are involved in (Bathgate et al., 2002; Brooks et al., 2005b; Brooks & Kemp, 2011; Cosgrave & Williams, 2019; Fuller, Brooks, et al., 2007). However, there have been a number of studies that have shown contrasting findings, showing that no differences exist between the positional injury rates (Brooks et al., 2005b; Holtzhausen et al., 2006; West, Starling, et al., 2020; Williams et al., 2013). Interestingly, a recent study by Fuller et al. (2020) identified that at the international level, forwards sustained more match injuries than backs during the Rugby World Cup, which is in agreement with previous Rugby World Cup studies (Fuller et al., 2008, 2013, 2017). In addition, each positional group sustained a higher proportion of injuries in different activities; the backs during non-contact running activities and the forwards during the ruck and maul (Fuller et al., 2020). Research by Owen and colleagues (2015) is in agreement with Fuller et al. (2020), stating that forwards sustained more impact injuries such as muscular damage from close contact events. However, research within professional level Rugby Union has shown contrasting findings (Brooks et al., 2005b; Holtzhausen et al., 2006; West, Starling, et al., 2020; Williams et al., 2013). The difference between these studies may be due to a number of factors; differences in playing levels, variations in the susceptibility of players in incurring injuries and injury reporting behaviour. Specifically, a review by Viviers and colleagues (Viviers et al., 2018) suggest that the intensity of competition increases as the level of play increases. Within international Rugby Union the increased intensity during matches may result in more frequent involvements in close contact events when competing for the ball, an aspect of match play more frequently experienced by forwards than backs (Owen et al., 2015; Viviers et al., 2018). Whilst research has produced contrasting findings, the high impact nature of matches mean that injury rates remain consistently high, regardless of the physical differences in match demands between positions.

Timing of match injuries

In addition to the findings associated with injury rates between positional groups, research has identified that injury rates differ between match quarters. Previous research has shown that the first quarter of matches often show the lowest number of injuries in comparison to all other match quarters, with a higher proportion of injuries reported during the third quarter (Bathgate et al., 2002; Best et al., 2005; Holtzhausen et al., 2006; Williams et al., 2013). Within the study by Bathgate et al. (2002), only 7% of injuries were sustained within the first match quarter, with almost half of all match injuries reported within the third quarter (40%). Best et al. (2005) showed similar findings, where 38% of injuries occurred within the third quarter of matches. Injury incidence analysis has shown similar findings, with a meta-analysis by Williams et al. (2013) demonstrating that the injury incidence within the third match quarter was substantially higher than the first match quarter (119 vs 57 injuries/1000 hours). Studies that showed increases in the number of injuries between match quarters have consistently suggested fatigue as an implicating factor. Specifically, it has been suggested that players who remain on the pitch for longer periods of time have shown alterations to technique, which potentially leads to higher proportions of injuries from tackle events (Burger et al., 2016; Davidow et al., 2018; Gabbett, 2008). In addition, the utilisation of replacement players within matches has been suggested to influence injury rates, primarily due to their increased physicality and higher involvements in match events, specifically within the third and fourth quarter of matches (Bathgate et al., 2002; Lacome et al., 2016; Michael et al., 2019). Within Rugby Union, current laws dictate that up to eight replacement players can be used within a match (World Rugby, 2021b). This means that over half of the team can be permanently replaced throughout the duration of a match, a factor which has been suggested to influence match injuries since the introduction of tactical replacements in 1996 (Bathgate et al., 2002). In comparison to other team sports such as Association Football, where only three substitutions can be made for a team of 11 players (The FA, 2021), the potential impact of replacement players within Rugby Union is further emphasised. However, research analysing the impact of replacement players on injuries within a match is limited. It therefore remains unknown whether the regulations associated with replacing over half a team within a Rugby Union matches needs to be revised.

The incidence of starter and replacement players within the final match quarter has previously been reported, with Brooks et al. (2005b) identifying that the incidence of injuries was higher for players who started a match (114 injuries/1000 hours) than those who were brought on as replacements (87 injuries/1000 hours). Within the study by Brooks et al. (2005b), fatigue was again suggested as an implicating factor for differences in injury incidence between match quarters. Though injury incidence was higher for starters than replacement players in the final match quarter, further insight into these differences is limited. Specifically, the method of calculating the exposure for starter and replacement players was not identified within the study by Brooks et al. (2005b). This is key when analysing differences between these player types, primarily due to the differences in time-in-game experienced by starter and replacement players. From the differences identified with regards to match demands (Lacome et al., 2016; Michael et al., 2019), investigating injury rates within these players further by implementing exposure analysis that is relevant to each type of player is warranted. In addition, exploring the specific injury mechanisms during matches may provide further insight into the injury rates, establishing whether differences in performance influence match injuries and require player-specific injury risk mitigation strategies.

Injury mechanism and Performance Analysis

Contact injury mechanisms

A key stage in the development of appropriate injury risk mitigation strategies is to identify the mechanism leading to injury. Within Rugby Union, injury surveillance incorporates the identification of match events that lead to injury, considering both contact and non-contact mechanisms. A factor that has remained consistent within Rugby Union is that contact mechanisms are responsible for the highest proportion of injuries within matches (Brooks et al., 2005b; Cross, Kemp, et al., 2016; Fuller et al., 2008, 2013, 2020; Fuller, Brooks, et al., 2007; Holtzhausen et al., 2006; Kemp et al., 2008; Moore et al., 2015; West, Starling, et al., 2020). Research has demonstrated that over 64% of injuries during matches were sustained during contact events (Brooks et al., 2005b; Fuller et al., 2017, 2020; Holtzhausen et al., 2006), with collision, lineouts, mauls, rucks, scrums and tackles consistently reported as the specific contact mechanisms contributing to the highest proportion of injuries.

Though often lower proportions of injuries are sustained during the ruck (4-9%; Fuller et al., 2013, 2017, 2020; Moore et al., 2015), maul (2-4%; Fuller et al., 2013, 2017, 2020) and scrum (3-11%; Brooks et al., 2005b; Fuller et al., 2013, 2017, 2020; Moore et al., 2015), collisions and tackle events primarily contribute to the highest proportion of injuries sustained from contact events. Whilst research within Rugby World Cups combine accidental and non-accidental collisions (responsible for between 10-17% of injuries; Fuller et al., 2013, 2017, 2020), a recent study by West and colleagues (2020) identified that accidental collisions had a higher risk for injury than non-accidental collisions, based on injury burden. However, the tackle event has consistently contributed to over 40% of contact related injuries within matches (Fuller et al., 2017; Moore et al., 2015; West, Starling, et al., 2020). Due to the high proportion of injuries sustained within the tackle event, injuries are often reported separately based on being tackled or making a tackle. Whilst the proportions of injuries within each type of tackle has shown variation within previous research, being tackled has more consistently resulted in higher proportions of injuries (22-59%; Fuller et al., 2013, 2017; Moore et al., 2015; Whitehouse et al., 2016) than tackling (18-41%; Fuller et al., 2013, 2017, 2020; Moore et al., 2015; West, Starling, et al., 2020; Whitehouse et al., 2016). Brooks et al. (2005b) further emphasised the contribution of the tackle event to match injuries by identifying that side on tackles were the type of tackle responsible for the highest proportion of injuries (51%), followed by head on tackles (34%). Though contact events are typically presented as proportions, Williams and colleagues (2013) also demonstrated that the incidence of injuries from being tackled was higher than when tackling (29.0 vs 19.0 injuries/1000 hours).

The high proportions of injuries consistently shown within the tackle event is primarily due to the high frequency of the tackle event within matches (Fuller et al., 2008, 2013, 2017; Moore et al., 2015; Ranson et al., 2018; Williams et al., 2013). In a study by Fuller et al. (2007), the number of contact events per game was reported as 456.8, with the tackle event leading to five times more injuries than any other contact event. This has consistently been supported in recent research within professional Rugby Union, with a recent study by West and colleagues (2020) emphasising the high proportion of injuries sustained in the tackle event. Both the high proportion of injuries sustained within the tackle event and the high frequency of tackles within a match has warranted further investigation, specifically analysing the relationship between the frequency of events and consequent injuries.

Propensity analysis

Though injury incidence and hazard and odds ratios are a suitable method of analysis for injury data, event analysis requires a method that implements a ratio-based calculation to provide context to the injuries sustained within the event (Ekstrand et al., 2006; Nordström et al., 2014; Rafferty et al., 2018; Williams, Trewartha, Kemp, Brooks, et al., 2017). In this case, injury propensity can be calculated in order to describe the number of injuries sustained in relation to the number of events that have occurred, represented as the number of injuries per 100 or 1000 events (Bahr et al., 2020; Fuller, Brooks, et al., 2007). Tackle events often occur most frequently during matches, showing a substantially higher number of events per game than collisions (221.0 vs 14.8, respectively) and scrums (221.0 vs 28.9, respectively; Fuller, Brooks, et al., 2007). However, when calculating the propensity for injury in each contact event, collisions and scrums showed an injury propensity of 10.5 and 8.1 injuries/1000 events, respectively (Fuller, Brooks, et al., 2007). Whilst the tackle event occurs more frequently during matches, the propensity for injury is comparatively lower (6.1 injuries/1000 events; Fuller, Brooks, et al., 2007). In addition, collapsed scrums have shown a higher propensity for injury than scrums that did not collapse, even though collapsed scrums occurred less frequently (Taylor et al., 2014). The increased propensity from collapsed scrums results in a higher risk for injury within these events, primarily due to the low number of collapsed scrums that occur with a high frequency of injury. Increases in propensity and injury risk from collapsed scrums has resulted in the amendment of scrum laws in 2007 in order to provide better control over the event (Brooks & Kemp, 2008). In the 2012/13 and 2013/14 season, laws were amended further to minimise the number of collapsed scrums and reduce the impact forces from each group of players (Reboursiere et al., 2018). Since the change in laws in the 2013/14 season, World Rugby has reported a 25% reduction in the compression forces experienced by players, and consequently reduced the number of scrum injuries and scrum collapses (World Rugby, 2019b). Whilst World Rugby law changes have reduced the injury risk in scrum events, contact events such as collisions become challenging to control. Specifically, accidental collisions within matches often carry a higher injury risk than non-accidental collisions, meaning that controlling for injuries sustained during this event is not always possible (West, Starling, et al., 2020). Though the tackle event is of a variable nature, the regulations surrounding aspects of the tackle, such as the tackle height, have previously been amended to reduce the risk of injury (Tucker, Raftery, Kemp, et al., 2017; World Rugby, 2019a). However, the continued reporting of high injury proportions sustained within the tackle emphasise the importance of continued analysis into the event to reduce the impact on match injuries.

As a consequence of the high proportions of injuries sustained from the tackle event during matches, studies have been published in Rugby Union that investigate the tackle mechanisms leading to injuries (Burger et al., 2016; Davidow et al., 2018; Fuller, Brooks, et al., 2007; Hendricks et al., 2016; Tierney et al., 2018; Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). Specifically, concussion has been a priority injury over recent seasons and has resulted in the use of video analysis to identify high risk tackles (Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). Research identified that 76% of head injuries requiring assessment occurred during tackles, and that the propensity for head injuries was greater for shoulder tackles, front-on tackles and high-speed tackles (Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). Furthermore, analysing the characteristics of a tackle, such as the type or the legality of the tackle, identified that the propensity of head injuries were greater during illegal tackles and during head-to-head contact between the tackler and the ball carrier (Tucker, Raftery, Kemp, et al., 2017). These findings consequently led to World Rugby implementing law changes to the tackle, introducing sanctions for tackle events where players did not use their arms or made direct contact with a players head (World Rugby, 2019a). The analysis of injuries using performance analysis techniques in Rugby Union has therefore focused heavily on the association of tackle characteristics and concussive injuries, providing essential knowledge on concussion injury rates from a tackle event (Davidow et al., 2018; Hendricks et al., 2016; Tierney et al., 2018; Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). However, the continually high proportion of injuries sustained during the tackle event and the greater propensity for injury in different types of tackles has warranted further detailed analysis into the tackle event within Rugby Union. In order to encourage consistency between performance analysis research, in 2020 a consensus statement was published that outlined key performance indicators to utilise when analysing either the proficiency, or to describe a contact event during a Rugby Union match (Hendricks et al., 2020). The consensus statement utilised examples from previous research that implemented either technique proficiency to determine successful outcomes within a match, or event descriptors that provided a description of the contact event that led to successful outcomes as well as events that caused injury (Hendricks et al., 2013, 2014, 2015; Lim et al., 2011; Prim et al., 2006; Tucker, Raftery, Kemp, et al., 2017).

Event analysis

The method of analysing tackle proficiency has previously been implemented within Rugby Union, specifically in association with injury occurrence (Burger et al., 2016; Davidow et al., 2018; Tierney et al., 2018). Burger and colleagues (2016) made comparisons in tackle proficiency between tackles that resulted in injury and tackles that did not result in injury. Furthermore, research analsyed the proficiency of tackles requiring a HIA compared with the proficiency of an injury-free tackles (Davidow et al., 2018; Tierney et al., 2018). Studies utilising the proficiency criteria are in agreement that proficiency scores were lower in tackles that resulted in injuries or those that required a HIA. In addition, research identified specific variables associated with the proficiency influenced the outcome score, with criteria such as body positioning and anticipation scoring a lower proficiency in an injury related tackle (Davidow et al., 2018; Tierney et al., 2018). Though a reduction in proficiency of the tackle was evident in head impact tackles, the reductionist approach of proficiency scoring for a complex event such as the tackle limits the understanding of the tackle characteristics that can lead to injury. In addition, analysis of tackle proficiency does not provide information on the injury rates associated with the tackles that score low in proficiency. This is primarily due to the fact that analysis of tackle proficiency is usually undertaken separately to injury epidemiology research.

Consequently, previous research has implemented categorical variables that describe the different characteristics within a tackle that leads to injury, such as the tackle type, body position and the direction (Hendricks et al., 2016; Tierney et al., 2016; Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). The use of descriptive characteristics allows researchers to identify tackle variables that occur more frequently during injury-related tackles compared to non-injury tackles, accommodating the calculation of injury propensity for the variables that lead to injuries. Within studies investigating tackle characteristics and head injuries, front-on tackles, the speed of the player and awareness of an impending tackle showed a higher association with head injuries (Hendricks et al., 2016; Tierney et al., 2016; Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). In addition, the study by Tucker et al. (2017) identified that active shoulder tackles and head to head, head to elbow and head to knee contact had a higher propensity for head injury. Though head injuries represent a priority injury within Rugby Union, the continually high injury rates across all match injuries, specifically within the tackle, has warranted further investigation into tackles associated with injury.

Therefore, research within both Rugby League and Rugby Union has also implemented descriptive characteristics to investigate differences between a tackle resulting in any injury or no injury (Hendricks et al., 2016; Hopkinson et al., 2021). The descriptive characteristics utilised in these studies provides an improved understanding of the factors associated with the tackle event that influenced injuries (Hendricks et al., 2016; Hopkinson et al., 2021; Tucker, Raftery, Fuller, et al., 2017;

Tucker, Raftery, Kemp, et al., 2017). Findings identified that slower approaches in a tackle and player awareness of the impending tackle reduced the likelihood of injury (Burger et al., 2016; Hopkinson et al., 2021). In addition, tackles where the arms were below the shoulder, and the heads of the ball carrier and tackler collided was an important characteristic in the distinction between an injurious and non-injurious tackle (Hopkinson et al., 2021). However, comparing an injury inciting tackle against all other tackles within a match lacks specificity. When considering the many variables that can contribute to injuries within a tackle, such as the role of the player (i.e., ball carrier or tackler), the specific individual involved and the type of player (i.e., starter or replacement), comparing against all tackles may generalise results across an event of a variable nature that may differ between players. The continued analysis across a team-level reflects the analysis methods traditionally implemented in epidemiological research in Rugby Union, neglecting the potential for the identification of different characteristics between individuals (Roe et al., 2017). However, a recent study by Hopkinson et al. (2021) employed a player-specific method of analysing injury versus non-injury inciting tackles, matching the tackles that resulted in injuries with non-injurious tackles for the role of the player and the team and opponent within the same match. Though this method provided matched samples of tackles for comparisons of important tackle characteristics, research is yet to apply the same principle within professional Rugby Union. In addition, though the role of the player as a ball carrier or tackler has been considered in previous research (Burger et al., 2016; Davidow et al., 2018; Hendricks et al., 2015, 2016; Hopkinson et al., 2021; Tucker, Raftery, Kemp, et al., 2017), the influence of starter and replacement players is yet to be explored. As previous research has indicated that replacement players influence the physicality of a match and are often involved in a higher number of match events, including this factor in the analysis of the tackle events that lead to injury could provide important insights into injuries sustained within the tackle event.

Summary

This review of literature has highlighted the current injury problems within professional Rugby Union, and the work that has been undertaken to try and mitigate the risk of injury. The publication of a consensus statement has provided researchers with essential definitions and data collection procedures to adhere to when collecting injury surveillance data (Fuller, Molloy, et al., 2007). However, there remains limitations within the recommendations of the consensus statements, specifically in the analysis of injuries and the consistency of adherence between research. Whilst the substantial body of literature reporting injury rates in professional Rugby Union has provided valuable insight into the problem within matches (Bathgate et al., 2002; Brooks et al., 2005b, 2006; Rafferty et al., 2018; Ranson et al., 2018; West, Starling, et al., 2020; Whitehouse et al., 2016; Williams et al., 2013), the continued analysis of team-level injury rates negate the potential for individual differences within a team to be explored. Furthermore, a factor that has remained consistent throughout Rugby Union research is that the tackle event contributes to the highest proportion of injuries during matches (Brooks et al., 2005b; Cross, Kemp, et al., 2016; Fuller et al., 2008, 2013, 2020; Fuller, Brooks, et al., 2007; Holtzhausen et al., 2006; Kemp et al., 2008; Moore et al., 2015; West, Starling, et al., 2020), with specific tackle characteristics found to influence injuries (Burger et al., 2016; Hendricks et al., 2016; Hopkinson et al., 2021; Tucker, Raftery, Kemp, et al., 2017). In addition, the period within the match has been found to influence the injuries sustained within matches, with the third and fourth quarter showing higher injury incidence (Bathgate et al., 2002; Brooks et al., 2005b; Holtzhausen et al., 2006; Williams et al., 2013). Fatigue has consistently been suggested as an influencing factor, though research has also suggested that replacement players who are primarily used in the second half of matches, also influence these increasing injury rates (Bathgate et al., 2002; Lacome et al., 2016). However, research is yet to fully investigate the injury rates and mechanisms of starter and replacement players throughout a match, and the influence of using replacement players on the injuries sustained within a match.

Research rationale

Improving player welfare is an essential consideration within sport, and injury surveillance constitutes the first stage of developing effective injury risk mitigation strategies (Finch, 2006; Roe et al., 2017; van Mechelen et al., 1992). The continually high injury incidence within professional Rugby Union warrants further investigation, however, the continued analysis at a team-level negates the identification of injury risk at an individual level. Specifically, the limited research analysing the effect of replacement players on injuries within a match requires a player-specific analysis of exposure, injury rates and mechanisms. Identifying whether the physical impact of replacement players consequently effects the injuries sustained within a match is crucial for informing the regulations surrounding the use of replacement players within Rugby Union matches. This in turn will contribute to the improvement of player welfare, where evidence informed decisions surrounding the risk of injury can be implemented within Rugby Union. With this in mind, this thesis will investigate the rates of injury within professional Welsh Rugby Union and the use of consensus statements within injury surveillance research. It will then look to overcome some of the limitations outlined in the review of literature to provide a better understanding of the injury rates within professional Rugby Union.

Chapter 3: Four-year match injury surveillance in male Welsh professional Rugby Union teams.

Introduction

Understanding injury rates and establishing effective injury risk mitigation strategies relies on a well-structured and proficient data collection. The Translating Research into Injury Prevention Practice (TRIPP) framework was established to guide injury research, with surveillance constituting the first stage of data collection (Finch, 2006). Injury surveillance research has been conducted within various sports (Alonso et al., 2010; Ekstrand et al., 2011b; Frost & Chalmers, 2014; Fuller et al., 2020; Prien et al., 2017), however, inconsistency in definitions and data collection procedures make comparisons between sports challenging. Consequently, consensus statements detailing injury definitions and data collection procedures were developed within specific sports, as well as a more recently published general consensus within all sport (Bahr et al., 2020; Fuller et al., 2006; Fuller, Molloy, et al., 2007; Junge et al., 2008; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Ranson, et al., 2016; Pluim et al., 2009; Timpka et al., 2014; Turner et al., 2012).

The consensus statement published within Rugby Union has meant that research published after 2007 has allowed for comparisons between studies using the same definitions and data collection procedures (Fuller et al., 2020; Moore et al., 2015; Ranson et al., 2018; West, Starling, et al., 2020). Rugby Union has consistently shown high injury rates when compared to other team sports, with the men's international and professional level showing the highest injury rates within the game (Viviers et al., 2018; Williams et al., 2013). Across different levels of Rugby Union, injury incidence has ranged from 55.4 injuries per 1000 match hours at a professional club level to 180 injuries per 1000 match hours for a single international team (Fuller et al., 2013; Holtzhausen et al., 2006; Moore et al., 2015). In addition, injury burden within multiple professional Rugby Union teams across sixteen season has shown values as high as 2178 days-lost per 1000 hours (West, Starling, et al., 2020). The high incidence and burden are further emphasised when compared with other team sports. Specifically, within professional football an injury incidence of 27.5 injuries per 1000 match-hours and an injury burden of 88.5 days-lost per 1000 match-hours (specifically for hamstring injuries) has been reported (Ekstrand et al., 2011b; Ekstrand, Waldén, et al., 2016).

The differences in incidence between Rugby Union and other team sports are primarily due to the demands placed upon players during matches, with Rugby Union requiring many different high intensity and collision-based movement patterns (Owen et al., 2015; Roberts et al., 2008). Within Rugby Union matches, two teams compete against each other, with each team on the field of play consisting of 15 players split into eight forwards and seven backs. The physical demand can differ between positions, with forwards often spending more time competing for the ball than the backs, resulting in a greater number of impact events (Owen et al., 2015). The differing positional demands often result in different injury outcomes, with forwards sustaining a higher number of injuries than the backs, but the backs sustaining injuries that result in more days-lost (Bathgate et al., 2002; Brooks et al., 2005b; Owen et al., 2015). However, even with differences in match demands the injuries across body areas remains similar (Owen et al., 2015). Specifically, the head and shoulder are the body areas most commonly injured within matches (Bathgate et al., 2002; Best et al., 2005; Fuller et al., 2013; Moore et al., 2015), with the knee often constituting the most severe injury, resulting in the highest number of days-lost (Bathgate et al., 2002; Brooks et al., 2005b; Fuller et al., 2008, 2013). Moreover, concussion has been one of the most problematic and consistent injuries occurring in Rugby Union. Concussion injury incidence has been rising year-on-year since 2006, ranging from 1.4 per 1000 match-hours at a professional club level (Holtzhausen et al., 2006) to 21.5 per 1000 match-hours when the professional and international level were combined (Rafferty et al., 2018). With consistently high overall injury incidence as well as rising incidence of specific injuries, understanding the causes of injuries is essential. Previous research has consistently identified that contact events during matches constitutes the principle cause of injuries, with tackling or being tackled accounting for 40-58% of match injuries (Bathgate et al., 2002; Best et al., 2005; Fuller et al., 2008, 2013; Fuller, Brooks, et al., 2007; Holtzhausen et al., 2006; Moore et al., 2015).

Whilst injury surveillance research has been published outlining the injury rates and mechanisms at a professional level within England, Australia and South Africa (Bathgate et al., 2002; Brooks et al., 2005b; Holtzhausen et al., 2006; West, Starling, et al., 2020), it is unknown whether injury rates of the professional clubs in Wales is similar to previously reported rates. In addition, it is yet unknown whether injury rates and mechanisms have changed over recent seasons within the Welsh professional cohort. Therefore, the aim of this study was to assess match injury incidence, burden and mechanism over a four-year period for the four professional male Welsh Regional Rugby Union teams. Additionally, match injury incidence and burden for forwards and backs was compared over the four-year period.

Methods

Participants

Participants were the players selected for the first team squad of each club across the four seasons. To be considered a first team player, participants must predominantly have been selected for the first team rather than an Academy or second team. Each player provided informed consent for their injury data to be collected and analysed. Ethical approval was obtained from the University's Research Ethics committee.

Procedure

The Welsh Rugby Union injury surveillance programme was established in 2012 and player injury records from the four professional male Welsh Regional Rugby Union teams, the only professional level Rugby Union clubs in Wales, have been collected since its inception. The prospective nature of the data collection mitigates potential recall errors that can occur with retrospective reporting of player exposure and injury occurrence (Fuller, Molloy, et al., 2007). The surveillance period reported covers four seasons (2012/13, 2013/14, 2014/15 and 2015/16), from the 1st of July 2012 to the 30th of June 2016 (inclusive). The injury definitions and data collection procedures followed the recommendations from the international consensus statement on Rugby Union injury surveillance (Fuller, Molloy, et al., 2007).

Baseline information about player position, date of birth and anthropometrics for each player that participated in regional competitions was provided. Throughout the four seasons, one designated medical team member from each regional team recorded all time-loss injuries. The designated medical team member was responsible for recording injury details such as: date of injury and return to play, injury location, Orchard Sports Injury Classification System (OSICS version 10) code (Rae & Orchard, 2007), playing position (forward or back), mode of onset (gradual, sudden, impact, insidious), mechanism of injury (contact or non-contact) and injury recurrence. At the end of each month all data was sent to an independent researcher at the University (ISM). Injury records and exposure data were checked and reconfirmed if necessary to minimise missing data.

Definitions

All injury definitions were based on the international Consensus Statement for Rugby Union (Table 4; Fuller, Molloy, et al., 2007). The recurrence of an injury was reported based on the clinical judgement of the designated medical team member collecting the injury data.

Table 4 The time-loss injury definition, recurrent injury definition and injury severity used in the study based on the recommendations outlined in the consensus statement by Fuller et al. (2007).

Injury Measure	Definition
Time-loss Injury	*Any physical complaint sustained by a player during the season that rendered the player unavailable for match selection for more than one day, following midnight of the day of injury, irrespective of whether a match was scheduled on that day*
Recurrent Injury	*An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury*
Injury Severity	*The number of days that have elapsed from the date of injury to the date of the player's return to full participation and availability for match selection*

Data analysis

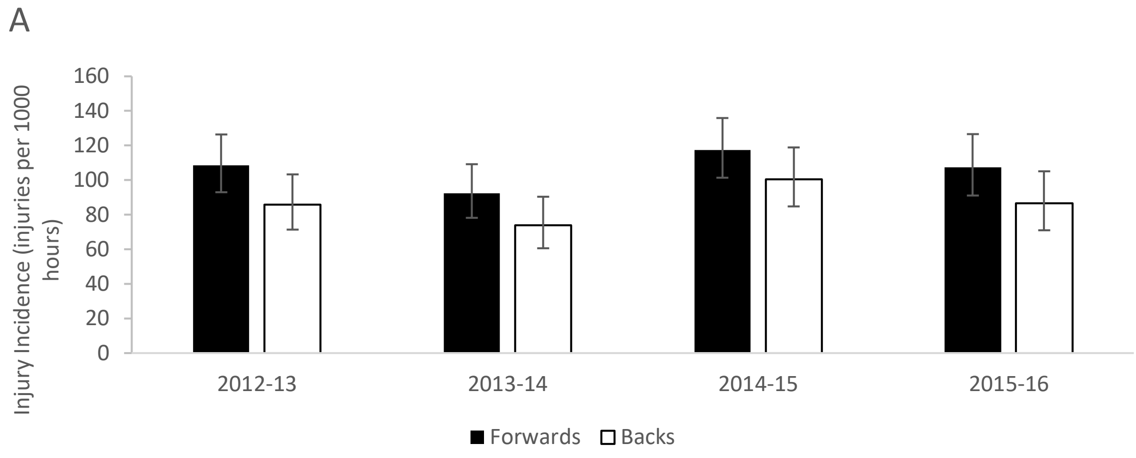
Match exposure was calculated based on 15 players being exposed for 80 minutes. Where forward and backs were compared, exposure was based on either eight or seven players playing for 80 minutes, respectively. Only injuries sustained in regional matches i.e. the Celtic League/PRO 12, European competitions, Anglo Welsh cup and any practice matches, were used during analysis. Match injury incidence was calculated as the number of injuries per 1000 match hours, with 95% confidence intervals (CI). The severity of injuries were presented as both the mean days unavailable with standard deviation (SD), and median days unavailable with interquartile range (IQR). Injury burden was calculated as days-lost per 1000 hours ((∑ days-lost/∑ exposure hours)x1000) and provides an overview of injury risk (Ekstrand, Hägglund, et al., 2013; Fuller, 2018), with 95% confidence intervals (CI). All data was tested for normal distribution. Match incidence and severity for forwards and backs were analysed separately. Forwards and backs data were combined to analyse injuries based on body area, mechanism of injury and recurrent nature of injuries. Based on the injury diagnosis from the OSICS code, the incidence and burden for the top five specific injuries was calculated for each season. To compare two injury incidences a rate ratio (RR) was calculated, with a significant difference identified by the 95% CI for the RR not intersecting with unity. Comparisons for significant differences between positional height and weight, number of injuries per season and mean injury severity per season was analysed using the Mann-Whitney-Wilcoxon test. Comparisons for significant differences between the number and mean severity of injuries across seasons within positions was analysed using the Friedman test. Comparisons for significant differences between seasons for body area was analysed using the Kruskal-Wallis test. Significance was accepted as $p<0.05$ and all significance testing were computed using the *stats* package in R (R Core Team, 2020).

Results

A total of 783 players were selected across the four seasons, with squad sizes remaining similar between each season, ranging from 40 to 57 players (49 ± 5.1). Forwards were significantly taller (189.4 ± 6.9 cm vs 183.9 ± 5.9 cm, respectively, $p < 0.001$) and heavier than the backs (110.8 ± 8.7 kg vs 92.5 ± 8.0 kg, respectively, $p< 0.001$). A total of 548 matches were played throughout the four seasons (range: 124 to 143 matches per season), equating to 10960 match hours overall. There were 1086 match injuries across the four seasons, equating to an injury incidence of 99.1 injuries per 1000 match hours. There was a total of 28170 days unavailable due to injury across the four seasons, equating to an overall burden of 2570.3 days-lost per 1000 match hours. Sixty-one percent of players sustained at least one match time-loss injury in 2012/13, 56% in 2013/14, 59% in 2014/15 and 51% in 2015/16.

Position (forwards vs backs)

The overall number of match injuries and match injury incidence was similar between positions (forwards: 621 injuries, 106.4 injuries/1000 match hours; backs: 443 injuries, 86.8 injuries/1000 match hours; RR: 1.23, 95% CI 0.92-1.63). Even though the forwards appeared to have a higher injury incidence than the backs, there was no significant difference in the number or incidence of match injuries between positions across the four seasons (Figure 5).



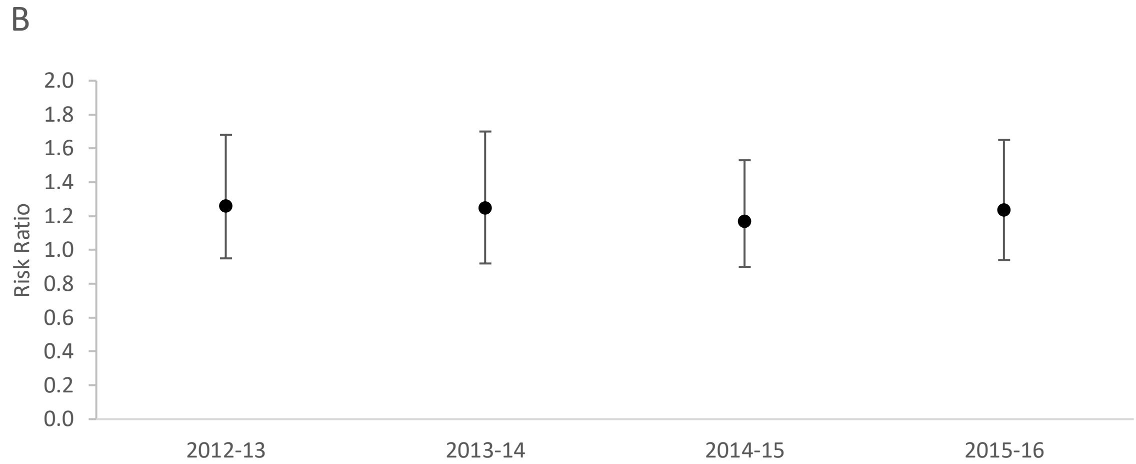


Figure 5 A) Match injury incidence (injuries/1000 hours) for forwards and backs for each season. Lines represent upper and lower 95% CI. B) The RR between the injury incidence of forwards and backs for each season. Lines represent upper and lower 95% CI.

The injury severity (mean days-lost per injury) was similar across the four seasons (Figure 6).

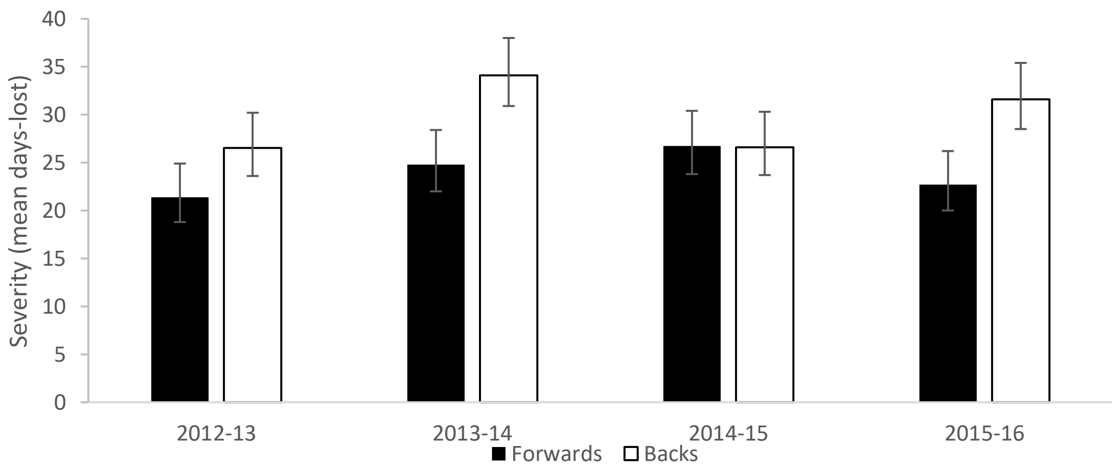


Figure 6 Match injury severity (mean days-lost) for forwards and backs for each season. Lines represent the standard deviation (SD).

The overall burden across the four seasons was similar between positions (2548.7 vs 2542.2 days-lost/1000 match hours for forwards and backs, respectively). The injury burden was higher for the backs than the forwards in the 2013/14 and 2015/16 season, with forwards showing a higher burden than the backs in the 2014/15 season only (Figure 7).

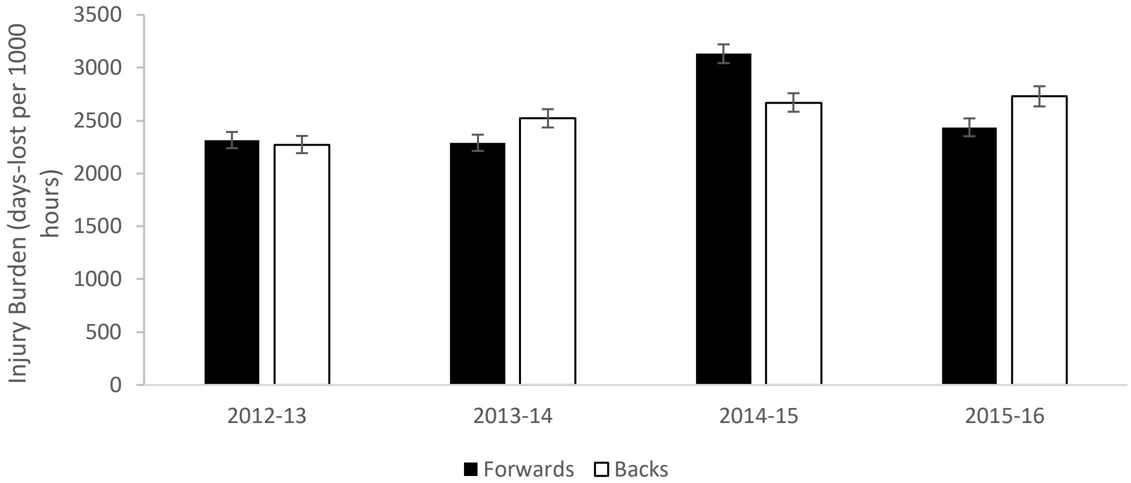


Figure 7 Match injury burden (days-lost per 1000 hours) for forwards and backs for each season. Lines represent upper and lower 95% CI.

Body region

The head, shoulder, knee and ankle had the highest match injury incidence across the four seasons (Table 5), with only the head injury incidence showing a significant increase from 2012/13 to 2015/16. Of the head injuries, 80 to 95% each year were concussions. Match injury burden for the shoulder and knee were consistently higher than any other body region (Table 5). The mean severity was similar between seasons for all body areas (Appendix A).

Table 5 Match injury incidence (injuries/1000 hours) and burden (days-lost/1000 hours), with upper and lower 95% CI.

Body Area	Season 2012/13	2013/14	2014/15	2015/16
Head				
Incidence	12.4 (8.9–17.3)	13.2 (9.6–18.2)	20.3 (15.7-26.3)	22.6 (17.4-29.4)
Burden	115.2 (103.3-128.4)	155.4 (141.4-170.7)	316.4 (296.4-337.7)	309.3 (288.2-332.0)
Neck				
Incidence	6.0 (3.7-9.7)	3.9 (2.2-7.0)	5.2 (3.1-8.6)	5.6 (3.3-9.5)
Burden	192.2 (176.7-209.1)	28.2 (22.6-35.2)	57.7 (49.5-67.2)	112.9 (100.4-126.9)
Shoulder				
Incidence	12.4 (8.9-17.3)	11.8 (8.4-16.6)	11.9 (8.5-16.7)	11.7 (8.1-16.8)
Burden	437.9 (414.1-463.0)	476.8 (451.9-503.1)	668.2 (638.9-698.8)	401.2 (377.0-426.9)

Elbow				
Incidence	1.1 (0.4-3.4)	2.1 (0.9-4.7)	0.4 (0.1-2.8)	0.4 (0.1-2.8)
Burden	87.6 (77.3-99.2)	34.3 (28.1-41.9)	42.0 (35.1-50.2)	26.2 (20.5-33.4)
Forearm				
Incidence	0.7 (0.2-2.8)	0.7 (0.2-2.8)	0.3 (0.04-2.1)	0.4 (0.1-2.8)
Burden	20.2 (15.6-26.2)	98.9 (87.9-111.3)	97.9 (87.1-110.1)	5.2 (3.0-9.0)
Wrist & Hand				
Incidence	4.6 (2.7-7.9)	3.6 (1.9-6.7)	4.9 (2.9-8.3)	1.6 (0.6-4.3)
Burden	76.6 (67.0-87.5)	103.6 (92.3-116.2)	263.3 (245.1-282.8)	95.6 (84.2-108.6)
Chest				
Incidence	3.2 (1.7-6.2)	1.4 (0.5-3.7)	2.4 (1.1-5.0)	2.4 (1.1-5.3)
Burden	47.5 (40.1-56.3)	58.6 (50.3-68.3)	21.7 (16.9-27.8)	26.6 (20.9-33.9)
Lumbar				
Incidence	2.8 (1.4-5.6)	1.8 (0.7-4.3)	1.4 (0.5-3.7)	0.8 (0.2-3.2)
Burden	13.5 (9.8-18.6)	11.4 (8.1-16.1)	9.8 (6.8-14.2)	6.9 (4.3-11.1)
Hip/Groin				
Incidence	7.1 (4.6-11.0)	3.6 (1.9-6.7)	6.6 (4.2-10.4)	3.2 (1.6-6.4)
Burden	85.1 (75.0-96.6)	31.8 (25.8-39.1)	99.7 (88.8-112.0)	25.0 (19.5-32.1)
Posterior Thigh				
Incidence	6.7 (4.3-10.5)	6.1 (3.8-9.8)	6.6 (4.2-10.4)	7.7 (4.9-12.1)
Burden	155.7 (141.8-171.0)	162.5 (148.2-178.1)	115.7 (103.9-128.9)	172.6 (157.0-189.8)
Anterior Thigh				
Incidence	7.8 (5.1-11.9)	5.4 (3.3-9.0)	12.2 (8.8-17.0)	7.3 (4.6-11.6)
Burden	47.5 (40.1-56.3)	41.1 (34.2-49.3)	110.5 (99.0-123.4)	58.1 (49.3-68.4)
Knee				
Incidence	11.7 (8.3-16.5)	10.4 (7.2-15.0)	13.6 (9.9-18.6)	11.7 (8.1-16.8)
Burden	451.8 (427.7-477.3)	548.6 (521.8-576.7)	511.5 (485.9-538.4)	695.2 (663.1-728.8)
Lower Leg				
Incidence	7.4 (4.8-11.4)	5.7 (3.5-9.3)	5.2 (3.1-8.6)	7.3 (4.6-11.6)
Burden	206.7 (190.6-224.2)	86.8 (76.5-98.4)	51.0 (43.4-60.0)	73.0 (63.1-84.5)
Ankle				
Incidence	9.2 (6.3-13.5)	8.9 (6.0-13.2)	12.9 (9.3-17.8)	6.9 (4.3-11.1)
Burden	230.5 (213.4-248.9)	337.9 (317.0-360.1)	377.3 (355.4-400.5)	241.1 (222.5-261.2)
Foot				
Incidence	2.1 (0.9-4.7)	2.9 (1.5-5.8)	2.4 (1.1-5.0)	4.0 (2.2-7.4)
Burden	111.3 (99.6-124.3)	183.6 (168.4-200.2)	54.5 (46.6-63.8)	161.3 (146.2-177.9)

In terms of specific injuries, concussion incidence increased, and anterior thigh haematoma incidence decreased from the 2012/13 to the 2015/16 season (Table 6). No other significant changes in specific injuries were observed. The severity of the three specific injuries remained similar across the four seasons. Concussion injury incidence and burden was the highest of all specific injuries, with an increase in burden shown from the 2012/13 to the 2015/16 season (86.5 vs 302.4 days-lost per 1000 match hours, respectively). An increase in burden was also seen for the acromioclavicular (AC) joint (71.3 in 2012/13 vs 130.6 days-lost per 1000 match hours in 2015/16), whereas anterior thigh haematoma was the only injury to show a decrease in injury burden (48.6 in 2012/13 vs 17.7 days lost per 1000 match hours in 2015/16).

Table 6 Match injury incidence (injuries/1000 hours) and burden (days-lost/1000 hours), with upper and lower 95% CI, mean injury severity (mean days-lost), with standard deviation and median severity (median days-lost) with the interquartile range, of the three specific injuries that were in the top five injury incidence for at least three seasons.

Injury	**Season**			
	2012/13	**2013/14**	**2014/15**	**2015/16**
Concussion				
Incidence	10.6 (7.4-15.2)	11.4 (8.1-16.1)	17.8 (13.5-23.4)	21.4 (16.3-28.0)
Burden	86.5 (76.3-98.1)	112.9 (101.1-126.1)	266.1 (247.8-285.7)	302.4 (281.5-324.8)
Mean Severity	8.1 (5.8)	9.9 (3.9)	14.7 (23.1)	14.1 (21.3)
Median Severity	6 (5.3-10.0)	9 (8.0-10.3)	8 (6.0-12.5)	10 (7.0-14.8)
Anterior Thigh Haematoma				
Incidence	8.2 (5.4-12.3)	6.1 (3.8-9.8)	7.7 (5.1-11.7)	2.4 (1.1-5.3)
Burden	48.6 (41.1-57.5)	32.5 (26.5-39.9)	60.5 (52.1-70.2)	17.7 (13.2-23.8)
Mean Severity	6 (3.2)	5 (3.5)	8 (7.9)	7 (4.5)
Median Severity	5 (3.5-9.0)	4 (3.0-5.0)	5 (3.0-8.0)	5 (4.3-11.0)
Acromio-clavicular (AC) Joint				
Incidence	3.9 (2.2-7.0)	3.9 (2.2-7.0)	5.2 (3.1-8.6)	5.6 (3.3-9.5)
Burden	71.3 (62.1-81.9)	73.2 (63.8-83.9)	97.6 (86.8-109.8)	130.6 (117.1-145.6)
Mean Severity	18 (27.5)	17 (9.8)	19 (18.2)	23 (31.7)
Median Severity	7 (4.5-21.0)	17 (11.0-22.3)	13 (10.0-17.0)	15 (9.3-20.3)

Mode and mechanism of injury

Impact and sudden onset were responsible for the highest percentage of injuries (38 to 55%) across each season (Appendix A). Between 72-80% of match injuries were due to contact mechanisms, with similar values shown across the four seasons. The three main mechanisms of contact injuries were collision, tackled and tackling (12-21%, 20-31% and 30-42% respectively) where seasonal values were similar.

Injury recurrence

The percentage of recurrent injuries remained similar across the four seasons (mean 17% ± 1.9). The overall incidence of recurrent injuries was 17.2 injuries per 1000 match hours, with values remaining similar each year (incidence range: 15.0 – 21.7). The overall severity of recurrent injuries across the four seasons was 28 ±2.5 days-lost, with severity remaining similar between recurrent and non-recurrent injuries throughout each season (recurrent range: 25 – 30; non-recurrent range: 22 – 29 days unavailable; $p = 0.19$).

Discussion

The aim of this study was to investigate injury rates and mechanisms across four seasons in professional Welsh Rugby Union teams and compare positional differences in match injury incidence, severity and burden. The number, incidence and severity of match injuries were similar between forwards and backs. The head, shoulder and knee body regions had the highest injury incidence for both positions, and the shoulder and knee had the highest injury burden. In terms of specific injuries, concussions accounted for the highest injury incidence for both positions and increased over the surveillance period, but there was a reduction in the incidence of anterior thigh haematomas for the same period. The tackle event contributed to the highest proportion of injuries sustained during matches each season, with between 50-63% of injuries sustained in the tackle event across the four seasons.

Injury incidence

Overall match injury incidence in the current study was 99.1 injuries/1000 match hours, which is higher than that previously reported in professional club Rugby Union (55.4, to 91 injuries/1000 match hours; Brooks et al., 2005b; Holtzhausen et al., 2006; Ranson et al., 2018), but lower than that reported for international level Rugby Union (180 injuries per 1000 hours; Moore et al., 2015). Differences between injury incidence at the professional and international level can be attributed to the differences in both the intensity and number of matches, with a lower number of matches played within a season and increased demands placed upon players at the international level (Moore et al., 2015; Williams et al., 2013). Interestingly, the injury rates in the current cohort is higher than recently reported within English professional Rugby Union (West, Starling, et al., 2020). This may be due to the differences in the number of teams and seasons, with the current study only investigating injuries sustained within four teams across four seasons. When comparing this to the study by West and colleagues (2020), who investigated injuries within 16 teams across 16 seasons, the potential for differences both within teams and across seasons may contribute to the differing injury rates. Though collecting data across multiple seasons may result in differing data collection methods (West, Starling, et al., 2020), the high injury rate shown in the current study warrants further investigation into the injuries sustained within the Welsh professional cohort.

Body region

The head, knee and shoulder were the body regions with the highest injury incidence and burden, following a similar trend seen in previous injury surveillance research (Bathgate et al., 2002; Fuller et al., 2008, 2013; Moore et al., 2015). When categorised into specific injuries, the injury burden of concussion was 50-60% higher than any other specific injury and also had the highest combined injury incidence across four seasons (15.3 injuries/1000 match hours). The increase in head injury incidence over time, and high incidence and burden of concussion, supports similar finding in previous research (e.g. 6.6 concussions/1000 player hours in 2008; Brooks & Kemp, 2008) to 15.8 concussions/1000 hour in 2016; England Professional Rugby Injury Surveillance Project Steering Group, 2017) and emphasises that concussion continues to be a priority injury throughout Rugby Union (Brooks & Kemp, 2008; England Professional Rugby Injury Surveillance Project Steering Group, 2017; Moore et al., 2015). Although concussion remains a priority for injury risk mitigation, the increases seen from research published in 2008 may also be attributed to increasing awareness through compulsory education on concussion symptoms and diagnosis. Within Wales, concussion education was mandated for all key stakeholders involved in Rugby Union (players, clinicians, referees and coaches) and directly targeted concussion knowledge deficits and common misconceptions identified by Mathema et al. (2016). In addition, the introduction of the Head Injury Assessment protocol by World Rugby, the global governing body, in the professional game may contribute to improved diagnosis and recognition of concussive injuries (Cross et al., 2019; World Rugby, 2021a).

Mechanism of injury

Interestingly, AC joint injury burden was the only other specific injury to show an increase from the 2012/13 to the 2015/16 season. In contrast, anterior thigh haematomas were the only injury to show a decrease in injury incidence and burden (48.6 vs 17.7 days-lost/1000 match hours in 2012/13 and 2015/16, respectively). These findings, together with the increase in concussion incidence and unchanged match injury incidence, show that the injury risk is changing within Rugby Union. Over the four-year surveillance period, the following trend was observed, a larger injury risk to the upper body region accompanied by a lower impact-related injury risk to the lower body region. It is conceivable that this change in injury risk is associated with the tackle event, which caused between 50-63% of all match injuries across the four seasons. Contact, and specifically the tackle event, has consistently been reported as causing the highest proportion of match injuries (Bathgate et al., 2002; Best et al., 2005; Fuller et al., 2008, 2013; Fuller, Brooks, et al., 2007; Holtzhausen et al., 2006; Moore et al., 2015). Tackle technique may therefore be changing towards connecting with a ball carrier higher up the body, and whilst high tackle technique has been identified as a risk factor (Brooks & Kemp, 2008; Fuller, Brooks, et al., 2007), it is not known whether tackle technique has been changing over previous years. New tackle sanction categories have been introduced by World Rugby to mitigate this injury risk (Tucker, Raftery, Kemp, et al., 2017). Yet, preliminary data has shown the incidence of tackle-related injuries and concussions to be similar before and after the new sanctions (England Professional Rugby Injury Surveillance Project Steering Group, 2017). It remains to be seen whether continued use of the tougher sanction helps reduce injury risk across Rugby Union.

Injury recurrence

In contrast to previous findings, recurrent injuries had a similar severity to new injuries (Brooks et al., 2005b; Ekstrand et al., 2011a; Waldén et al., 2005), though the incidence remained substantially lower than new injuries each season. The differences observed in the current study in comparison to previous research could be attributed to the recurrent injury diagnosis being based solely on the recall of the clinician. Though the consensus statement outlines the definition for diagnosing recurrent injuries, research has furthered the categorisation of injuries by emphasising the importance of considering subsequent injuries that are not of the same type and location (SIC 1.0 and 2.0; Finch & Cook, 2014; Fuller, Molloy, et al., 2007; Hamilton et al., 2011; Toohey et al., 2018). However, within research following the recommendations of the consensus statement, the use of subsequent injury categorisation is not advocated. Consequently, the methods implemented by research within professional level sport to report the categorisation of injuries that are not considered new can vary and present a challenge when attempting to compare between studies.

Limitations

One of the main limitations in the current study was the analysis of injury rates and mechanisms solely at a team level. Though the proportion of players sustaining a time-loss injury each season was reported, further differences between the player-exposure and injury rates was not considered. Furthermore, the method through which the team level injury incidence and 95% CI's were calculated did not consider the potential for differences between teams. Whilst methods such as regressions can account for clustering by team within the analysis, the methods implemented in the current study followed the recommendations outlined in the consensus statement (Fuller, Molloy, et al., 2007), and provides insight into the injury rates within the cohort.

A further limitation was the lack of specificity when analysing the tackle event. Though the tackle was identified as the contact event responsible for the highest proportion of injuries within matches, and a change in the pattern of injuries was established, further analysis into the mechanisms for the changing injury patterns was not feasible due to the nature of injury surveillance data. Whilst the purpose of injury surveillance research is to establish the mechanisms of injuries, a more detailed analysis of the specific tackle characteristics may provide further insight into the changing injury patterns observed in this study.

Conclusion

Injury incidence was higher than previously reported for professional Rugby Union, with the incidence and burden remaining similar between the positional groups. The higher incidence rate identified by the current study warrants further exploration to establish whether there is a general trend towards increasing injury rates over recent years. A changing match injury risk was observed, with reductions in anterior thigh haematomas but increases in concussion and AC joint incidence and burden leading to the overall match injury incidence remaining relatively stable. Tackle technique could be a risk factor contributing to these changes observed over the seasons. Further work considering the mechanism behind these changes is warranted, specifically examining injury trends within the cohort in more detail and exploring the potential changes in tackle techniques. Though recurrent injury incidence was reported in the current study, following the recommendations outlined in the consensus statement, the lack of further analysis regarding the nature of subsequent injury limits the understanding of the inter-injury relationships within this cohort. Further work is warranted to understand the nature of reporting these types of injuries within other professional sport following recommendations outlined in consensus statements.

Chapter 4: Recurrent and subsequent injuries in professional sport: a systematic review.

Introduction

Injury risk associated with participation in sport can vary depending on the type of sport and level of play (Bahr & Holme, 2003a; Fuller et al., 2017; Giroto et al., 2017; Hägglund et al., 2016; Jacobson & Tegner, 2007; Lathlean et al., 2018; Orchard et al., 2006; Roe et al., 2018). One of the main priorities for any medical team in a professional or elite sporting environment is to reduce the number of days a player is unavailable throughout a season. This can be achieved through prospectively recording injuries in order to help inform the development of interventions aimed at injury risk mitigation and rehabilitation (Bahr & Krosshaug, 2005; Verhagen & Van Mechelen, 2010). Frameworks outlined by van Mechelen et al. (1992) and Finch (2006) identify that using objective data from injury surveillance to establish the injury problem is the first stage of effective injury risk mitigation. Previously published consensus statements have therefore outlined definitions and procedures to follow when conducting injury surveillance in specific sports such as Athletics, Aquatic sports, Association Football, Cricket, Horse Racing, Rugby Union and Tennis (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Junge et al., 2008; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Ranson, et al., 2016; Pluim et al., 2009; Timpka et al., 2014; Turner et al., 2012).

A limitation with the current reporting of injury rates within injury surveillance research is the lack of distinction between new and recurrent injuries. Within traditional injury surveillance, all recorded injuries are new injuries unless they are the exact same injury as a previous one, in which case they are referred to as a recurrent injury (Finch & Cook, 2014). Yet often no distinction is made in reported injury rates. Though Chapter 3 reported the rate of recurrent injuries within the Welsh professional cohort (17.2 injuries/1000 match hours), the initial team-level injury incidence included all injuries sustained by players within the study period (99.1 injuries/1000 match hours). Whilst reporting the recurrent injury rate provides insight into the recurrent injuries sustained within the cohort, the lack of clarity on whether an injury is new or recurrent within epidemiological research presenting the overall injury rate makes developing injury risk mitigation strategies challenging. The challenge is further emphasised when considering the increased risk of injury following previous injury and increased severity of recurrent injuries (Brooks et al., 2005b; Ekstrand et al., 2011a; Theisen et al., 2013; Toohey et al., 2017). Further challenges arise when players sustain multiple injuries, contributing multiple entries to the overall injury database. Whilst some studies identify that players have sustained multiple injuries during the injury surveillance period, they do not always provide any detail on the type or location of the injuries (Fortington et al., 2017; Moore et al., 2015). Furthermore, there are often discrepancies between using multiple (several unrelated injuries), recurrent (more than one occurrence of the exact same injury) or subsequent (any injury occurring after the index injury, where the index injury represents the first recorded injury of an athlete within a surveillance period) terminology to describe the injury occurrence, despite the different definitions (Finch et al., 2017; Finch & Cook, 2014; Hamilton et al., 2011; Jacobson & Tegner, 2007; Stubbe et al., 2015; Toohey et al., 2018).

Although consensus statements have outlined a standard method of reporting and definition for recurrent injuries, subsequent injuries that do not present with the same injury diagnosis are overlooked (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Junge et al., 2008; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Ranson, et al., 2016; Pluim et al., 2009; Timpka et al., 2014; Turner et al., 2012). Consequently, research has aimed to classify subsequent injuries as local, recurrent, re-injury or exacerbation and has provided more specific categories for a clinical and data driven categorisation through subsequent injury categorisation models (SIC 1.0 and 2.0; Finch, 2006; Finch & Cook, 2014; Fuller, Bahr, et al., 2007; Hamilton et al., 2011; Toohey et al., 2018). The publication of standardised data collection procedures in consensus statements and specific subsequent injury categorisation models provide an opportunity for research to identify the recurrent or subsequent nature of injuries. However, it remains unknown whether injury surveillance research within professional and elite sport investigate recurrent or subsequent injuries, limiting the current understanding of the occurrence of these types of injuries.

This study systematically reviews the reporting of recurrent and subsequent injuries in prospective injury surveillance research within professional and elite sports that have a published, peer-reviewed consensus statement on the definitions and procedures for reporting injuries.

Methods

The preferred reporting items for systematic reviews and meta-analysis (PRISMA) statement was followed to ensure accurate reporting throughout (Moher et al., 2009). The systematic review was prospectively registered on PROSPERO international prospective register for systematic reviews (CRD42019119264).

Search

The online databases of SCOPUS, Embase (via Ovid) and Medline (via Ovid) were used to search for articles. The search strategy included articles published after 2005, the earliest publication date of the peer-reviewed consensus statement in the included sports (Orchard et al., 2005), until the 23rd of July 2020. The search was limited to English language articles, with the search on Embase and Medline limited to full text and human participants. Only sports with a published peer-reviewed consensus statement on the definitions and data collection procedures for reporting injuries were included in the search strategy. To ensure research reporting injuries in professional or elite sports was returned, the search strategy included injury and sports terms linked with Boolean operators "AND" and "OR". The following terms were included in the search:

- Injury terms: injuries, injury, recurrent, subsequent
- Sport terms: football, rugby, athletics, swimming, cricket, diving, waterpolo, tennis, horseracing, professional, elite.

The terms were entered into the search engine as follows; injury OR injuries AND recurrent OR subsequent AND football OR rugby OR athletics OR swimming OR cricket OR diving OR waterpolo OR tennis OR horseracing AND professional OR elite.

Study selection

All results returned by the online databases were exported to EndNote for the organisation of references and removal of duplicates before titles and abstracts were screened. Once duplicates had been removed, titles and abstracts of all remaining articles were initially screened for the inclusion of injury reporting in professional or elite level football (including Australian Football League, soccer and Gaelic football), rugby (including rugby union, rugby league and rugby sevens), athletics, aquatic sports (including swimming, water polo, diving and biathlon), cricket, tennis and horse racing (injuries to the jockey only). Conference abstracts, commentaries and systematic and literature reviews were excluded, and only full text articles were eligible. The selection of articles identified for full text screening were then screened to identify whether they included: (1) prospectively collected data, which provides a more accurate method of data collection when recording the exposure and injury details within sport (Meeuwisse et al., 2007); (2) data collection procedures and definitions following a consensus statement; (3) injury records maintained by one designated medical team member for consistency within injury recording; (4) data on professional or elite level sport. Articles reporting injuries in amateur level sport were excluded to enable a consistent comparison across the same level of sport. When the original full text article could not be located, authors were contacted directly. The reference list of included articles was also searched to identify further appropriate studies. An initial sample of 10% of titles and abstracts (n=170) were screened by the primary (LB) and second author (JV-C). As there was an almost perfect agreement between authors (Cohen's K 0.97), the primary author screened all remaining titles and abstracts. All full text articles outlined for each stage of review following the screening of titles and abstracts were reviewed by both authors independently (LB and JV-C). If there were any discrepancies between the authors on the inclusion of an article, these were discussed and if no agreement was made a third author (ISM) was used as an adjudicator. There was an almost perfect agreement on the full text articles screened (Cohen's K 0.83). Discussion on inclusion resolved the disagreement between authors.

Data extraction

Data were extracted from the eligible full text articles and recorded in an Excel spreadsheet. The extracted data contained information on (1) how the data were collected (i.e. prospective cohort); (2) injury definitions and procedures used, including how new and recurrent injuries were defined; (3) length of data collection period; (4) number of teams or players and level of play; (5) sex of the participants; (6) number of injuries sustained overall, and where relevant the match and training injury incidence; (7) number of recurrent or subsequent injuries, including the subsequent injury category, the recurrent injury rate, the type or severity of recurrent injuries. As the search criteria included only professional and elite sports with consensus statements, all articles included followed the injury definitions and data collection procedures of the respective sports consensus statements. Definitions of injury and recurrent injury in each of the sports consensus statement are shown in Table 7. Study quality was assessed using an amended Downs and Black (1998) checklist. The checklist was amended to exclude questions associated with confounders and intervention studies (questions five, eight, 13 and 25) due to the prospective nature of data collection within the studies.

Table 7 The definitions of a new injury and recurrent injury from consensus statements.

Author Year	Sport	Injury Definition	Recurrent Injury Definition
Orchard et al., (2005)	Cricket	Any injury or other medical condition that either (a) prevents a player from being fully available for selection for a major match or (b) during a major match, causes a player to be unable to bat, bowl or keep wicket when required by either the rules or the team's captain.	A recurrent injury is one to the same side and body part and of the same injury type as an injury that previously qualified as a significant injury earlier in the same season, but which had recovered.
Fuller et al., (2006)	Football	Any physical complaint sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time-loss from football activities. An injury that results in a player receiving medical attention is referred to as a "medical-attention" injury and an injury that results in a player being unable to take a full part in future football training or match play as a "time-loss" injury.	An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury. A recurrent injury occurring within 2 months of a player's return to full participation is referred to as an "early recurrence"; one occurring 2 to 12 months after a player's return to full participation as a "late recurrence" ; and one occurring more than 12 months after a player's return to full participation as a "delayed recurrence".
Fuller et al., (2007)	Rugby	Any physical complaint, which was caused by a transfer of energy that exceeded the body's ability to maintain its structural and/or functional integrity, that was sustained by a player during a rugby match or rugby training, irrespective of the need for medical attention or time-loss from rugby activities. An injury that results in a player receiving medical attention is referred to as a "medical-attention" injury and an injury that results in a player being unable to take a full part in future rugby training or match play as a "time-loss" injury.	An injury of the same type and at the same site as an index injury and which occurs after a player's return to full participation from the index injury. A recurrent injury occurring within 2 months of a player's return to full participation is referred to as an "early recurrence"; one occurring 2 to 12 months after a player's return to full participation as a "late recurrence" ; and one occurring more than 12 months after a player's return to full participation as a "delayed recurrence".

Junge et al., (2008)	Multi-Sport (IOC)	Any musculoskeletal complaint newly incurred due to competition and/or training during the tournament that received medical attention regardless of the consequences with respect to absence from competition or training.	An injury of the same location and type, which occurs after an athlete's return to full participation from the previous injury.
Pluim et al., (2009)	Tennis	Any physical or psychological complaint or manifestation sustained by a player that results from a tennis match or tennis training, irrespective of the need for medical attention or time loss from tennis activities.	A medical condition of the same type and at the same site linked to an index medical condition and which occurs after a player's return to full participation from the index medical condition.
Turner et al., (2012)	Horse Racing	Any physical complaint sustained by a person that results from competitive riding, training or other recognised activity that brings a person into contact, or in close vicinity and with the potential for contact, with one or more thoroughbred racehorses, irrespective of the need for medical attention or time loss from horse racing activities.	An injury of the same type and at the same site as an index injury, and the one that occurs after a person's return to full participation in equine-related activities following the index injury.
Timpka et al., (2014)	Athletics	A physical complaint or observable damage to body tissue produced by the transfer of energy experienced or sustained by an athlete during participation in Athletics training or competition, regardless of whether it received medical attention or its consequences with respect to impairments in connection with competition or training. A time loss injury or illness is one that leads to the athlete being unable to take full part in athletics training and/or competition the day after the incident occurred.	An incident of the same type and at the same site linked to an index incident and which occurs after an athlete's return to full function and participation from the index recordable incident.
Mountjoy et al., (2016)	Aquatic	A physical complaint or observable damage to body tissue produced by the transfer of energy experienced or sustained by an athlete during participation in training or competition in an aquatic discipline, regardless of whether it received medical attention or its consequences with respect to impairments in competition or training. A time-loss injury or illness leads to the athlete being unable to take full part in FINA activities.	Injury to same location and of the same type as the index injury, where the index injury has completely healed.
Orchard et al., (2016)	Cricket	A general time-loss injury is any injury (or illness) that results in a player being considered unavailable for match-play, irrespective of whether a match or training was actually scheduled.	A recurrent injury is one of the same type which reoccurs in the same season (surveillance year) after it has been defined as recovered.

Reporting of results

Extracted data were summarised for each article. The methods of reporting injuries, number and incidence of recurrent injuries and the proportions and categories for subsequent injuries were collated in order to provide a narrative overview of results. When analysing and reporting injuries in the current review, combining new and recurrent injuries was defined as the total injury rate.

Results

The online database search returned 1708 articles (Figure 8). Once duplicates were removed, 1322 titles and abstracts were screened, and 199 articles met the inclusion criteria outlined for this stage. The 199 articles were eligible for full text screening, and an additional 13 articles were identified in references. Of the 212 full text articles screened, 81 articles met the inclusion criteria. However, 30 (37%) of these articles did not report the recurrence of injuries within the study, therefore resulting in 51 articles (one article containing two studies) being eligible for data extraction.

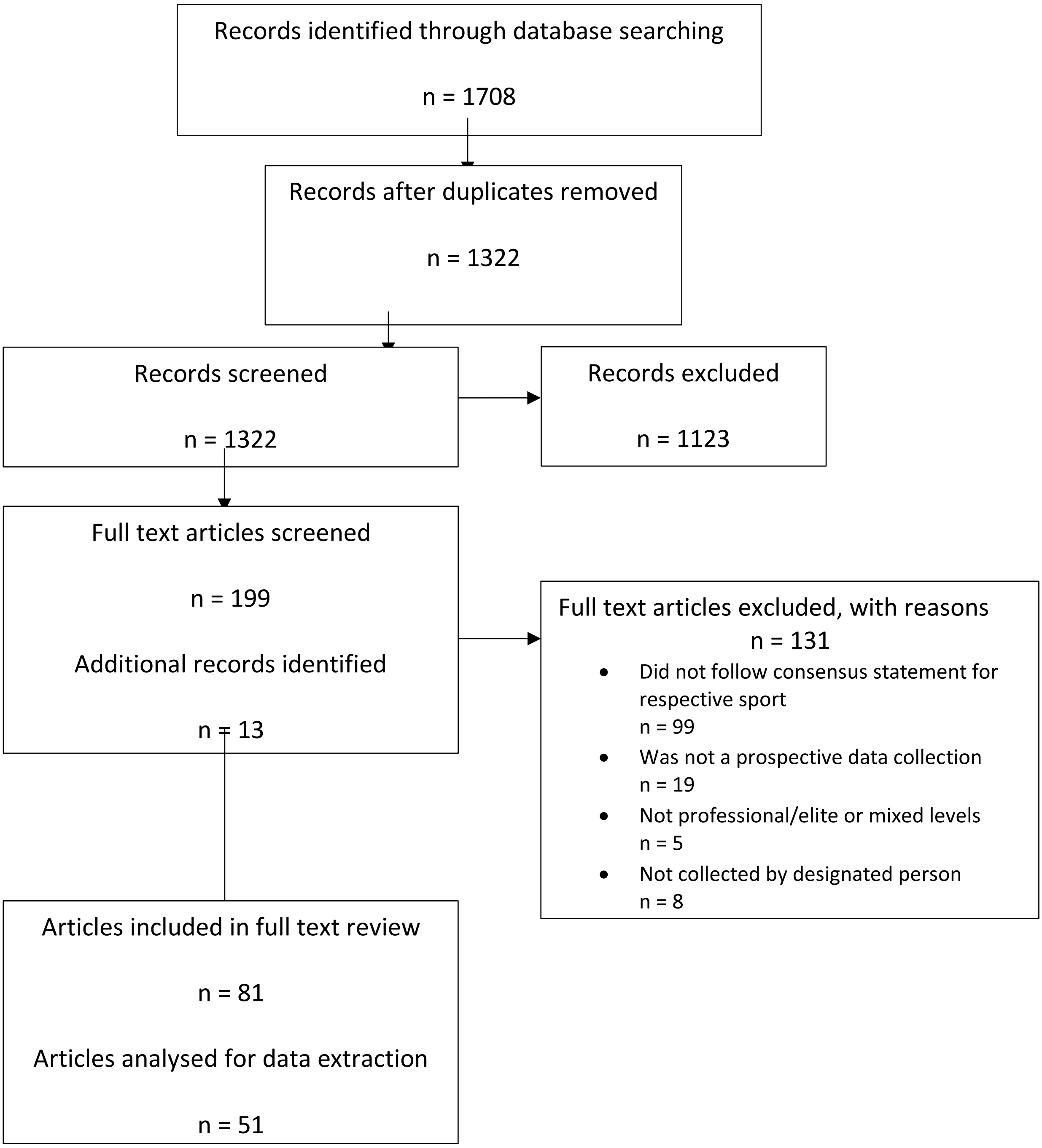


Figure 8 PRISMA flow diagram.

The number of studies within each sport varied, with 31 studies in football/soccer (Beijsterveldt et al., 2015; Bengtsson et al., 2020; Bjørneboe et al., 2014; Dvorak et al., 2011; Eirale et al., 2012, 2013; Ekstrand et al., 2011a, 2011b, 2012; Ekstrand, Van Dijk, et al., 2013; Ekstrand, Askling, et al., 2013; Ekstrand, Waldén, et al., 2016; Ekstrand, Lee, et al., 2016; Ekstrand et al., 2020; Ekstrand & Torstveit, 2012; Ergün et al., 2013; Gajhede-knudsen et al., 2013; Gomez-Piqueras et al., 2018; Hagglund et al., 2011, 2013; Hägglund et al., 2016; Hallen & Ekstrand, 2014; A. Jones et al., 2019;

Larruskain, Celorrio, et al., 2018; Larruskain, Lekue, et al., 2018; Lee et al., 2014; Lundblad et al., 2013; Nordström et al., 2014; Noya Salces et al., 2014; Petersen et al., 2010; Stubbe et al., 2015), 13 in rugby (two rugby sevens, eleven rugby union; Cross, Kemp, et al., 2016; Fuller et al., 2008, 2013, 2017; Kemp et al., 2008; Kenneally-Dabrowski et al., 2019; Ma et al., 2016; Moore et al., 2015, 2018; Pearce et al., 2011; Rafferty et al., 2018; Toohey et al., 2019; Williams, Trewartha, Kemp, Cross, et al., 2017), five in athletics (Alonso et al., 2009, 2010, 2012; Edouard et al., 2013, 2014), one in Olympic multi-event (Junge et al., 2009) and one in cricket (Moore et al., 2018; Table 8). There were no studies from aquatic sports, horseracing or tennis. Although there were a range of sports included, only one study reported injury rates specifically in female sport (Ma et al., 2016). The duration of data collection ranged from 3 days (Edouard et al., 2013) to 16 seasons (Bengtsson et al., 2020; Ekstrand et al., 2020). In the studies where data collection was conducted across multiple seasons, studies often did not clarify how many athletes were involved each season, instead opting to report the overall number of athletes involved across all seasons (Bengtsson et al., 2020; Ekstrand et al., 2011a; Ekstrand, Van Dijk, et al., 2013; Gajhede-knudsen et al., 2013; Hallen & Ekstrand, 2014; Nordström et al., 2014). There was a wide range in the number of participants included in the data collection, from 36 athletes (Eirale et al., 2012) to 9672 athletes (Junge et al., 2009), whilst nine studies only reported the number of teams without providing the number of individual athletes that participated (Bjørneboe et al., 2014; Ekstrand et al., 2011b; Ekstrand, Lee, et al., 2016; Ekstrand, Waldén, et al., 2016; Hallen & Ekstrand, 2014; Moore et al., 2018). Only ten studies reported the number of athletes sustaining the total number of injuries (Cross, Kemp, et al., 2016; Ekstrand, Lee, et al., 2016; Ekstrand, Van Dijk, et al., 2013; Gomez-Piqueras et al., 2018; Moore et al., 2018; Nordström et al., 2014; Rafferty et al., 2018; Stubbe et al., 2015; Toohey et al., 2019) and two studies reported the proportion of players who sustained more than one injury (Moore et al., 2015; Stubbe et al., 2015). The majority of studies (n = 37) used a time-loss definition for injury, five used a medical attention definition, five used a medical attention and time-loss definition and four used an all-encompassing definition. The number of injuries sustained within the studies ranged from 15 injuries across three years within 552 athletes (Ma et al., 2016) to 22942 injuries across one to 16 seasons within 116 teams (Ekstrand et al., 2020).

Table 8 Description of the quality of the article, data collection period, sex of participants, sport, number of teams or athletes/players, the injury definition used within the study and the injury data reported.

References	Data Quality	Data Collection	Sex	Sport	Number of Teams/ Players	Injury Definition	Number of Injuries (incidence)	Number of Recurrent or Subsequent Injuries (proportion)	Recurrent Injury Incidence	Subsequent Injury Category
van Beijstervel dt et al., (2015)	16/23	Continuous Prospective 6 years	Male	Football	14 clubs	Time-loss	2365 (4.8/1000 hours)	20% (58% of muscle injuries were recurrent)	-	-
Bengtsson et al., (2020)	11/23	Prospective Cohort 16 seasons	Male	Football	64 teams 4088 players	Time-loss	16087 (25.0/1000 match hours)	219	46.9 injuries/1000 match hours	-
Bjørneboe et al., (2014)	13/23	Continuous Prospective 6 Years	Male	Football	14 clubs	Time-loss	2365 (4.8/1000 hours)	20%	-	-
Dvorak et al., (2011)	12/23	Prospective Up to 1 month	Male	Football	32 teams 736 players	All encompas sing	125 match (time-loss = 40.1/1000 match hours) 104 training (time-loss = 4.4/1000 training hours)	12 (11.5%)	-	-
Eirale et al., (2012)	14/23	Prospective 17 months	Male	Football	36 players	Time-loss	78 (78.0/1000 match-hours)	19 (24.4%)	1.9/1000 hours	-

Eirale et al., (2013)	14/23	Prospective Cohort 3 seasons	Male	Football	609 players	Time-loss	826 (4.97/1000 hours)	97	-	-
Ekstrand et al., (2011b)	13/23	Prospective Cohort 7 seasons	Male	Football	14 teams	Time-loss	4483	12%	-	-
Ekstrand et al., (2012)	11/23	Prospective Cohort 4 seasons	Male	Football	23 teams 816 players	Time-loss	516	16%	-	-
Ekstrand et al., (2011a)	11/23	Prospective, throughout Season 1-9 seasons	Male	Football	51 teams 2299 players	Time-loss	2908	16%	-	-
Ekstrand et al., (2012)	9/23	Prospective, throughout Season 8 seasons	Male	Football	54 teams 2379 players	Time-loss	51	29%	-	-
Ekstrand et al., (2013)	14/23	Prospective 1-12 seasons	Male	Football	3487 players	Time-loss	67 fractures (0.037/1000 match hours)	7 refractures (25%)	-	-
Ekstrand et al., (2013)	12/23	Prospective Cohort 1 season	Male	Football	31 teams 1032 players	Time-loss	393	49 (12%)	-	-
Ekstrand et al., (2016)	11/23	Prospective, throughout seasons 8 seasons	Male	Football	46 teams	Time-loss	1488	16%	-	-
Ekstrand et al., (2016)	11/23	Long-term Prospective Observational 13 seasons	Male	Football	36 clubs	Time-loss	1614 (1.2/1000 hours)	216 (13%)	-	-
Ekstrand et al., (2020)	8/23	Prospective	Male	Football	116 teams	Time-loss	22942	3016 (1.3-48%)	-	-

		1-16 seasons								
Ergün et al., (2013)	10/23	Prospective 3 years	Male	Football	52 players	Medical Attention and Time-loss	44 injuries – 29 time-loss (30.4 match time-loss injuries/1000 hours)	11 (25%)	-	-
Gajhede-Knudsen et al., (2013)	10/23	Prospective 1-11 seasons	Male	Football	27 teams 1743 players	Time-loss	8029	12% (27% of Achilles injuries were recurrent)	-	-
Gomez-Piqueras et al., (2018)	13/23	Prospective 2 seasons	Male	Football	1 team 71 players	All encompassing	165	12 (22%)	-	-
Hägglund et al., (2011)	11/23	Prospective Cohort 9 seasons	Male	Football	51 teams 2299 players	Time-loss	139	1 in 5	-	-
Hagglund et al., (2013)	14/23	Prospective 9 seasons	Male	Football	26 clubs 1401 players	Time-loss	6140	564 (27%)	-	-
Hägglund et al., (2016)	11/23	Prospective 1-14 seasons	Male	Football	43 Top-level 19 Elite	Time-loss	11581 Top-level (7.2/1000 hours), 3836 Elite (7.4/1000 hours)	1615 (17%) Top-level, 794 (25%) Elite	1.00/1000 hours Top-level, 1.52/1000 hours Elite	-
Gajhede-Knudsen et al., (2013)	10/23	Prospective 1-11 seasons	Male	Football	27 teams 1743 players	Time-loss	8029	12% (27% of Achilles injuries were recurrent)	-	-

Larruskain et al., (2018)	13/23	Prospective 6 seasons	Male	Football	107 players	Time-loss	160 injuries (1.64/1000 hours – 7.49/1000 match hours, 0.71/1000 training injuries)	64 (24 (15%) less than 2 months, 40 (25%) within same season)	0.25/1000 hours less than 2 months, 0.41/1000 hours within same season	-
Larruskain et al., (2018)	14/23	Prospective 5 seasons	Mixed	Football	85 players	Time-loss	483 (8.31/1000 hours men, 6.3/1000 hours women)	135 (31% for men, 23% for women)	2.55 recurrence/1 000 hours for men, 1.42/1000 hours for women	-
Hallen and Ekstrand, (2014)	12/23	Prospective 1-12 seasons	Male	Football	89 teams	Time-loss	17371, 5603 muscle injuries	15%	-	-
Jones et al., (2019)	10/23	Prospective Cohort 1 season	Male	Football	10 teams 243 players	Time-loss	473 (9.11/1000 hours)	27.3% hamstring, 20% groin, 10% quads	-	-
Lee et al., (2014)	12/23	Prospective 1 season	Male	Football	7 teams 152 players	Time-loss	296 (7.4/1000 hours – 61.1 for match, 3.4 for training)	52 (21%) 29% early recurrence, 39% late recurrences, 32% delayed recurrence	-	-
Lundblad et al., (2013)	10/23	Prospective Cohort 11 seasons	Male	Football	27 teams 1743 players	Time-loss	8029 – 346 MCL injuries (0.33/1000	11%	-	-

							hours – 1.31 match, 0.14 training)			
Nordström et al., (2014)	11/23	Prospective Observational 1-11 seasons	Male	Football	46 teams 1665 players	Time-loss	8695 – 71 concussions	756 subsequent to concussion	-	-
Noya-Salces et al., (2014)	11/23	Prospective, throughout season 1 season	Male	Football	16 clubs 427 players	All encompassing	1293 – 524 match (43.5/1000 hours), 769 training (3.6/1000 hours)		4.7 in match, 0.4 in training per 1000 hours	-
Petersen et al., (2010)	11/23	Prospective, throughout season 12 months	Male	Football	16 teams 374 players	All encompassing	46 – 28 in match (1.82/1000 hours), 14 in training (0.12/1000 hours)	8 (25%)	-	-
Stubbe et al., (2015)	13/23	Prospective 39 weeks	Male	Football	8 teams 217 players	Time-loss	286 (6.2/1000 hours)	8% 76 players sustained multiple – 40 injured twice, 16 injured 3 times, 11 injured 4 times, 9 injured 5 times or more	0.5 recurrence/1000 hours	-

Cross et al., (2016)	11/23	Prospective Cohort 2 seasons	Male	Rugby	810 players	Time-loss	181 (8.9/1000 hours)	-	116.1 – 144.6/1000 hours	-
Fuller et al., (2008)	13/23	Prospective, throughout tournament 7 weeks	Male	Rugby	626 players	Time-loss	161 match, 60 training (83.9/1000 hours)	9 match, 16 training	-	-
Fuller et al., (2013)	14/23	Prospective, throughout tournament 7 weeks	Male	Rugby	615 players	Time-loss	171 match, 35 training (89.1 match, 2.2 training injuries/1000 hours)	24 (14%) match, 17% training	-	-
Fuller et al., (2017)	14/23	Prospective, throughout tournament 7 weeks	Male	Rugby	639 players	Time-loss	173 match, 20 training (90.1 match, 1.0 training injuries/1000 hours)	20 (11.6%) match, 3 (15%) training	-	-
Kenneally-Dobrowski et al., (2019)	11/23	Prospective 5 years	Male	Rugby	74 players	Time-loss	30 hamstring injuries – 63% training, 37% match	7%	-	-
Kemp et al., (2008)	10/23	Prospective, Weekly throughout season 3 seasons	Male	Rugby	13 clubs 757 players	Time-loss	155 match, 14 training. 96 match concussions, 5 training	10%	-	-
Ma et al., (2016)	14/23	Prospective Cohort 3 years	Female	Rugby	552 players	Medical Attention	15 (32.6/1000 hours)	24%	-	-

						and Time-loss				
Moore et al., (2015)	13/23	Prospective, throughout tournament 3 years	Male	Rugby	1 team 78 players	Time-loss	144 match (180.0/1000 hours), 41 training (4.7/1000 hours)	19%	-	-
Moore et al., (2018)	10/23	Prospective 3 seasons	Male	Rugby	1 team	Time-loss	648	29% were subsequent	-	59% SIC 10 21% SIC 2,3 or 4
Pearce et al., (2011)	9/23	Prospective 4 seasons	Male	Rugby	899 players	Time-loss	147 (3.3/1000 match hours, 0.09/1000 training hours)	15-20%	-	-
Rafferty et al., (2018)	10/23	Prospective, throughout season 4 years	Male	Rugby	4 teams 429 players	Time-loss	2441 injuries – 1602 match (94.5 – 177.0/1000 hours), 514 training	18% greater risk of injury after concussion	-	-
Toohey et al., (2019)	12/23	Prospective Cohort 2 seasons	Mixed	Rugby	90 players	Medical Attention	365 43.2/1000 hours	95.2% players sustained at least 1 subsequent injury	-	80.7% SIC VIII, 10.3% SIC VII, 6.1% SIC VI
Williams et al., (2017)	10/23	Prospective Cohort 8 seasons	Male	Rugby	1556 players	Time-loss	9597 time-loss – 6903 match,	8180 (85%) subsequent injuries –	-	70% were 'new'

							2617 training	6063 in match, 2087 in training		14% were 'local' 16% were 'recurrent'
Junge et al., (2009)	10/23	Prospective, throughout Championships 16 days	Mixed	Multi-Events	92 teams 9672 athletes	Medical Attention	1055 (96.1 per 1000 registered athletes)	47 (5.5%)	-	-
Alonso et al., (2009)	11/23	Prospective 8 days	Mixed	Athletics	49 teams 1980 athletes	Medical Attention	105 time-loss injuries (53.0 time-loss per 1000 athletes)	15 (8%)	-	-
Alonso et al., (2010)	13/23	Prospective 9 days	Mixed	Athletics	47 teams 1486 athletes	Medical Attention	236 (135.4/1000 registered athletes)	10.6%	-	-
Alonso et al., (2012)	15/23	Prospective 9 days	Mixed	Athletics	61 countries 1512 athletes	Medical Attention	249 (134.5/1000 registered athletes)	23 (9.3%)	-	-
Edouard et al., (2013)	14/23	Prospective, throughout Championship 3 days	Mixed	Athletics	440 athletes	Medical Attention and Time-loss	30 injuries – 8 time-loss (47.5/1000 registered athletes	1	-	-
Edouard et al., (2014)	15/23	Prospective, during Championship 5 days	Mixed	Athletics	1244 athletes	Medical Attention and Time-loss	132 (98.4/1000 registered athlete, 46.2 time-loss/1000	8 (6.1%)	-	-

							registered athletes)			
Moore et al., (2018)	10/23	Prospective 3 Years	Male	Cricket	1 team	Medical Attention and Time-loss	286 – 96 time-loss	90% were subsequent	-	51% SIC 10 8% SIC 7 or 8 5% SIC 2,3,4 or 6

Risk of bias assessment

The studies assessed by the amended Downs and Black (1998) checklist scored between eight and 16 out of a possible 23 points. Studies with a lower quality score typically failed to report the following; 1) the participant characteristics (n = 34), 2) whether there was any attempt at blinding the participants (n = 50) and 3) whether there was any loss to follow up (n = 46).

Recurrent injuries

All recurrent injury definitions were compliant with the consensus statement for the respective sport and are shown in Table 7. Of the 51 studies (one of the 50 articles contained two studies; Moore et al., 2018), 44 reported recurrent injuries as either a number, percentage, incidence or a combination of these. Almost half of the articles, 21 of the 44, reported both the number and the percentage of recurrent injuries (Alonso et al., 2009, 2012; Bengtsson et al., 2020; Dvorak et al., 2011; Edouard et al., 2014; Ekstrand, Van Dijk, et al., 2013; Ekstrand, Waldén, et al., 2016; Ekstrand et al., 2011a, 2012, 2020; Ekstrand, Askling, et al., 2013; Ekstrand, Lee, et al., 2016; Ergün et al., 2013; Fuller et al., 2013, 2017; Gomez-Piqueras et al., 2018; Hagglund et al., 2013; Junge et al., 2009; Lee et al., 2014; Lundblad et al., 2013; Petersen et al., 2010), 13 only reported the percentage (Alonso et al., 2010; Bjørneboe et al., 2014; Ekstrand et al., 2011b; Ekstrand & Torstveit, 2012; Gajhede-knudsen et al., 2013; Hagglund et al., 2011; Hallen & Ekstrand, 2014; A. Jones et al., 2019; Kemp et al., 2008; Kenneally-Dabrowski et al., 2019; Ma et al., 2016; Moore et al., 2015; Pearce et al., 2011), three only reported the number (Edouard et al., 2013; Eirale et al., 2013; Fuller et al., 2008), five reported the number, percentage and the incidence (Eirale et al., 2012; Hägglund et al., 2016; Larruskain, Celorrio, et al., 2018; Larruskain, Lekue, et al., 2018; Stubbe et al., 2015) and two only reported the incidence (Beijsterveldt et al., 2015; Noya Salces et al., 2014). The number of recurrent injuries ranged from one (Edouard et al., 2013) to 3016 (Ekstrand et al., 2020), the proportion ranged from 5.5% (Junge et al., 2009) to 48% (Ekstrand et al., 2020) and the incidence ranged from 0.5 to 2.55 recurrent injuries per 1000 hours (Bjørneboe et al., 2014; Larruskain, Lekue, et al., 2018). Only 16 of the 44 studies reporting recurrent injuries provided further detail regarding the severity of injury, with one study reporting the number and percentage of recurrent injuries that were time-loss injuries (Alonso et al., 2009), one study reporting the proportion of total days-lost due to recurrent injuries (Moore et al., 2015), two studies reporting the time lost for recurrent injuries (Alonso et al., 2010, 2012) and 12 comparing the severity of new and recurrent injuries (Ekstrand et al., 2011a, 2011b, 2012; Ekstrand & Torstveit, 2012; Ergün et al., 2013; Gomez-Piqueras et al., 2018; Kemp et al., 2008; Lee et al., 2014; Lundblad et al., 2013; Pearce et al., 2011; Stubbe et al., 2015). Of the 12 studies comparing the severity of new and recurrent injuries, seven studies reported recurrent injuries to be more severe than new injuries (Ekstrand et al., 2011b, 2011a; Ekstrand & Torstveit, 2012; Kemp et al., 2008; Pearce et al., 2011; Stubbe et al., 2015), four studies reported no differences in severity (Ekstrand et al., 2012; Gomez-Piqueras et al., 2018; Lee et al., 2014; Lundblad et al., 2013) and one study reported recurrent injuries to be less severe than new injuries (Ergün et al., 2013).

Subsequent injuries

Although subsequent injury categorisation models have been published since 2011 (Hamilton et al., 2011), only seven of the 51 studies used the subsequent injury terminology. Three of the seven studies analysed injuries sustained subsequent to concussion, where two studies reported the risk of injury following a concussion using a hazard ratio (1.38; Rafferty et al., 2018; and 1.45 to 4.07 between 0-12 months; Nordström et al., 2014) as well as the median days to the next injury and the total number of injuries following a concussion (36 median days to next injury; Rafferty et al., 2018; and 153 injuries subsequent to concussion; Nordström et al., 2014). The third study reported the incidence of subsequent injury for players who returned from concussion in 14 days or less or more than 14 days (116.1 and 144.6/1000 hours respectively; Cross, Kemp, et al., 2016), along with the median time to subsequent injury following concussion (53 days to subsequent injury; Cross, Kemp, et al., 2016). One of the seven studies modified the subsequent injury classification from Hamilton and colleagues (2011) to provide three options for subsequent injury, namely ‘new’, ‘local’ and ‘recurrent’ (Williams, Trewartha, Kemp, Cross, et al., 2017). Within this study, 85% of injuries were classed as subsequent injuries, with 70% of the subsequent injuries reported as new injuries, 14% as local and 16% as recurrent. Two of the seven studies utilised the SIC 1.0 model (Finch & Cook, 2014) to report the percentage of subsequent injuries (Moore et al., 2018), where 89-91% of injuries were categorised as subsequent, rather than an initial injury (Moore et al., 2018). The studies were also in agreement that the majority of subsequent injuries were categorised as SIC 10 (injury to different body part, unrelated to an index injury) with proportions ranging from 51% to 59% (Moore et al., 2018). Although injuries were also classified in other categories, the proportion of these injuries was comparatively lower. Within the sport of rugby, 21% of subsequent injuries were categorised as SIC 2, 3 or 4 (same body site and nature, related to index injury) and none were categorised as SIC 5 (same body site and nature, unrelated to an index injury). Within cricket, 15% of subsequent injuries were coded as SIC 7 or 8 (same body site but different nature, related or unrelated to index injury), 14% were SIC 2, 3, 4 or 6 (same body site and nature, related or unrelated to index injury) and none were categorised as SIC 5 (same body site and nature, unrelated to an index injury; Moore et al., 2018). The seventh study utilised an updated version of the SIC 1.0 model outlined by Finch and Cook (2014) which included a data driven category for classifying subsequent injuries retrospectively (Toohey et al., 2018). Within this study 81% of subsequent injuries were SIC 2.0 VIII (injury to different site and of different nature), 10% were SIC 2.0 VII (different site, same nature), 6% were SIC 2.0 VI (same site, different nature) and less than 3% were categories II-V (re-injury after recovery, same site, nature, side and structure; acute exacerbation before recovery, same site, nature, side and structure; injury of same site, nature, side; injury of same site and nature; Toohey et al., 2019).

Discussion

This systematic review aimed to identify how recurrent or subsequent injuries have been reported across professional and elite sports. Consensus statements have been published to provide professional and elite sport with guidelines for data collection procedures and injury definitions, allowing more consistent comparisons across sport (Fuller et al., 2006; Fuller, Molloy, et al., 2007; Junge et al., 2008; Mountjoy et al., 2016; Orchard et al., 2005; Orchard, Ranson, et al., 2016; Pluim et al., 2009; Timpka et al., 2014; Turner et al., 2012). Furthermore, subsequent injury categorisation models have been published in order to provide researchers and clinicians with a more accurate definition of subsequent injury (Finch & Cook, 2014; Fuller, Bahr, et al., 2007; Hamilton et al., 2011; Toohey et al., 2018). However, the current review identified that there remains disparity both within and between sports on the methods utilised when reporting recurrent or subsequent injuries.

Reporting injuries

An important finding identified in the current review was that studies often analysed and presented injury data as pooled values across a range of seasons or years and within a large range of athletes. A similar finding was identified by Fortington and colleagues (2017), where the systematic review highlighted that the majority of the studies analysed pooled injury data across teams and seasons. Furthermore, studies with a lower quality score according to the Downs and Black (1998) assessment in the current review were often studies that pooled data across a number of seasons without specifying the number of new participants each season. The consistent reporting of pooled injury data across multiple participants or seasons fails to consider differences between individual athletes across seasons and could impact the analysis and interpretation of injury data. This is emphasised by the lower quality score identified in the Downs and Black (1998) assessment and suggest that injury rates within these types of studies should be interpreted with caution due to the lack of specificity across the numerous seasons. Specifically, injury rates from studies in football (Bengtsson et al., 2020; Bjørneboe et al., 2014; Eirale et al., 2012; Ekstrand, Waldén, et al., 2016; Ekstrand et al., 2011b, 2011a, 2012, 2020; Ekstrand, Lee, et al., 2016; Ekstrand, Van Dijk, et al., 2013; Ekstrand & Torstveit, 2012; Ergün et al., 2013; Gajhede-knudsen et al., 2013; Gomez-Piqueras et al., 2018; Hagglund et al., 2011, 2013; Larruskain, Celorrio, et al., 2018; Larruskain, Lekue, et al., 2018; Lundblad et al., 2013; Nordström et al., 2014), rugby (Cross, Kemp, et al., 2016; Kemp et al., 2008; Kenneally-Dabrowski et al., 2019; Ma et al., 2016; Moore et al., 2015, 2018; Pearce et al., 2011; Rafferty et al., 2018; Toohey et al., 2019; Williams, Trewartha, Kemp, Cross, et al., 2017) and cricket (Moore et al., 2018) suffer from this problem. Pooling the injury data for the analysis and interpretation of injury rates prevents the identification of individual risk for recurrent or subsequent injuries. When considering the diversity of individuals within a team and the importance of effective injury interventions, grouping the analysis prevents individual risks from being identified and utilised to individualise injury risk mitigation protocols (Roe et al., 2017).

In an attempt to enhance injury management protocols, Roe et al. (2017) proposed a six-stage operational framework that considers individual athlete characteristics before developing intervention protocols. However, the initial stages of the framework developed by Roe et al. (2017) remains focused on the group-level identification of injury risk, before identifying the importance of individualising the analysis of risk factors. The continued interpretation of group-level analysis is supported in the current review, where only 12 studies provided further detail on the contribution of athletes to the total injury rates. Twelve studies reported the number of players that sustained the overall number of injuries (Cross, Kemp, et al., 2016; Ekstrand, Van Dijk, et al., 2013; Ekstrand & Torstveit, 2012; Ergün et al., 2013; Gomez-Piqueras et al., 2018; Moore et al., 2015, 2018; Nordström et al., 2014; Rafferty et al., 2018; Stubbe et al., 2015; Toohey et al., 2019) and two specified the proportion of individuals that sustained more than one injury (Moore et al., 2015; Stubbe et al., 2015). The study by Moore et al. (2015) demonstrated that as many as nearly one fifth of players within a team sustained five or more injuries over three years, supporting the potential for diversity between players as outlined by Roe et al. (2017). As a consequence of the variation of injury patterns within a team, analysis within injury surveillance research should look to explore a more individualised approach to enable the development of bespoke prevention protocols (Roe et al., 2017).

In the current review, there were also variations in the data collection period used between studies, where some athletes were followed for less than a week in athletics and others followed for up to 16 seasons in football (Edouard et al., 2013, 2014; Ekstrand et al., 2020). Within the studies where data collection extended across seasons, there was often a lack of information on the number of participants involved in each season (Ekstrand et al., 2011a, 2020; Ekstrand, Van Dijk, et al., 2013; Gajhede-knudsen et al., 2013; Hägglund et al., 2016; Hallen & Ekstrand, 2014; Lundblad et al., 2013; Nordström et al., 2014). Furthermore, although the majority of the studies prospectively collected data over more than one playing season (67%), five studies collected injury data in a championship environment that often lasted less than 10 days (Alonso et al., 2009, 2010, 2012; Edouard et al., 2013, 2014). As subsequent injuries have been reported to occur as late as 114 days following initial injury in previous research (Cross, Kemp, et al., 2016), the lack of a follow up period within championship environments has the potential to under-report the risk of sustaining a subsequent injury from continued participation. In addition, reporting injuries sustained within a season alone fails to consider the influence of pre or post-season on the reporting of subsequent injuries (Fortington et al., 2017). For example, if a study was to conduct injury surveillance with a team across a season and a player sustained an injury in the pre-season, any injury during the season could be considered a subsequent injury. However, if injury surveillance is conducted within the in-season period alone, any subsequent injuries sustained during the season would be inaccurately represented. Both the short timeframe of data collection and potential for out of season injuries to be missed suggest that standard recommendations associated with reporting recurrent or subsequent injuries should be established. Ensuring that the data collection period enables the accurate capturing of subsequent injuries would allow more consistent reporting between sports and improve the understanding of recurrent and subsequent injury risk.

Definition of recurrent injuries

The definition of recurrent injuries outlined in consensus statements are similar between sports, therefore allowing a more consistent comparison between the rate of recurrent injuries reported. However, there remain inconsistencies in the way recurrent injuries are reported. One of the main findings in this systematic review was that 30 of the articles were excluded from data extraction as they failed to report recurrent injuries at all, even when following the definitions and data collection procedures outlined by a consensus statement. Within the studies that did report injury recurrence, a number of studies only identified the proportion within the total number of injuries (Alonso et al., 2010; Beijsterveldt et al., 2015; Bjørneboe et al., 2014; Ekstrand et al., 2011b; Ekstrand & Torstveit, 2012; Gajhede-knudsen et al., 2013; Hagglund et al., 2011; Hallen & Ekstrand, 2014; A. Jones et al., 2019; Kemp et al., 2008; Kenneally-Dabrowski et al., 2019; Ma et al., 2016; Moore et al., 2015), providing insufficient detail about the nature or consequence of the recurrent injuries. Additionally, only ten studies provided detail of the body area associated with recurrent or subsequent injuries, meaning appropriate (re)injury risk mitigation strategies cannot be recommended. The lack of specificity with recurrent injury diagnosis becomes more of an issue when considering the contribution of previous injury to injury risk, with research identifying that previous injures, often a long as three years prior to a new injury, significantly increases current injury risk (Ekstrand et al., 2006; Theisen et al., 2013; Toohey et al., 2017). Furthermore, within studies reporting the recurrence of injuries, diagnosis may rely on the clinician's (and athlete's) ability to recall the injury history of the athlete. Although it is not discussed in any of the prospective injury surveillance studies, recurrent injury categorisation is technically *retrospective* and possibly prone to recall bias and lack of awareness of injury history. This latter aspect can be potentially mitigated against in sports settings where the clinician has worked with the athletes for a sustained period of time. However, the issue surrounding the *retrospective* nature cannot be eliminated unless clinicians actively look at the athlete's injury records in the injury surveillance system, or utilise subsequent injury models developed for the application of categorising subsequent injuries in sport (Finch & Cook, 2014; Fuller, Bahr, et al., 2007; Hamilton et al., 2011; Toohey et al., 2018).

Subsequent injuries

In an attempt to reduce the recall bias and potential lack of awareness associated with diagnosing recurrent injuries, a data driven categorisation that can be applied *post-hoc* to the injury data that is not reliant on specific clinical knowledge during the data analysis has been suggested (Toohey et al., 2018). Following the subsequent injury model outlined by Hamilton and colleagues (2011), Finch and Cook (2014) developed a more specific categorisation of subsequent injuries that facilitates the identification of potential individual injury dependencies (SIC 1.0). In an attempt to improve the application of subsequent injury diagnoses, Toohey and colleagues (2018) adapted the SIC 1.0 categorisation model to create the SIC 2.0 categorisation model, encompassing a clinically driven approach and data driven approach that can be retrospectively applied to injury data. However, the limited uptake of the subsequent injury categorisation models in the current review means there is still a lack of specificity when reporting recurrent or subsequent injuries. Whilst the first categorisation of subsequent injuries was published in 2011 (Hamilton et al., 2011), 90% (n = 36) of the studies published after 2011 in the current study failed to categorise subsequent injuries. Although the SIC 1.0 and 2.0 were utilised in three studies in the current review, the study by Williams and colleagues (2017) used a modified version of a previous classification system, which aimed to simplify the subsequent injury diagnosis based on the type and location of injury alone. The majority of the subsequent injuries sustained in the study by Williams and colleagues (2017) were categorised as different injuries to the index injury, and the remaining injuries were of the same type or location. Although comparisons can still be made between studies utilising either simplified subsequent injury models or the SIC 1.0 and 2.0, the specificity of the SIC models allows researchers and clinicians to gain a better understanding of subsequent injuries and encourages the development of more specific prevention protocols (Moore et al., 2018; Toohey et al., 2018).

The accurate diagnosis of subsequent injuries can have a significant clinical impact, especially when considering the influence of previous injuries on sustaining new injuries (Arnason et al., 2004; Orchard, 2001; Toohey et al., 2017). Three of the seven studies using the subsequent injury terminology specifically focused on the next injury after a concussion (Cross, Kemp, et al., 2016; Nordström et al., 2014; Rafferty et al., 2018), demonstrating that concussive injuries were associated with an increased risk of sustaining subsequent injuries. In addition to an increased risk, the studies by Cross and colleagues (2016) and Rafferty and colleagues (2018) demonstrated that there was a reduced number of days before a subsequent injury following concussion when compared with non-concussive injuries. Although this provides clinicians with important information regarding recovery from concussive injuries, the lack of detail in research associated with subsequent injuries following other types of injuries limits the potential for understanding the relationship with different types injuries. As previous research has shown that a history of previous injury is positively associated with sustaining future injury (Theisen et al., 2013; Toohey et al., 2017), exploring relationships between subsequent injuries sustained following different types of injuries could inform clinicians on the potential patterns between new and subsequent injuries, further aiding the development of injury risk mitigation protocols.

Limitations

A limitation in the current study was that the search strategy was limited to English language, meaning that articles reporting recurrent or subsequent injuries in other languages would not have been included. A further limitation was the restriction of studies within professional or elite level sports. The restriction to professional or elite sport resulted in studies reporting injuries within amateur and collegiate athletes being excluded from the review, even if recurrent injuries had been reported. However, ensuring only one level of sport were included in the review provides consistency both with the accuracy of injury diagnosis by professional medical provision and data collection procedures following a consensus statement for accurate comparisons between studies. Further research could incorporate all levels of sports, making comparisons between injury data to demonstrate whether discrepancies exist between playing levels. In addition, the results from some of the studies should be interpreted with caution due to the low score in the Downs and Black (1998) assessment. Whilst the prospective nature of injury surveillance research makes aspects such as blinding participants and medical personnel challenging, the pooling of injury data across multiple seasons could influence the analysis and interpretation of injury rates. For example, pooling injury data could mask the potential difference in injury rates between individual athletes that take part in one season, but not another. This could consequently influence the overall injury rate reported within each season.

Conclusion

Reporting the recurrent or subsequent nature of an injury remains inconsistent within research, even with the publication of consensus statements and the subsequent injury categorisation models. Furthermore, only a few studies have utilised subsequent injury categorisation models to accurately categorise subsequent injuries, meaning that risk of subsequent injury following an initial injury remains unclear. The lack of recurrent and subsequent injury reporting shows research is not providing an adequate understanding of the injury risk, meaning that injury risk mitigation protocols for recurrent and subsequent injuries may be insufficient. In addition, the continued pooling of injuries for analysis does not allow for the opportunity to investigate the injury rates of individuals within a team and negates the identification of potentially differing injury risk between individuals. As injury risk mitigation relies on accurate injury surveillance data, utilising the SIC model in future research will allow clinicians and researchers to distinguish between new and recurrent or subsequent injuries and improve our understanding of the role of inter-injury relationships in tertiary prevention strategies. Furthermore, exploring an individualised approach to injury analysis may identify differences between players within a team and consequently accommodate more effective injury management, targeted at individual players rather than across a team.

Chapter 5: Is team-level injury analysis giving us the full story? Exploring a player-specific approach to analysing injuries.

Introduction

Sports injury surveillance systems have been widely implemented within professional Rugby Union (Rafferty et al., 2018; Ranson et al., 2018; West, Starling, et al., 2020) and have consistently adhered to the recommendations outlined in the consensus statement presented by Fuller and colleagues, including reporting the type, location and mechanism of injury (Fuller, Molloy, et al., 2007; Williams et al., 2013). However, Chapter 4 identified that there remain inconsistencies in the way injuries are reported within elite and professional sport following consensus statements, specifically when analysing the recurrent or subsequent nature of injuries. Though the analysis of Rugby Union injury rates has typically been conducted at a team-level (Ranson et al., 2018; West, Starling, et al., 2020; Williams et al., 2013; Chapter 3), Chapter 4 highlighted that pooling injury data across players results in lower quality research. However, measuring the injury rate at a team-level can be useful for comparative purposes, accommodating the evaluation of the effectiveness of injury risk mitigation strategies aimed at improving player welfare (Finch, 2006; Moore et al., 2015; Rafferty et al., 2018).

The continued focus on team-level analysis is primarily driven by recommendations outlined in the consensus statement, where the team-level injury incidence is calculated by summing the injuries sustained by each player to produce a total number of injuries for the whole team, and then divided by a standarised team-based estimate of match exposure (i.e., 15 players exposed for 80 minutes; Fuller, Molloy, et al., 2007). However, the recommendation to use the standard match length (i.e., 80 minutes) as the measure of exposure is unlikely to account for differences in match exposure between players due to replacements, head injury assessments and sin bins (where a player sits out of a game for 10 minutes). Player-specific differences in exposure could consequently influence the analysis of team-level exposure, and in turn, the calculation of team-level injury incidence. In addition, when considering the number of individuals within a team and likely differences between players, the focus on team-level analysis may mask the potential for differences in injury rates at a player-specific level. In an attempt to individualise the management of injury risk, Roe and colleagues (2017) suggested a six stage operational framework at a more player-specific level. The initial stages of this six-stage framework however, remain focused on analysing injury trends, risk factors and sporting demands at a team level, prior to considering a player-specific profile (Roe et al., 2017). The continued reporting of team-level injury rates, specifically within Rugby Union, therefore fails to consider the injury rates at a player-specific level and may not provide accurate player-specific information to develop effective injury management strategies.

Whilst the use of the standard match length to calculate team-level injury incidence is a common approach used within Rugby Union epidemiology (Brooks et al., 2005a, 2005c; Kemp et al., 2008; Williams, Trewartha, Kemp, Brooks, et al., 2017), Williams and colleagues (2017) analysed injuries on an individual level by calculating the player-specific exposure to matches, using the number of matches a player participated in. Unsurprisingly, Williams and colleagues (2017) demonstrated that players with greater match exposure were at a higher risk of injury than those who were exposed to fewer matches. The differences in injury risk based on the exposure to matches emphasises the importance of considering injuries at a player-specific level. With this in mind, the extent to which team-level analysis of injury incidence can account for potential variations in player-specific incidence of injury needs to be established. Whilst the consensus statement provides recommendations for team-level exposure, there are yet to be any investigations into the player-specific exposures and corresponding player-specific injury incidence. Although Williams and colleagues (2017) demonstrated differences in player-specific exposure using the number of matches, the injury incidence at a player-specific level using the standard match length as a measure of exposure is yet to be explored. Furthermore, global positioning systems (GPS) have been utilised to demonstrate the differing demands placed upon players during a match, specifically highlighting the differing positional demands in high intensity running and high impact collisions (Cahill et al., 2013; Portillo et al., 2014; Roberts et al., 2008). However, the use of GPS in the calculation of player-specific exposure is yet to be considered. Calculating player-specific injury incidence using both the standard match length as a measure of exposure and player-specific GPS-derived measures of match exposure would accommodate the comparison of match exposure measures in the analysis of player-specific injury incidence.

Although the adherence to the consensus statement method of analysing injury incidence has enabled comparisons to be made between epidemiological studies in Rugby Union, anecdotally this method of reporting injury rates is unintuitive and is often challenging to communicate in a coaching or clinical environment. As an alternative to reporting injury incidence, injury risk analysis using regression analysis and hazard ratios has been utilised in research investigating exposure to injury in sport as well as subsequent injury, specifically following concussion (Hulin et al., 2016; Rafferty et al., 2018; Williams, Trewartha, Kemp, Brooks, et al., 2017; Windt et al., 2017). However, there is limited research that has quantified the probability of sustaining an injury on a player-specific level, a development which could provide a more familiar and therefore more understandable method of communicating injury risks to professionals involved within a team. Consequently, Parekh and colleagues (2012) suggested using a risk metric, namely the Poisson probability, in order to calculate the probability of sustaining a number of injuries within a given number of exposure hours. Whilst the Poisson probability is a standard method of risk analysis in statistics, it is yet to be widely adopted in the sport injury setting. Parekh and colleagues (2012) therefore analysed the incidence and consequent probability of injury for a single player from schoolboy rugby. They demonstrated, based on a player-specific injury incidence of 43.3 injuries/1000 hours, that the probability of sustaining zero, one or five injuries when exposed to 17.5 hours of rugby (i.e. 15 matches in a season) was 46.9%, 35.5% and 0.1%, respectively (Parekh et al., 2012). Whilst Parekh and colleagues (2012) demonstrated the probability of injury for one player, presenting probabilities of injury risk across a larger cohort of players and exploring differences in player-specific injury risk is yet to be investigated.

To examine both the team-level and player-specific injury incidence, using different match exposure calculations, and explore a more familiar analysis of injury risk across a large player cohort, this study aimed to: 1) compare estimates of team-level and player-specific injury incidence using standard match length and player-specific GPS-derived measures of match exposure; and 2) implement an alternative method for presenting player-specific injury risk using the Poisson probability metric.

Methods

Participants

The participants in the current study were male first team squad members of each Welsh regional club between the 2016/17 and the 2018/19 seasons (mean age: 23.7 ± 3.5 years, height: 1.85 ± 0.11 m and mass: 102.6 ± 13.1 kg). All players provided informed consent for their injury data to be collected and analysed and for their GPS data to be retrospectively analysed. Ethical approval was obtained from the University's Research Ethics committee.

Procedure

The injury surveillance period reported in this study covered three seasons (2016/17, 2017/18 and 2018/19). A season ran from the 1st of July to the 30th of June (inclusive). The injury definitions and data collection procedures followed the recommendations from the international consensus statement on Rugby Union injury surveillance (Fuller, Molloy, et al., 2007). Throughout the three seasons, one designated medical team member from each of the four regional teams recorded all time-loss injuries. At the end of each month all data were sent to an independent researcher at the University (LB). Injury records were checked and reconfirmed if necessary, to increase the accuracy of the data. Only injuries sustained when playing for regional competitions i.e. the PRO14, European competitions, U23 competitions, Anglo Welsh cup and any practice matches, were used during analysis.

Exposure and movement characteristics during all regional matches were recorded by a Cataplult Optimeye S5 device (Catapult Innovations, Melbourne, Australia; sampling rate, 10 Hz). The devices were inserted into a vest, positioned between the scapulae, and were worn by all players during all matches after completion of the warm-up and before the start of a match. The devices were turned on a minimum of 30 minutes before kick-off, while outdoors on the stadium's pitch to ensure satellite connectivity. The GPS data in the current study represented match-time only and excluded the timing for substitution or head injury assessments. The GPS data was collected prospectively from the 1st of July 2016 to the 30th of June 2019 and included data on the distance covered (m) and meterage ($\mathrm{m \cdot min^{-1}}$). The locomotor-based outcomes derived from these units (e.g. speed and distance) have been used in previous research (Cummins et al., 2019; Hulin et al., 2016; Windt et al., 2017) and have been found to have acceptable reliability and validity, with less than a 1% error reported for measuring total distance (Johnston et al., 2014; Varley et al., 2012). The data was then collated via Catapult's Openfield software (versions 1.15 to 1.17), which allowed the specific variables of interest to be coded on the data files in real-time.

Data analysis

GPS exposure

Match-exposure time (minutes) per player was calculated by dividing the meterage ($\mathrm{m \cdot min^{-1}}$) by the distance covered (m). The minutes per player, per match was capped at 80 minutes in order to represent the standard length of a match. The minutes of exposure were then divided by 60 and summed per player, per season to give the hours of exposure for the calculation of injury incidence. Data was missing for 3% (n =177) of instances for match exposure. Within players, a maximum of 33% of match exposure data was missing for one player (Appendix B). Where players were missing GPS data for distance covered (m) and meterage ($\mathrm{m \cdot min^{-1}}$), the players median value (median imputation) of match exposure was calculated, which is more robust than calculating the mean when there are potential outliers in the data (Salgado et al., 2016).

Injury incidence

The team injury incidence across the three seasons and for each season separately was calculated using the total number of injuries and the match exposure using standard match length (Fuller, Molloy, et al., 2007):

$$match\ exposure\ hours = number\ of\ matches \times number\ of\ players \times (80/60)$$

where number of matches represent the total number of matches in a season, number of players represents the total number of players on the pitch at any given time for one team (15 players) and 80 represents the length of a singular match in minutes. Total GPS-derived match exposure was summed across players, each season. Match injury incidence was calculated as the number of injuries sustained per 1000 match hours per season with 95% confidence intervals (CI). To compare the injury incidence using the standard match length and the GPS derived exposure, a rate ratio (RR) was calculated, with a significant difference identified if the 95% CI for the RR did not cross one. The number of injuries, standard match length measure of exposure and the GPS-derived match exposure hours were also summed per player, per season and were used to calculate the player-specific injury incidence per player, per season to provide a range of incidence values across players for three seasons as well as within each season separately.

Injury risk

The Poisson probability has been used in statistical risk analysis and calculates the probabilities of a given number of events occurring within a given interval of time (Parekh et al., 2012). In the current study, the Poisson probability was used to estimate the probability of sustaining a given number of injuries (k) in a given number of exposure hours (t)

$$P(k) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}$$

where λ = injury incidence divided by 1000 (e.g. an incidence of 55.0 injuries/1000 match hours is 0.0550), t = the number of match exposure hours, e = the base of the natural logarithm and $k!$ = factorial of 'k' (Parekh et al., 2012). The probability of sustaining one injury was calculated using the dpois function from the *stats* package in R, which is the probability of 'k' (only one) injury occurring within a given period of exposure. The probability of sustaining two or more injuries was calculated using the ppois function from the *stats* package in R, which is the cumulative probability of more than or equal to 'k' (more than or equal to two) injuries occurring within a given period of exposure.

The probability of only one injury or two or more injuries occurring was calculated for each individual using three exposure categories and individual injury incidence per season. The three exposure categories were calculated using the player-specific GPS-derived match exposure hours each season, with the 25th percentile, median and 75th percentile of match hours representing the low, median and high exposure categories respectively. In order to show the relationship between injury incidence and the probability of an injury occurring, two graphs were plotted for each of the probability calculations using incidence and log transformed incidence. Log transformed incidence was used to account for the large range of player-specific injury incidences. All data was analysed using R (R Core Team, 2020).

Results

A total of 487 injuries were sustained by 111 players, which represents 34% of the total player cohort across three seasons (a total of 330 players across the three seasons; 224 in the 2016/17 season, 232 in the 2017/18 season and 258 in the 2018/19 season). There was a total of 5090 GPS match exposure hours for the 111 players across the three seasons (range across players: 3-81 match exposure hours per player). Sixteen players sustained one injury, 19 players sustained two injuries and 23 players sustained more than six injuries across the three seasons. The range of injuries for the players over the three seasons was between one and 16 (Appendix B).

Team-level injury incidence

The three-season incidence using the standard match length was 59.5 injuries/1000 match hours (95% CI: 54.5 – 65.1) and the three-season incidence using GPS was 95.7 injuries/1000 match hours (95% CI: 87.6 – 104.6). There was a difference in the three-season incidence (RR: 0.62, 95% CI: 0.45 – 0.86). There was also a difference between the standard match length incidence and GPS incidence in each season. However, in the 2016/17 only 45% of players from the total player cohort provided consent, 50% in the 2017/18 season and 56% in the 2018/19 season. When adjusting the standard match length exposure calculation for the proportion of players providing consent each season, there was no difference between the proportional standard match length and GPS injury incidence in the 2016/17 and 2017/18 season, however there was a difference in injury incidence in the 2018/19 season (Table 9).

Player-specific injury incidence

The range for player-specific injury incidence using the standard match length across the three seasons was 27.8 – 500.0 injuries/1000 match hours. The range for player-specific injury incidence using GPS derived match exposure across the three seasons was 34.0 – 1014.5 injuries/1000 match hours. The range for player-specific injury incidence per season is shown in Table 9. Figure 9 shows a subset of the difference between the standard match length and GPS incidence each season for all players (all players included in Appendix B).

Table 9 The team-level injury incidence (injuries/1000 match hours) using GPS-derived match exposure, the standard match length, and proportional standard match length (with 95% CI and RR compared to GPS injury incidence) and the player-specific range for injury incidence (injuries/1000 match hours) using the GPS-derived match exposure and the standard match length.

Season		**GPS (injuries/1000 match hours)**	**Standard Match Length (injuries/1000 match hours)**	**Proportional (injuries/1000 match hours)**
2016/17	Team-level	96.9 (81.7-114.8)	48.2 (40.7-57.1)	107.1 (90.6-126.6)
	Rate Ratio	-	*0.50 (0.35-0.70)*	*1.11 (0.84-1.45)*
	Player-Specific Range	32.0 – 11901.6	24.2 – 750.0	-
2017/18	Team-level	83.6 (71.4-97.9)	53.8 (46.0-63.0)	107.6 (91.4-126.7)
	Rate Ratio	-	*0.64 (0.46–0.91)*	*1.29 (0.97-1.71)*
	Player-Specific Range	34.0 – 3769.5	25.0 – 750.0	-
2018/19	Team-level	106.8 (93.0-122.8)	78.3 (68.2-90.0)	139.9 (117.6-166.5)
	Rate Ratio	-	*0.73 (0.55–0.98)*	*1.31 (1.02-1.69)*
	Player-Specific Range	39.0 – 2663.7	31.3 – 656.3	-

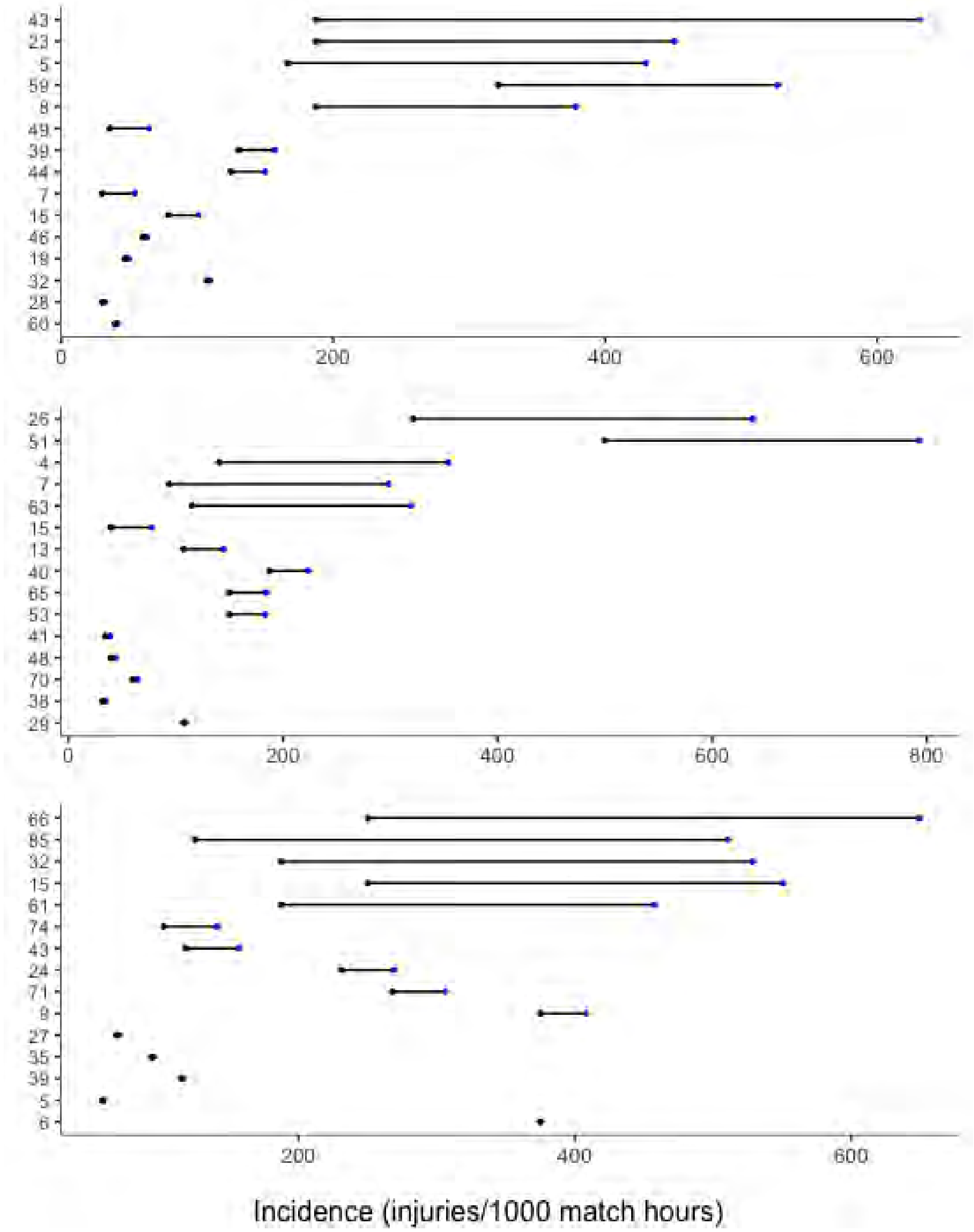


Figure 9 A subset of the difference between the player-specific injury incidence (injuries/1000 match hours) using standard match length and GPS-derived exposure each season across all players. Black points represent the standard match length injury incidence, blue points represent the GPS-derived injury incidence.

Ninety four percent of players fell outside of the 95% CI for the three-season team-level injury incidence for both the standard match length and GPS. For the standard match length injury incidence per season, 97% of players fell outside of the 95% CI in the 2016/17 season, 87% in the 2017/18 season and 89% in the 2018/19 season (Figure 10A). For the GPS injury incidence per season, 88% of players fell outside of the 95% CI in the 2016/17 season, 84% in the 2017/18 season and 85% in the 2018/19 season (Figure 10B). The players with an injury incidence below 40 injuries/1000 match hours were primarily due to a high number of match hours with a low number of injuries. In contrast, the players with an injury incidence above 600 injuries/1000 match hours primarily sustained a relatively high number of injuries in a low number of match hours.

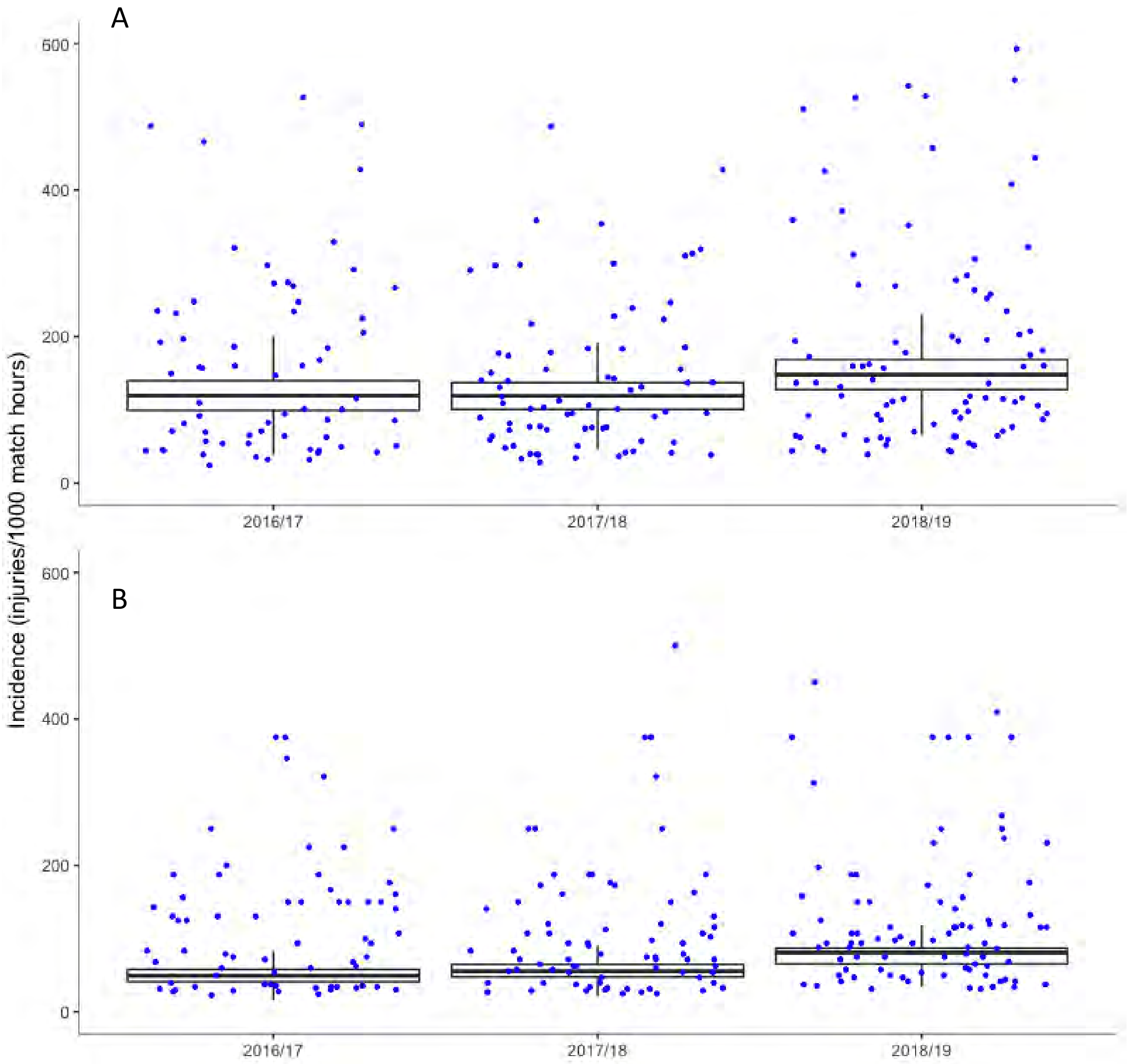


Figure 10 Box plots for the distribution of player-specific injury incidence with A) team-level incidence using standard match length and corresponding 95% CI with outliers (incidence above 600 injuries/1000 match hours) removed and B) team-level incidence using GPS-derived match exposure and corresponding 95% CI with outliers (incidence above 600 injuries/1000 match hours) removed.

Team-level injury probability

The probability of sustaining only one injury or two or more injuries were calculated for the team GPS incidence each season. Table 10 shows the probability of injury for low, median and high hours. The probability of sustaining only one injury decreased as the exposure hours increased, with a similar probability seen for the low and median exposure hours. In contrast, the probability of sustaining two or more injuries increased as the exposure hours increased, with the low hours showing the lowest probability for sustaining two or more injuries.

Table 10 The probability of sustaining only one injury or two or more injuries for the team-level GPS-derived injury incidence each season.

Season	Incidence (injuries/1000 match hours)	Probability of 1 injury			Probability of 2 or more injuries		
		Low	Median	High	Low	Median	High
2016/17	96.9	37%	32%	23%	23%	49%	67%
2017/18	83.6	36%	34%	26%	20%	42%	62%
2018/19	106.8	37%	32%	26%	28%	47%	62%

Player-specific injury probability

The probability of sustaining only one or two or more injuries in low, median and high exposure hours are shown in Figure 11. The player-specific probability of sustaining only one injury is low when the injury incidence is below 30 injuries/1000 match hours. However, as the injury incidence increases, the probability of only one injury occurring increases to a peak between 30 and 100 injuries/1000 match hours, followed by a decrease in the probability of sustaining only one injury as the incidence increases. Although the low, median and high match exposure hours show that the probability of sustaining only one injury is similar, being exposed to a low number of match hours showed a higher probability of sustaining only one injury at the same incidence than the median and high quartile hours. In contrast, the probability of sustaining two or more injuries shows an increasing trend as the injury incidence increases (Figure 11). Being exposed to a high number of match hours generally showed a higher probability of sustaining two or more injuries at the same injury incidence as the median and low quartile hours. A plateau occurs when the probability of sustaining only one injury is 0% and when the probability of sustaining two or more injuries reaches 100%.

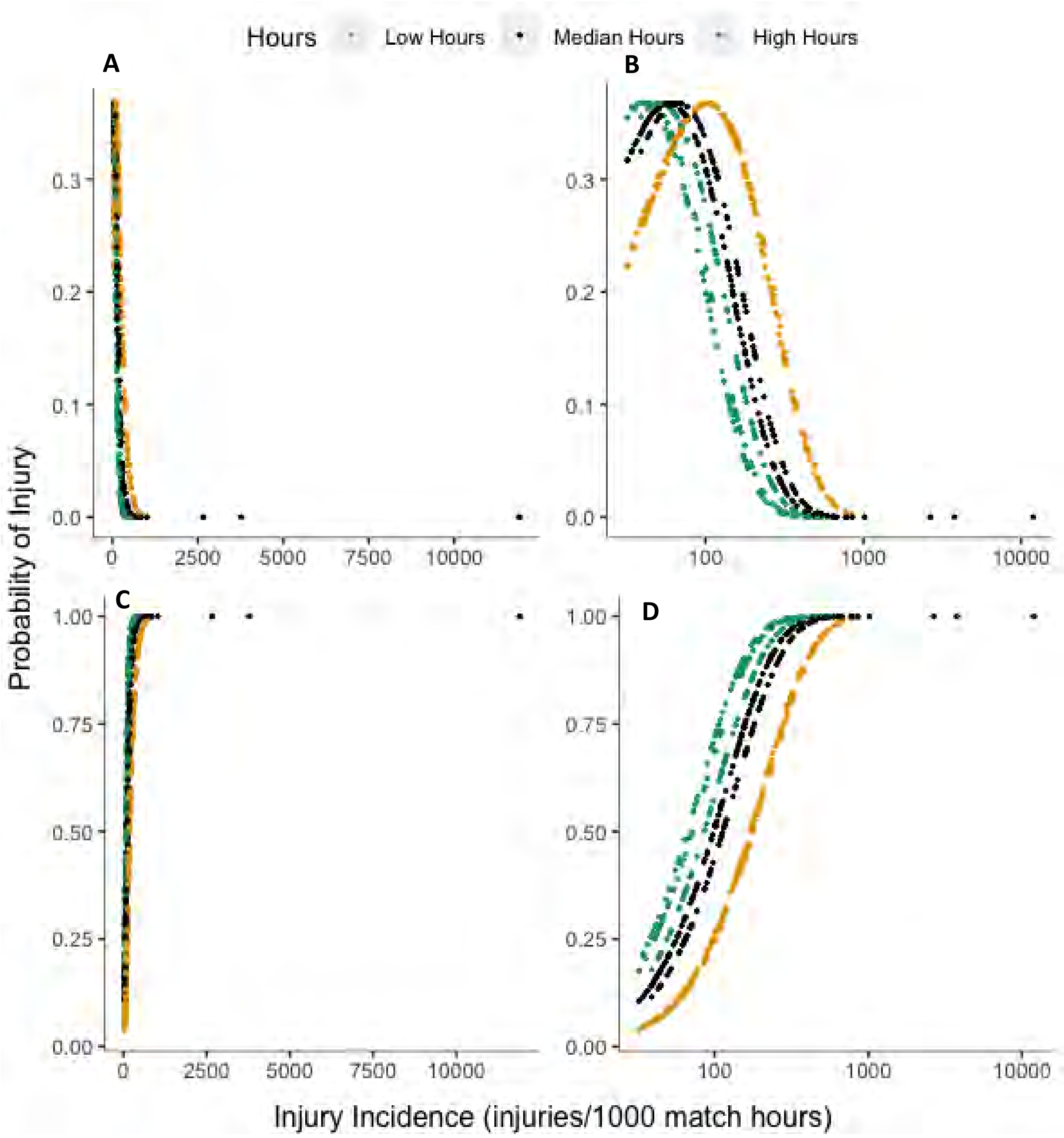


Figure 11 The probability of sustaining only one injury or two or more injuries using the three GPS-derived match exposure categories per season for all players. A) The probability of sustaining only one injury; B) The probability of sustaining only one injury with log transformed incidence on horizontal axis; C) The probability of two or more injuries; D) The probability of two or more injuries with log transformed incidence on horizontal axis.

When grouping the player-specific incidence into ranges and using the median GPS-derived match exposure hours per season, a low injury incidence resulted in a higher probability of sustaining only one injury than the probability of sustaining two or more injuries (Table 11). An incidence of less than 50 injuries/1000 match hours and up to 200 injuries/1000 match hours shows a similar upper probability of sustaining only one injury (36% vs 37%, respectively). As the injury incidence increases, the probability of sustaining only one injury decreases and the probability of sustaining two or more injuries increases.

Table 11 The probability (%) of sustaining one injury, or two or more injuries in the median GPS-derived match exposure hours using player-specific GPS-derived match exposure hours per season.

Injury Incidence (injuries/1000 match hours)	Probability of 1 injury in median exposure hours	Probability of 2 or more injuries in median exposure hours
< 50	32 - 36%	11 - 21%
51 - 200	12 - 37%	18 - 85%
201 – 350	2 - 15%	80 - 98%
351 - 500	0.2 - 3%	97 - 98%
> 500	< 0.4%	100%

Discussion

The aims of this study were to compare estimates of match exposure using standard match length and GPS-derived match exposure to calculate injury incidence at a team and player-specific level. Furthermore, the study aimed to implement the Poisson probability metric to calculate the probability of one or two or more injuries. There was a difference between the team-level injury incidence using the standard match length and GPS-derived exposure across the three seasons and within each season separately. However, when the standard match length was adjusted for the number of players providing consent, the team-level injury incidence using GPS-derived exposure and proportional standard match length was similar. The standard match length underestimated the player-specific injury incidence, with the upper range of player-specific injury incidence showing substantially higher values using GPS-derived exposure. Interestingly, the majority of players (> 84%) fell outside of the 95% confidence intervals for the team-level injury incidence using both standard match length and GPS-derived exposure each season. The probability of sustaining only one injury decreased as the incidence of injury increased, where exposure to a low number of match hours showed a higher probability of sustaining only one injury than median or high match exposure hours. In contrast, the probability of sustaining two or more injuries increased as injury incidence increased, where exposure to high match hours generally showed a higher probability of sustaining two or more injuries at the same injury incidence than being exposed to median or low match hours.

Team-level injury incidence

A key finding in the current study was the difference between the team-level injury incidence using the standard match length and GPS-derived exposure. However, when the standard match length was adjusted for the number of players providing consent (45-56%), the team-level injury incidence using GPS-derived exposure and proportional standard match length was similar. This demonstrates that the standard match length calculation using 15 players exposed for 80 minutes recommended by Fuller and colleagues (2007) does not adequately calculate team-level injury incidence if the entire player cohort have not provided consent for their data to be analysed. Whilst previous research investigating injury rates in Rugby Union have indicated that players provided consent, there has been no indication as to what proportion of the entire player cohort this represents (Fuller et al., 2020; Moore et al., 2015; West, Starling, et al., 2020; Chapter 3). In the current study, when the standard number of players was calculated as the proportion of players providing consent, the team-level injury incidence was similar to the GPS team-level incidence in the 2016/17 and 2017/18 season, but not the 2018/19 season. This indicates that if 50% of players within the study provided consent, the calculation of standard match length using 7.5 players exposed for 80 minutes represents a more adequate estimation of exposure for the calculation of team-level injury incidence. Therefore, calculating the exposure using the standard match length is dependent on the proportion of players providing consent.

Player-specific injury incidence

In addition to underestimating the injury incidence at a team level, the standard match length also underestimated the player-specific injury incidence, with the upper range of player-specific injury incidence showing substantially higher values using GPS-derived exposure. However, an important finding in this study was that the team-level 95% confidence intervals failed to cover > 84% of player-specific injury incidences, with a similar proportion of players falling outside of the 95% confidence intervals of the team-level standard match length and GPS injury incidence. This means that the team-level injury incidence does not appear to provide a rate of injury that is reflective of the underlying player-specific injury rate. Furthermore, using the standard match length to calculate player-specific injury incidence underestimates the incidence in comparison to using GPS derived exposure. This is the first time that this player-specific method has been used to calculate player-specific injury incidence during matches. Whilst epidemiological studies are yet to utilise player-specific GPS exposure, research looking at exposure to rugby training and matches has shown that differences in exposure lead to differences in injury risks (Hulin et al., 2016; Killen, Natasha et al., 2010; Williams, Trewartha, Kemp, Brooks, et al., 2017). In the study by Williams and colleagues (2017), players who were involved in less than 15 or more than 35 matches in the preceding 12 months had a higher risk for injury. The identification of differences in exposure hours leading to different injury risks provides an insight into the potential for differences in injury profiles of players within a team. These findings support this notion, with the large range of player-specific injury incidences identified across all three seasons highlighting the importance of considering player-specific exposure and injury profiles when investigating injury rates within a team. Future epidemiological research should, where possible, collect GPS exposure in order to establish more accurate injury incidence rates and differences in injury profiles of players within a team to encourage the development of appropriate prevention and rehabilitation strategies and reduce injury rates.

Injury risk

When considering the player-specific analysis of injury risk, if players were exposed to a low number of match hours, the probability of sustaining only one injury was higher at the same injury incidence than being exposed to median and high match hours, implying that lower match hours may lead to a lower risk of sustaining multiple injuries. In contrast, when match exposure hours were high, the probability of sustaining two or more injuries was higher at the same injury incidence than the median and low hours, implying that playing more hours led to an increased probability of sustaining multiple injuries. The increasing trend in injury probabilities emphasise the role of match exposure hours in relation to injuries, with the current study demonstrating that increasing levels of exposure to matches lead to a higher risk for multiple injuries. This is an important finding for injury surveillance research, where the analysis of injuries solely at a team-level fails to identify players at higher risk for sustaining multiple injuries. The higher probabilities associated with higher exposure hours indicate that practitioners and coaches should monitor player match exposure hours throughout a season and consider ways to reduce levels of match exposure, such as through strategic replacements within matches and increasing squad rotation. However, since the introduction of tactical replacements in 1996, their impact within matches has been suggested to influence injury rates (Bathgate et al., 2002), though this is yet to be fully established. This may be due to the lack of recommendations for accurately calculating exposure at a player-specific level, specifically for starter and replacement players separately. Therefore, the method developed within this study may provide an opportunity for injuries at this player-specific level to be investigated. This may consequently contribute to the identification of high-risk players and support the development of individualised injury management strategies, as outlined in the framework by Roe and colleagues (2017).

Injury incidence within epidemiological research has provided valuable context to the injuries sustained across a season or a number of years (Moore et al., 2015; Williams et al., 2013; Chapter 3), yet it is often challenging to interpret and present in a clinical setting. In this circumstance, using a calculation that presents the probability of sustaining an injury can be considered a more clinically relevant metric that could be used to inform practice and contribute to the prevention of injuries. The Poisson probability has identified a trend in the probability of sustaining either one, or two or more injuries in association with the exposure to match hours in this study, demonstrating the possibility for this probability calculation to be used within professional Rugby Union. Though calculating the probability requires a players current injury incidence, clinicians within a professional setting have access to the number of injuries sustained by a player and the number of match exposure hours within a season. The use of injury incidence in the Poisson probability method therefore facilitates the potential development of a clinical tool that can calculate the probability of sustaining an injury within a given number of match exposure hours. For example, if a player had accumulated 31 hours of match exposure and six injuries, the injury incidence would be 196.5 injuries/1000 match hours. This injury incidence can then be used to calculate the probability of sustaining only one injury (11%) or two or more injuries (65%) in 17 hours of exposure. The Poisson probability method could then be implemented to aid squad selection, where practitioners can use the probability calculation to establish whether individual players have higher probabilities of sustaining multiple injuries within the expected number of match hours in a season.

Limitations

A limitation within the current study is the use of only match injuries and exposure for the calculation of injury incidence and risk. Whilst the majority of injuries in Rugby Union occur during matches (Best et al., 2005; Holtzhausen et al., 2006; Moore et al., 2015), players are exposed to higher training exposure than match exposure throughout a season (Quarrie et al., 2017; West, Williams, et al., 2020). In addition, there may be other confounders that were not accounted for within the Poisson model (Pourhoseingholi et al., 2012). For example, factors such as previous injury, age, cumulative exposure to sport and psychological stress can alter a players susceptibility to injury (Bittencourt et al., 2016). However, within observational studies where confounders such as those listed previously may not be available during data collection, there is naturally a higher risk of bias (Kuroki & Cai, 2008). The exploratory nature of the current study has therefore provided insight into the relationship between match exposure and injury risk, using a novel methods of analysis that can be eaily applied within the sport. Furthermore, though the analysis of injury risk using the overall number of exposure hours or player specific risk factors such as age or previous injury could provide further context for the risk within a season across all Rugby Union exposure, prevention strategies for reducing the risk of injuries are often implemented within matches, due to the higher risk for injury reported within matches (Fuller, Brooks, et al., 2007; Quarrie et al., 2017; Williams et al., 2013). Whilst this study provided a different method of calculating injury incidence using GPS-derived match exposure in comparison to the standard match length outlined in the consensus statement (Fuller, Molloy, et al., 2007), the continued high injury incidence rates demonstrate that injuries within Rugby Union remain high. A further limitation associated with the injury incidence is the lack of clustering, which can account for potential differences between teams with regards to exposure and injuries. However, all four teams within the current study play at the same level, within the same competitions, therefore providing consistency between teams for match exposures.

Conclusion

In conclusion, the standard calculation of match exposure using 15 players exposed for 80 minutes underestimates team-level injury incidence in comparison to GPS-derived exposure when the entire player cohort has not provided consent. When the standard match length is adjusted for the proportion of consented players, the injury incidence in comparison to GPS-derived exposure is similar. However, team-level analysis provides a poor understanding of injury rate and risk for players within a team. In addition to the player-specific injury incidence, using the Poisson probability provided a different interpretation of injury that has a more clinically relevant application when considering the risk for injury in professional Rugby Union. In the future, the Poisson probability provides opportunities for the development of live risk calculations, where medical practitioners could identify players at a higher risk for injury and influence how players are utilised within a team. Though an increase in squad rotation could reduce the impact of higher match exposures on injury risk, the possible use of tactical replacements during matches to mitigate injury risk needs to be investigated further to establish the influence of implementing this method.

Chapter 6: Injury rates and mechanisms of starter and replacement players

Introduction

Match injuries in Rugby Union occur frequently, and research has shown that players can often sustain multiple injuries across a number of seasons (Moore et al., 2015; Chapter 5). Epidemiological research has extensively explored the injuries sustained by Rugby Union players through injury surveillance, where factors such as the type, mechanism and timing of injuries have been reported (Bathgate et al., 2002; Best et al., 2005; Brooks et al., 2005b; Brooks & Kemp, 2008, 2011; Fuller et al., 2020; Moore et al., 2015; Ranson et al., 2018; West, Starling, et al., 2020; Williams, Trewartha, Kemp, Brooks, et al., 2017; Williams et al., 2013; Chapter 3). Chapter 5 explored the differences in injury rates between individual players within a team and found that team-level injury rates traditionally presented in epidemiological studies do not represent the cohort of individuals within the team. Chapter 4 further supports this notion, with the pooling of data across individuals to calculate injury rates a common occurrence within epidemiological research. However, within studies that pooled data, the quality of research was found to be lower, primarily due to the lack of information regarding the number of individuals involved and the number of injuries sustained within the cohort. Though little research has explored the differences in injury rates between players within a team, research has investigated the injury rates of players in different positional groups, forwards and backs (Bathgate et al., 2002; Brooks et al., 2005b; Brooks & Kemp, 2011; Cosgrave & Williams, 2019; Fuller, Brooks, et al., 2007). Whilst there have been some conflicting evidence, research has suggested that the differing demands experienced by the positional groups can result in different injury rates and mechanisms (Brooks et al., 2005b; Owen et al., 2015).

In addition to differences between positional groups within matches, the timing of match injuries has also been identified as an important factor in injury rates. Previous research has demonstrated differences in injury rates between match quarters, with the first quarter consistently showing the lowest injury rates and the third and fourth quarter showing the highest (Brooks et al., 2005b; Holtzhausen et al., 2006; Williams et al., 2013). Interestingly, a study by Bathgate and colleagues (2002) suggested that the differences seen in injury rates between quarters may be due to the introduction of tactical substitutions in 1996, primarily implemented within matches due to player fatigue (Bathgate et al., 2002). Research analysing the movement patterns of replacement players in comparison to starters demonstrates that replacement players have an impact on the physicality of a match, specifically with regards to their involvement in attacking and defensive strategies (Lacome et al., 2016; Michael et al., 2019). Current laws within Rugby Union dictate that over half of the team can be replaced within a match, with up to eight permanent replacements permitted (World Rugby, 2021b). However, research is yet to investigate whether this consequently affects injury rates. Whilst it has been demonstrated that the second half of matches often has a higher injury rate, research is yet to investigate whether this is affected by the introduction of a higher number of replacement players as the game goes on (Grainger et al., 2018). In 2005, a study by Brooks and colleagues (2005b) analysed the incidence of starter and replacement players during the final quarter of a match. It was identified that starters had a higher injury incidence than replacements (114 vs 87 injuries/1000 hours), with fatigue again suggested as a contributing factor to the higher incidences shown in the fourth match quarter. However, it is unclear how Brooks and colleagues (2005b) accommodated for the differing exposure times between the starter and replacement players, an important factor to consider when investigating differences in injury rates between players. Therefore, the difference in starter and replacement injury incidence using the player-specific exposure is yet to be explored further, specifically in association with the number of replacement players utilised within matches. The use of a player-specific approach could consequently provide an important insight into the use of replacement players within matches, informing current regulations and identifying if changes to the laws within the match are required.

The combined suggestion of fatigue influencing injury rates and the high proportion of injuries sustained during the tackle event within matches (Fuller et al., 2020; West, Starling, et al., 2020; Chapter 3) has encouraged more detailed analysis of the tackle event and its relationship with injuries (Burger et al., 2016; Davidow et al., 2018; Gabbett, 2008; Hendricks et al., 2016; Hopkinson et al., 2021; Tierney et al., 2018; Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). Within Rugby League, the use of standardised technical criteria to analyse the tackle event demonstrated that fatigued players showed progressive reductions in tackle technique

(Gabbett, 2008). The reductions in tackle technique, analysed using proficiency scores, has consequently been analysed in relation to injuries within Rugby Union (Burger et al., 2016; Davidow et al., 2018). Studies have identified that reductions in proficiency resulted in a higher risk for injury, primarily due to changes in body positions during the tackle (Burger et al., 2016; Davidow et al., 2018). However, the use of tackle proficiency as an identifier of injury risk is limited, primarily due to the lack of specific information regarding the characteristics within the tackle event that can influence a player sustaining an injury. This is important when considering the need for effective injury risk mitigation strategies that reduce the risk of injury associated with specific injury mechanisms. Consequently, tackle descriptors have been developed within research focusing on tackles that have resulted in head injury assessments (HIA) or concussions to identify high risk characteristics (Hendricks et al., 2016; Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). Within these studies, front on tackles, active shoulder drives and accelerating tacklers increased the likelihood of a head injury (Hendricks et al., 2016; Tucker, Raftery, Fuller, et al., 2017; Tucker, Raftery, Kemp, et al., 2017). Furthermore, research analysing the association of all match injuries sustained from the tackle event demonstrated that the speed of player, anticipation and type of tackle can increase the likelihood of any injury occurring (Burger et al., 2016; Hopkinson et al., 2021). Within previous research implementing tackle characteristic analysis, the role of the player (i.e., ball carrier or tackler) has also been found to influence the tackle characteristics that are considered a higher risk for injury. Tucker and colleagues (2017) identified that the tackler had a higher propensity, an event-based measure of injury, for HIA during the tackle than the ball carrier, primarily due to the tackler exhibiting a higher body position during the tackle event. However, a limitation within the current application of tackle analysis is the continued analysis across a team, with minimal consideration for the potential differences at a player-specific level. With research demonstrating that replacement players have higher involvements in attacking and defensive movements than their respective starters (Lacome et al., 2016), exploring the tackle event at a player-specific level that considers the type of player involved is warranted.

To investigate whether the physical impact of replacement players within a match influence the injury rates, this study aimed to: 1) analyse injury rates of starter and replacement players, to investigate the effect of replacement players on injury rates within a match and 2) explore if characteristics of injurious tackles differ between starter and replacement players.

Methods

Methods were as reported in Chapter 5, with data collected between the 1st of July 2017 to the 31st of August 2020 (inclusive). The video analysis of matches was extended to the 31st of March 2021 due to the Covid-19 pandemic affecting match schedules.

Participants

The participants were male first team squad members of each of the four Welsh professional clubs (mean age: 25 ± 3.6 years, height: 185.0 ± 10.4 m and mass: 102.9 ± 13.0 kg). Players provided informed consent for their data to be collected and analysed.

Injury analysis

Players who sustained injuries as a starter or a replacement player in PRO14 matches were identified using the injury surveillance database. Match exposure from the GPS data for each player was summed separately for when they started a match and when they were brought on as a replacement player each season.

Video analysis

Injury tackle

Injury surveillance data was used to source the corresponding video footage. Only injuries labelled as occurring from either being tackled or tackling were analysed. The injury surveillance data was also utilised to identify the time in the match the injury occurred, the player's position, whether the player was removed from the match immediately or later and whether the player started a match or was a replacement. Tackles were excluded from analysis based on adhering to at least one of the following criteria: 1) if a player was not removed and no medical attention was received (n = 53, 29%); 2) if the player injured/injury mechanism was unclear (n = 38, 21%); 3) if the player was injured in their first tackle event in their match (n = 14, 8%). Six injuries (3%) were not available for analysis and one injury (1%) could not be analysed due to the weather conditions of the match. From this criteria, a total of 69 (38%) injury tackles were analysed. The video footage corresponding to the injury was extracted from the WRU database. All videos were available in the public domain and analysed from a single angle.

Non-Injury tackle

A control cohort of non-injurious tackles were analysed to identify the tackle characteristics resulting in injury. A similar method to previous research (Hendricks et al., 2015; Hopkinson et al., 2021) was implemented, using the injured players non-injurious tackles from the same match as the control cohort. Injury and non-injury tackles were matched for the role of the player i.e., ball carrier or tackler. If a player was not involved in any non-injury matched tackles before the injury inciting tackle, the player was excluded from analysis (n=14, 8%). A total of 281 non-injury tackles were analysed in the control cohort.

Tackle analysis

All definitions and performance indicators followed the recommendations outlined in the consensus statement (Hendricks et al., 2020) and are shown in Appendix C. All video footage was analysed using Sports Code (version 12.2.13). The software allowed control over the speed of the video footage and for coded events to be saved, exported, and analysed further. A code window was developed by the lead author (LB) and included descriptors from the consensus statement with additional descriptors added where relevant, such as the status of the player (i.e., starter or replacement for injured and opposition players; Appendix C). The tackle characteristics analysed three different phases of the tackle; pre contact (1 second before), contact and post-contact (after initial contact had been made). Injury inciting tackles and their respective non-injury tackles were analysed using all relevant performance descriptors. All other tackles within a match were coded and labelled as either a ball carrier or a tackler event between either two starters, two replacements or a starter and a replacement.

Reliability

In order to allow correct and accurate interpretation of results from the analysis of performance, the assessment of reliability is essential (O'Donoghue, 2007). The two main methods of assessing the reliability are intra and inter reliability, both of which have been implemented within Rugby Union research (Hendricks et al., 2014, 2015, 2017; Hopkinson et al., 2021; Makdissi & Davis, 2016). Whilst intra-rater reliability can be useful when a coding system for analysing performance is complex and training additional individuals is not possible, the familiarity of an analyst with the system can result in reduced reliability and does not allow for the identification of possible misinterpretations of operational definitions (James et al., 2007; O'Donoghue, 2007). It is therefore suggested that inter-rater reliability provides a more robust method and should be utilised in performance analysis research, as any misinterpretations or inaccuracies associated with the operational definitions can be identified by the additional analyst, reducing the potential for systemic mistakes and bias from a single analyst (James et al., 2007; O'Donoghue, 2007). Consequently, within this study, inter-rater reliability was conducted. A total of 29 matches were randomly selected for reliability analysis and represented a total of 128 tackles. All reliability analysis were completed by two authors, the lead author (LB) and one of the supervisors, who is an experienced analyst (GR). The reliability analysis was an iterative process whereby five tackles were firstly analysed by each author, followed by a discussion and investigation of the analysis. The analysis was then agreed and refined. The Kappa statistic was used to evaluate the inter-rater reliability for the tackler and ball carrier separately, and for each specific tackle variable. A value above or equal to 0.80 is considered as very good agreement between authors and between 0.60 to 0.80 represents good agreement (O'Donoghue, 2010). A Kappa value of 0.70 was agreed as the cut off point for including variables in the analysis, due to the complexity of the analysis process and difficulty in ascertaining certain variables. Figures 12 and 13 demonstrate the reliability of each tackle variable for ball carriers and tacklers. The reliability value of 0.65 for the post-contact ground contact of the ball carrier meant this variable was excluded from analysis. The remaining variables fell between 0.81 and 1.00 for ball carrier tackles and between 0.74 and 1.00 for tacklers.

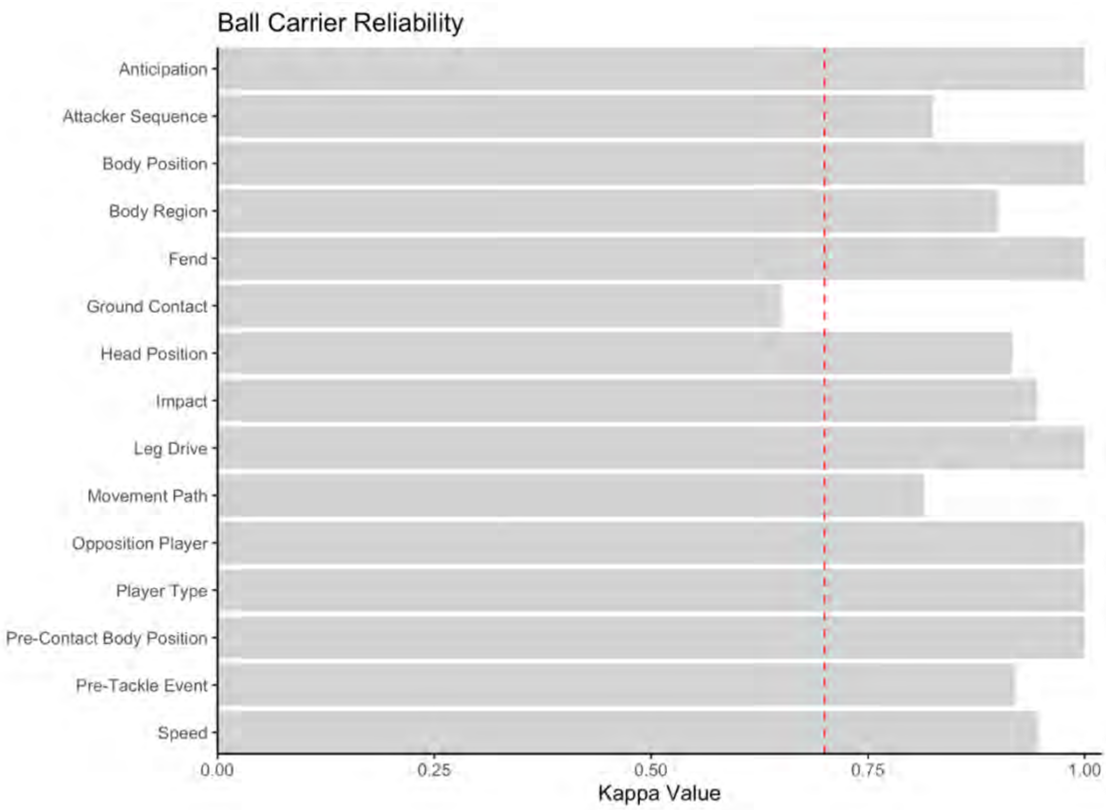


Figure 12 The reliability of tackle characteristics for the ball carrier in a tackle. The bars represent each tackle characteristic, and the red line represents the cut off agreement of 0.70.

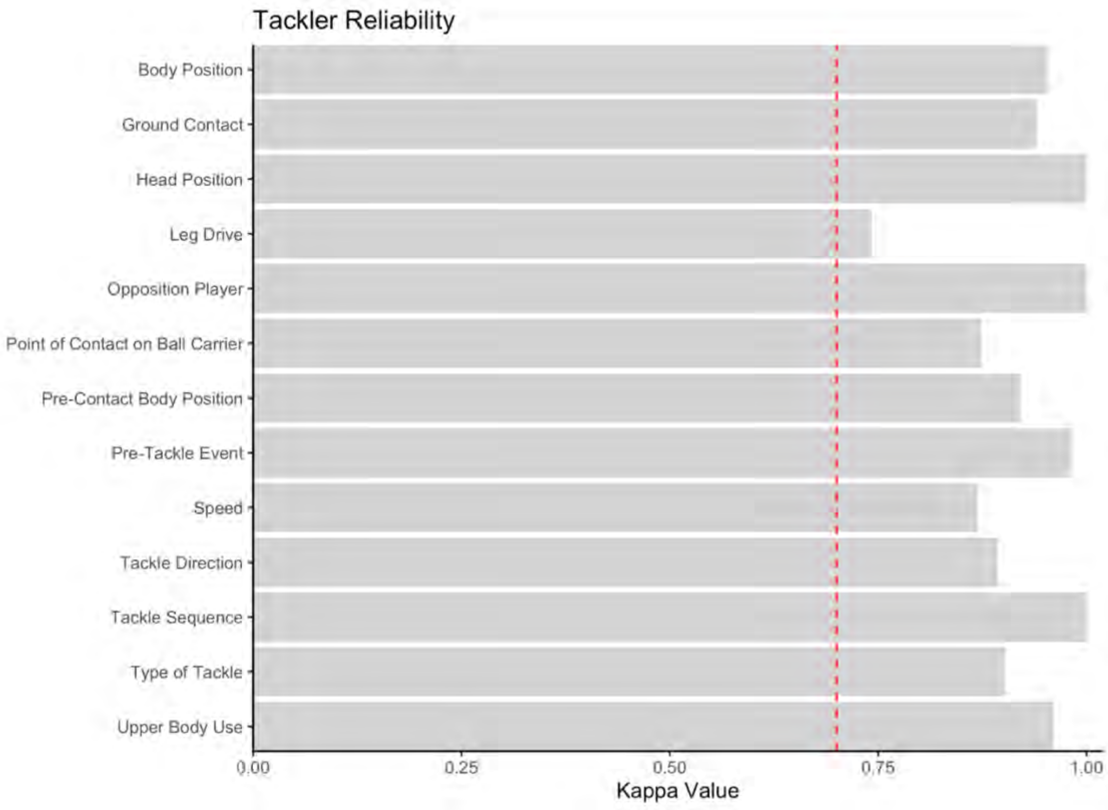


Figure 13 The reliability of tackle variables for the tackler in a tackle. The bars represent each tackle characteristic, and the red line represents the cut off agreement of 0.70.

Statistical analysis

The injury incidence and corresponding 95% confidence intervals (CI) and rate ratios (RR) for starter and replacement players was calculated using the GPS method outlined in Chapter 5. The relationship between the number of injuries and number of replacements was analysed using the incidence of injuries per 1000 player-exposures and proportion of all players sustaining an injury. The incidence/1000 player-exposures was calculated using:

$$injuries\ per\ 1000\ player\ exposures = \frac{number\ of\ injuries}{total\ number\ of\ players} \times 1000$$

where the number of injuries represents the injuries sustained by a team and the total number of players is represented as the number of replacements made by the team in a match added to the staring 15 players. To investigate the relationship between the number of injuries sustained and the number of replacements made, the number of replacements made for each team that sustained an injury within a match was identified using online match commentary and the GPS data. Where there were discrepancies between the number of replacements made between the two sources, videos of the matches were sourced and used to identify the number of replacements made by a team. For the analysis of replacement player time-in-game, the total exposure minutes for replacements used by a team within a match was summed. A generalized linear mixed model (GLMM) was also implemented using the *glmmTMB* package in R to analyse the number of injuries in relation to both the number of replacements used and the total number of replacement minutes within a match, with the match identification number used as the random intercept. An example of the formula used for the number of replacements used is shown below:

$$injuries \sim number\ of\ replacements\ made + (1\ |\ match\ identification\ number)$$

with the exponent of the beta (**β**) estimate reported in the results. The mechanism of injury was calculated as the proportion of injuries sustained from each match contact activity in relation to the total number of contact injuries for each group per season. The propensity of injury (number of injuries/100 tackle events) was calculated for tackle events between starters versus starters, replacements versus replacements and starters versus replacements. Descriptive statistics were used to demonstrate the most common tackle characteristics of starter and replacement players as a ball carrier and tackler separately. All statistical analysis was conducted using R (R Core Team, 2020).

Results

Match injury rates of starter and replacement players

A total of 290 injuries were sustained by 105 players, which represents 30% of the total player cohort across the three seasons (total of 345 players across three seasons; 232 in 2017/18, 258 in 2018/19 and 257 in 2019/20). The injury incidence for starters across the three seasons was higher than the replacement players; 80.8 injuries/1000 match hours (95% CI: 71.4-91.3) vs 57.2 injuries/1000 match hours (95% CI: 41.0-79.6), respectively (RR: 1.41; 95% CI: 1.00-1.98). Starters sustained more injuries than replacement players every season. The injury incidence of starters was higher in the 2018/19 and 2019/20 (Table 12).

Table 12 The total number of injuries, match hours and incidence (injuries/1000 match hours) with RR for starter and replacement players for the 2017/18, 2018/19 and 2019/20 season.

Season	Value	Starter	Replacement	Rate Ratio
2017/18	Number of Injuries	82	12	
	Total Hours	988	196	
	Incidence	83.0 (66.9-103.1)	61.3 (34.8-107.9)	*1.35 (0.97-1.88)*
2018/19	Number of Injuries	112	15	
	Total Hours	1253	234	
	Incidence	89.4 (74.3-107.6)	64.0 (38.6-106.2)	*1.40 (1.01-1.93)*
2019/20	Number of Injuries	61	8	
	Total Hours	928	189	
	Incidence	65.8 (51.2-84.6)	42.3 (21.1-84.6)	*1.56 (1.06-2.29)*

Number of replacements in a match

From the 2017/18 to the 2019/20 season, injuries occurred in 158 PRO14 matches. The number of replacements used within a match, ranged from two to eight. Fifty-nine percent of matches utilised the full eight replacements, 21% used seven replacements, 11% used six, 4% used five, 3% used four and 1% used three and two replacements.

The injury incidence was similar for each number of replacements made (Table 13). The highest incidence was for five and eight replacements, with three replacements showing the lowest incidence. Whilst the proportion of players injured was similar across all replacements made, there was a slight increase between less than five replacements and five or more. Similar to the incidence, five and eight replacements showed the highest proportion of injured players. When the number of replacements used were grouped, the incidence and the proportion of players injured was similar (Table 14).

Table 13 The number of replacements used in a match, the number of matches using that number of replacements, the incidence of injuries (injuries/1000 player-exposures; 95% CIs) and the proportion of players injured across three seasons.

No. of replacements	No. of matches replacements used	Incidence (injuries/1000 player-exposures)	Proportion of players injured (%)
2	1	58.8 (8.3-417.6)	5.9
3	1	55.6 (7.8-394.4)	5.6
4	5	63.2 (28.4-140.6)	6.3
5	6	83.3 (44.8-154.9)	8.3
6	18	71.4 (48.9-104.2)	7.1
7	33	81.3 (63.0-104.9)	8.1
8	94	86.0 (74.5-99.3)	8.6

Table 14 The grouped number of replacements, the number of matches using that number of replacements, the incidence of injuries (injuries/1000 player-exposures; 95% CIs) and the proportion of players injured across three seasons.

No. of replacements	No. of matches replacements used	Incidence (injuries/1000 player-exposures)	Proportion of players injured (%)
6 or less	31	71.7 (53.5-96.0)	7.2%
7	33	81.3 (63.0-104.9)	8.1%
8	94	86.0 (74.5-99.3)	8.6%

There was a 12% increase in the number of injuries for every number of replacements used (β 1.1151: 95% CI; 1.007-1.234) and this effect was significant ($p = 0.037$). When accounting for the match exposure time of replacement players there was a 0.01% increase in the number of injuries per 1 minute of replacement time, or 1% increase every 10 minutes, though this did not reach significance (β 1.001: 95% CI; 0.999-1.003, $p = 0.099$).

Contact event

The highest proportion of contact injuries were sustained during the tackle event (17-60%). For starters, the highest proportion of contact injuries in the 2017/18 and 2019/20 season were due to tackling (36% and 46%, respectively), with the 2018/19 season showing similar proportions for tackling and being tackled (31% and 32%, respectively). Replacement players primarily sustained injuries from being tackled in the 2017/18 and 2018/19 season (60% and 40%, respectively), and from tackling in the 2019/20 season (33%; Figure 14).

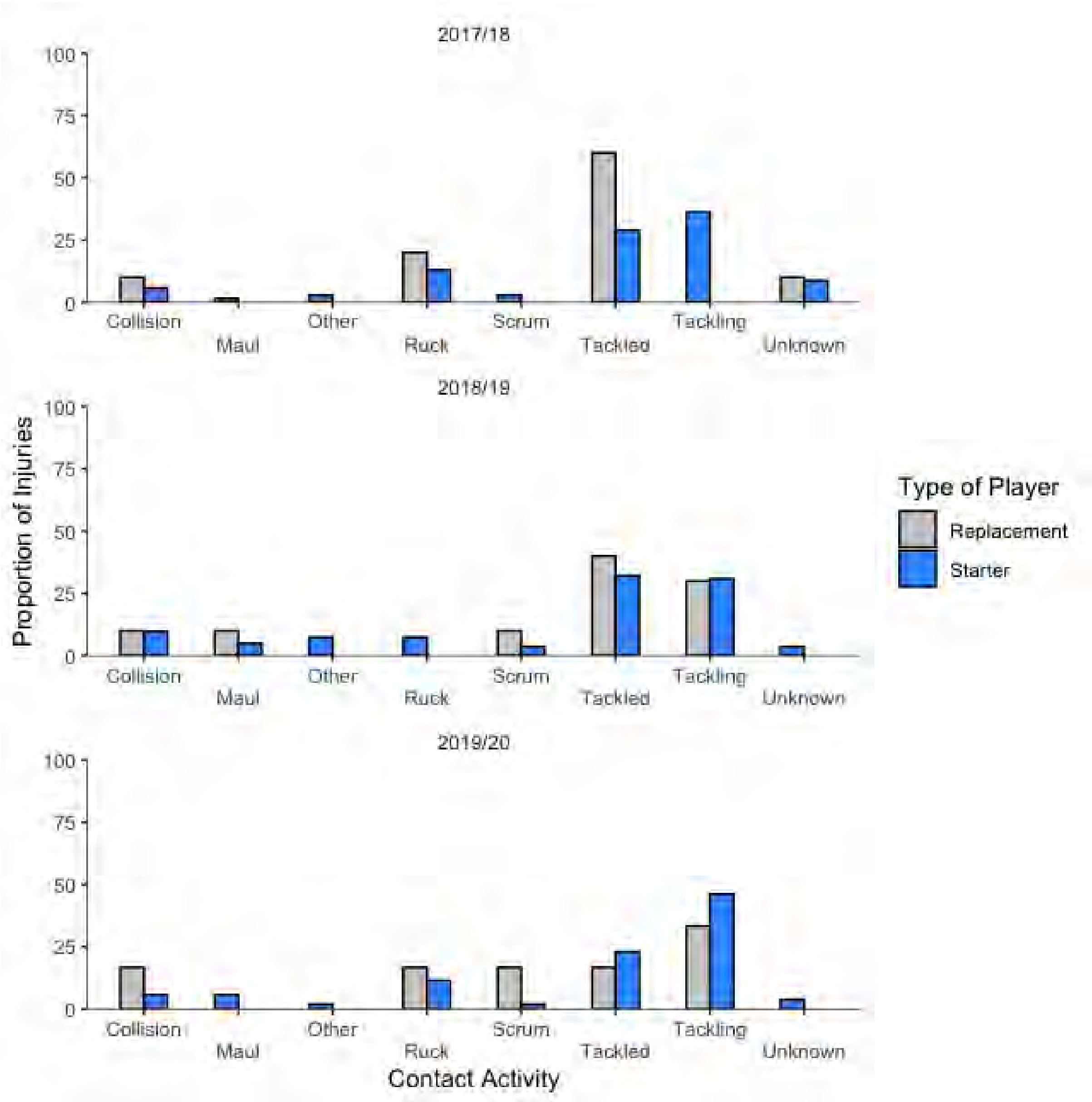


Figure 14 The proportion (%) of injuries sustained in each contact event in the 2017/18, 2018/19 and 2019/20 season for starter and replacement players.

Video analysis

A total of 59 matches were included in the analysis, with 263 tackler and 87 ball carrier tackles analysed. There was a total of 19 ball carrier injuries for starters and 3 ball carrier injuries for replacements. There was a total of 44 tackler injuries for starters and 3 tackler injuries for replacements.

Propensity

The highest propensity for injury was in tackles when the opposition player was a replacement (Table 15). Starters had a higher propensity for injury when the opposition player was a replacement than a starter (RR: 3.31 95% CI: 1.88-5.82). Replacement players had a higher propensity for injury when the opposition player was also a replacement (RR: 2.16, 95% CI: 1.32 – 3.54). There were no differences in the propensity of injury tackles when the injured player was a ball carrier. However, when the injured player was a tackler, a starter versus opposition replacement had the highest propensity for injury and was higher than the propensity of starter versus opposition starter (RR: 4.08, 95% CI: 2.28 – 7.29). There was no difference in the propensity of injury in replacement player tackles.

Table 15 The propensity (injuries per 100 tackle events) of all tackles, ball carrier tackles and tackler tackles between an injured starter vs opposition starter, injured starter vs opposition replacement, injured replacement vs opposition starter and injured replacement vs opposition replacement.

Tackle Type	Player Type (injured vs non-injured)	Number of Tackles	Propensity (injuries/100 tackle events) and 95% CI
All Tackler	Replacement vs Replacement	3	50.0 (16.1 – 155.0)
	Starter vs Replacement	12	63.2 (30.2 – 89.6)
	Replacement vs Starter	3	23.1 (7.4 – 71.6)
	Starter vs Starter	51	16.3 (12.0 – 20.6)
Ball Carrier Injured	Replacement vs Replacement	1	-
	Starter vs Replacement	2	66.7 (8.3 – 133.3)
	Replacement vs Starter	2	22.2 (5.6 – 88.6)
	Starter vs Starter	17	23.0 (12.6 – 31.7)
Tackler Injured	Replacement vs Replacement	2	40.0 (10.0 – 159.9)
	Starter vs Replacement	10	62.5 (32.1 – 104.5)
	Replacement vs Starter	1	25.0 (3.5 – 177.5)
	Starter vs Starter	34	14.3 (10.2 – 19.7)

Tackle characteristics

As a ball carrier, starter and replacement players showed similar characteristics when sustaining an injury (Table 16). Both groups sustained injuries when they were in an upright position pre-contact (79% for starter, 33% for replacement), with heads facing forwards (63% for starter, 67% for replacement). All ball carrier replacements were forwards, whereas starters were 50% forwards and 50% backs. The majority of starter and replacement players were injured in a tackle with an opposition starter (67% of replacements, 90% of starters).

Table 16 The tackle characteristics of ball carrier as a starter and a replacement in non-injurious and injurious tackles.

Characteristic	Starter-not injured; *N = 58*	Starter-injured; *N = 19*	Replacement-not injured; *N = 7*	Replacement-injured; *N = 3*
Attacker Sequence				
One on One	52 (90%)	15 (79%)	5 (71%)	2 (67%)
Sequential	5 (9%)	2 (11%)	0 (0%)	1 (33%)
Simultaneous	1 (2%)	2 (11%)	2 (29%)	0 (0%)
Body Position at Contact				
Bent at Waist	15 (26%)	7 (37%)	0 (0%)	0 (0%)
Falling/Diving	1 (2%)	1 (5%)	3 (43%)	1 (33%)
On Ground	1 (2%)	0 (0%)	0 (0%)	0 (0%)
Upright	41 (71%)	11 (58%)	4 (57%)	2 (67%)
Body Region Contacted				
Head and Neck	6 (10%)	6 (32%)	2 (29%)	1 (33%)
Legs	12 (21%)	3 (16%)	1 (14%)	0 (0%)
Mid-Torso	22 (38%)	5 (26%)	2 (29%)	2 (67%)
Shoulder	18 (31%)	5 (26%)	2 (29%)	0 (0%)
Fend				
Absent	46 (79%)	16 (84%)	5 (71%)	3 (100%)
Moderate	9 (16%)	2 (11%)	2 (29%)	0 (0%)
Strong	3 (5%)	1 (5%)	0 (0%)	0 (0%)
Impact of Contact				
High	6 (10%)	7 (37%)	1 (14%)	1 (33%)
Low	25 (43%)	4 (21%)	3 (43%)	1 (33%)
Medium	27 (47%)	8 (42%)	3 (43%)	1 (33%)
Opposition Player				

Characteristic	Starter-not injured; *N = 58*	Starter-injured; *N = 19*	Replacement-not injured; *N = 7*	Replacement-injured; *N = 3*
Opposition Replacement	1 (2%)	2 (11%)	0 (0%)	1 (33%)
Opposition Starter	57 (98%)	17 (89%)	7 (100%)	2 (67%)
Post-Contact Leg Drive				
Absent	50 (86%)	17 (89%)	6 (86%)	2 (67%)
Moderate	7 (12%)	2 (11%)	1 (14%)	0 (0%)
Strong	1 (2%)	0 (0%)	0 (0%)	1 (33%)
Ball Carrier Anticipation				
No	4 (7%)	3 (16%)	0 (0%)	0 (0%)
Yes	54 (93%)	16 (84%)	7 (100%)	3 (100%)
Pre-Contact Body Position				
Low	2 (3%)	1 (5%)	2 (29%)	1 (33%)
Medium	14 (24%)	3 (16%)	2 (29%)	1 (33%)
On Ground	2 (3%)	0 (0%)	0 (0%)	0 (0%)
Upright	40 (69%)	15 (79%)	3 (43%)	1 (33%)
Pre-Contact Head Position				
Away	15 (26%)	6 (32%)	1 (14%)	0 (0%)
Down	6 (10%)	1 (5%)	2 (29%)	1 (33%)
Up and forward	37 (64%)	12 (63%)	4 (57%)	2 (67%)
Pre-Contact Movement Path				
Arcing Run	1 (2%)	0 (0%)	0 (0%)	0 (0%)
Diagonal Run	6 (10%)	2 (11%)	1 (14%)	0 (0%)
Side-Step	22 (38%)	3 (16%)	3 (43%)	1 (33%)
Straight	29 (50%)	14 (74%)	3 (43%)	2 (67%)
Pre-Contact Speed				
Fast	23 (40%)	12 (63%)	2 (29%)	1 (33%)
Moderate	22 (38%)	4 (21%)	1 (14%)	1 (33%)
Slow	13 (22%)	3 (16%)	4 (57%)	1 (33%)
Pre-Tackle Event				
Kick in Play	7 (12%)	0 (0%)	0 (0%)	0 (0%)
Kick Off	2 (3%)	1 (5%)	0 (0%)	0 (0%)
Line Out	1 (2%)	0 (0%)	0 (0%)	0 (0%)
Open Field Running	3 (5%)	4 (21%)	1 (14%)	1 (33%)

Characteristic	Starter-not injured; *N = 58*	Starter-injured; *N = 19*	Replacement-not injured; *N = 7*	Replacement-injured; *N = 3*
Other Tackle	4 (7%)	0 (0%)	0 (0%)	0 (0%)
Ruck	0 (0%)	0 (0%)	1 (14%)	0 (0%)
Scrum	2 (3%)	1 (5%)	0 (0%)	0 (0%)
Static/Tactical	39 (67%)	13 (68%)	5 (71%)	2 (67%)
Position				
Backs	33 (57%)	10 (53%)	0 (0%)	0 (0%)
Forwards	25 (43%)	9 (47%)	7 (100%)	3 (100%)

As a tackler, all replacement injuries occurred when a replacement player was bent at the waist upon contact (Table 17). Starters sustained the highest proportion of injuries when the hip and head and neck of the ball carrier were contacted (28% and 26%, respectively). Replacement players sustained the highest proportion of injuries when the upper leg of the ball carrier was contacted (67%). Whilst the starters sustained the highest proportion of injuries from a smother tackle (57%), all replacement injuries were sustained during a shoulder tackle. In contrast to ball carrier tackles, the highest proportion of tackles to replacement players were sustained when the opposition player was a replacement, with the highest proportion of injuries for starters sustained when the opposition player was a starter. All replacements injured as a tackler were forwards.

Table 17 The tackle characteristics of tackler as a starter and a replacement in non-injurious and injurious tackles.

Characteristic	Starter-not injured; *N = 210*	Starter-injured; *N = 44*	Replacement-not injured; *N = 6*	Replacement-injured; *N = 3*
Body Position at Contact				
Bent at Waist	89 (42%)	16 (36%)	5 (83%)	3 (100%)
Falling/Diving	43 (20%)	13 (30%)	0 (0%)	0 (0%)
Upright	78 (37%)	15 (34%)	1 (17%)	0 (0%)
Direction of Tackle				
Behind	17 (8%)	2 (5%)	0 (0%)	0 (0%)
Front	125 (60%)	24 (55%)	5 (83%)	2 (67%)
Side	68 (32%)	18 (41%)	1 (17%)	1 (33%)
Point of Contact on Ball Carrier				
Arm	14 (7%)	3 (7%)	0 (0%)	0 (0%)

Characteristic	Starter-not injured; *N = 210*	Starter-injured; *N = 44*	Replacement-not injured; *N = 6*	Replacement-injured; *N = 3*
Head and Neck	22 (10%)	12 (27%)	1 (17%)	1 (33%)
Hip	38 (18%)	13 (30%)	0 (0%)	0 (0%)
Lower Leg	2 (1%)	0 (0%)	0 (0%)	0 (0%)
Shoulder	71 (34%)	6 (14%)	3 (50%)	0 (0%)
Torso	42 (20%)	5 (11%)	2 (33%)	0 (0%)
Upper Leg	21 (10%)	5 (11%)	0 (0%)	2 (67%)
Type of Tackle				
Arm	51 (24%)	10 (23%)	1 (17%)	0 (0%)
Jersey	1 (0%)	0 (0%)	0 (0%)	0 (0%)
Shoulder	20 (10%)	8 (18%)	2 (33%)	3 (100%)
Smother	137 (65%)	26 (59%)	3 (50%)	0 (0%)
Tap	1 (0%)	0 (0%)	0 (0%)	0 (0%)
Opposition Player				
Opposition Replacement	6 (3%)	10 (23%)	3 (50%)	2 (67%)
Opposition Starter	204 (97%)	34 (77%)	3 (50%)	1 (33%)
Tackler Leg Drive				
Absent	201 (96%)	44 (100%)	4 (67%)	3 (100%)
Moderate	7 (3%)	0 (0%)	2 (33%)	0 (0%)
Strong	2 (1%)	0 (0%)	0 (0%)	0 (0%)
Post-Contact Upper Body Usage				
No	85 (40%)	34 (77%)	3 (50%)	3 (100%)
Yes	125 (60%)	10 (23%)	3 (50%)	0 (0%)
Post-Contact to Ground				
Pulls BC to Ground	113 (54%)	10 (23%)	3 (50%)	0 (0%)
Releases	97 (46%)	34 (77%)	3 (50%)	3 (100%)
Pre-Contact Body Position				
Low	7 (3%)	3 (7%)	0 (0%)	0 (0%)
Medium	89 (42%)	11 (25%)	3 (50%)	1 (33%)
Upright	114 (54%)	30 (68%)	3 (50%)	2 (67%)
Pre-Contact Head Position				
Away	1 (0.5%)	0 (0%)	0 (0%)	0 (0%)
Down	3 (1%)	2 (5%)	0 (0%)	0 (0%)

Characteristic	Starter-not injured; *N = 210*	Starter-injured; *N = 44*	Replacement-not injured; *N = 6*	Replacement-injured; *N = 3*
Motion/Tracking	10 (5%)	2 (5%)	0 (0%)	0 (0%)
Up and forward	196 (93%)	40 (91%)	6 (100%)	3 (100%)
Pre-Contact Speed				
Fast	35 (17%)	14 (32%)	0 (0%)	0 (0%)
Moderate	110 (52%)	19 (43%)	4 (67%)	2 (67%)
Slow	65 (31%)	11 (25%)	2 (33%)	1 (33%)
Tackler Anticipation				
No	1 (0.5%)	1 (2%)	0 (0%)	0 (0%)
Yes	209 (100%)	43 (98%)	6 (100%)	3 (100%)
Pre-Tackle Event				
Kick in Play	30 (14%)	2 (5%)	0 (0%)	0 (0%)
Kick Off	7 (3%)	1 (2%)	0 (0%)	0 (0%)
Line Out	6 (3%)	0 (0%)	0 (0%)	0 (0%)
Maul	2 (1%)	0 (0%)	0 (0%)	0 (0%)
Open Field Running	7 (3%)	1 (2%)	0 (0%)	0 (0%)
Other Tackle	11 (5%)	3 (7%)	0 (0%)	0 (0%)
Ruck	1 (0%)	0 (0%)	0 (0%)	0 (0%)
Scrum	0 (0%)	2 (5%)	1 (17%)	0 (0%)
Static/Tactical	146 (70%)	35 (80%)	5 (83%)	3 (100%)
Tackle Sequence				
One on One	84 (40%)	17 (39%)	1 (17%)	2 (67%)
Sequential	69 (33%)	9 (20%)	1 (17%)	1 (33%)
Simultaneous	57 (27%)	18 (41%)	4 (67%)	0 (0%)
Position				
Backs	71 (34%)	18 (41%)	0 (0%)	0 (0%)
Forwards	139 (66%)	26 (59%)	6 (100%)	3 (100%)

Discussion

The aims of this study were to investigate whether the physical impact of replacement players within a match influence the injury rates. This was investigated by analysing the injury rates of starter and replacement players and the influence of replacement players on injuries within matches. In addition, the tackle characteristics of starter and replacement players was explored. The main findings from this study were that players who started a match had a higher injury incidence than replacements. Within the current cohort, 59% of matches used the full number of replacements legally permitted within Rugby Union. The incidence per 1000 athlete exposures was not influenced by the number of replacements used. However, there was a 12% increase in the number of injuries sustained per number of replacements used. When considering the number of minutes in a match for replacement players, there was a 1% increase in the number of injuries for every 10 minutes of replacement player exposure, though this did not reach significance. Interestingly, when the injured player was a tackler, the propensity for injury to a starter was higher when the opposition ball carrier was a replacement than when the opposition ball carrier was a starter. In addition, when the injured player was making a tackle, the body position of starter and replacement players showed differing characteristics within injury inciting tackles.

Match injury rates

One of the main findings from this study was that players who started a match sustained a higher number of injuries and had a higher injury incidence than replacements in the 2018/19 and 2019/20 seasons. Though there is limited research investigating differences between starter and replacement players, this study is in agreement with Brooks et al. (2005b) who demonstrated that staring players had higher injury incidence than replacement players in the final quarter of a match. The differences between starter and replacement players with regards to injury incidence can be attributed to the short period of exposure to injury inciting events experienced by replacement players within matches. Previous research has identified that the majority of replacements are made within the second half of matches, with forwards often replaced earlier in matches than backs, most frequently between 50-65 minutes (Lacome et al., 2016). Consequently, replacement players have lower exposure to match events that could lead to injury due to the comparatively lower time-in-game than starters, and this is likely to contribute to the lower injury incidence.

Replacement players within matches

An interesting finding in the current study was that over half of the matches in the current cohort (59%) used the full number of replacements legally permitted within a Rugby Union match. Furthermore, only 20% of matches used fewer than seven replacement players, though the number of replacements used did not influence the injury incidence or the proportion of all players injured. However, when analysing the effect of replacement players on the number of injuries sustained, there was a 12% increase in the number of injuries for every replacement used per team (p = 0.0037). Though this reached significance, the low proportion of matches using less than seven replacements may influence this finding. This is supported when considering the exposure minutes of replacement players, where the 1% increase in the number of injuries for every 10 minutes of replacement match exposure time did not reach significance (p = 0.099). This indicates that increases in the exposure time of replacement players within a match did not significantly influence the number of injuries sustained. Though research has identified that replacement players demonstrate higher physicality than their respective starters when brought on (Lacome et al., 2016; Michael et al., 2019), this does not seem to translate to higher injury rates. This may be related to the mechanisms associated with injuries, with both starter and replacement players in the current cohort sustaining most of their injuries during the tackle event. Though research has demonstrated that replacement players have a higher involvement in both attacking and defensive strategies than their starter counterparts (Michael et al., 2019), the techniques implemented by replacement players within these events may provide a level of protection against injury. Specifically, the potential for starter fatigue and the impact this may have on tackle technique may indicate that replacement players employ appropriate contact techniques due to their reduced time-in-game, reducing the potential for injurious tackle events.

Tackle injury propensity

When considering the propensity of injury during the tackle event, tackles involved with an opposition replacement had a higher injury propensity than tackles with an opposition starter. Specifically, when the injured player was a tackler, the propensity for injury to a starter was higher when the opposition ball carrier was a replacement than when the opposition ball carrier was a starter. This means that injuries to a starter making a tackle are more likely to occur when the opposition ball carrier is a replacement. The increase in propensity was only seen for starters, suggesting that the way in which a starter approaches a tackle against a replacement player increases the injury propensity. This may in part be due to the differences in player time-in-game, where replacement players may demonstrate increased readiness and impact as a ball carrier. This is supported in previous research, where the contribution of replacement players is more apparent when their team is attacking than when defending (Lacome et al., 2016). Furthermore, technique deficiencies as a tackler have been shown to increase the risk of injury, with increased player time-in-game suggested to decrease tackle proficiency (Davidow et al., 2018; Gabbett, 2008). The combination of player fatigue and increased contribution of replacement players as ball carriers may provide a reason for the differences in injury propensity within this study. However, caution is warranted when interpreting the differences shown in the propensity, due to the small number of tackles involving replacement players in comparison to tackles involving players who started a match.

Tackle characteristics

Interestingly, when the injured player was making a tackle, the body position of a replacement player was comparatively lower than that of a starter within injury inciting tackles. Replacement players were bent at the waist during contact for all injury inciting tackles, whereas starters showed similar proportions for the players body position being bent at the waist and upright during the tackle (36% vs 34%, respectively). Furthermore, replacement players injury inciting tackles were all shoulder tackles, predominantly contacting the upper leg of the ball carrier. Comparatively, starters predominantly made smother tackles and contacted the hip or the head and neck of the ball carrier during injury inciting tackles. This suggests that replacement players maintain a lower body position when sustaining an injury as a tackler. Additionally, differing characteristics identified between starter and replacement players demonstrate potentially different injury inciting events. The characteristics identified in the current study are supported by previous video analysis research analysing head injuries during the tackle. In 2017, Tucker and colleagues (2017) identified that when a tackler made an active shoulder tackle and contacted the ball carriers head, the propensity for HIA to the tackler was higher. A recent study by Hopkinson et al. (2021) further supports this notion, with head contact between the tackler and ball carrier shown to be an important factor in the likelihood of injury. Furthermore, studies analysing the proficiency of tacklers identified that a decrease in tackle technique influenced injury occurrence, suggesting that head contacts during tackles are often a result of decreased tackle proficiency (Davidow et al., 2018; Tierney et al., 2018). The higher proportions of injury inciting tackles where a starter has an upright position and contacts the ball carriers head and neck in the current study suggest that injuries sustained by starters may be due to a reduction in appropriate tackling technique. In contrast, replacement players seem to maintain appropriate technique as advocated by the law changes brought about from the study by Tucker et al. (2017), with the type of tackle, that is the shoulder tackle, showing potentially higher importance in relation to sustaining injuries. Though this study demonstrates similar findings to previous research, the analysis of starter and replacement players has provided further insight into the tackle event, demonstrating that injury related characteristics may differ between starter and replacement players. The differing injury related tackle characteristics are an important factor to consider when developing effective injury risk mitigation strategies. Strategies that specifically target the tackle technique of players who primarily start a match, with a focus on maintaining appropriate body positions when tackling within training may mitigate the risk of injury demonstrated in the current study.

Limitations

A limitation in the current study was the small sample size, specifically the small number of tackles involving replacement players in comparison to players who started a match. As the nature of using replacement players within Rugby Union mean that players are exposed to a match for shorter periods of time (Lacome et al., 2016), it is to be expected that they are involved in a fewer number of tackle events. However, when analysing injuries prospectively using real-life data, simulating injuries within the cohort is not possible. In this circumstance using exposure hours and analysis methods that are specific to each group of players allows the injuries to be analysed relative to the exposure.

Conclusion

In conclusion, starters sustain a higher number of injuries and have higher injury incidences than replacement players. Additionally, the match exposure time for replacements did not significantly affect the number of injuries sustained within a match. However, the propensity of injury to a player making a tackle was higher between starter and opposition replacement players than between starter and opposition staters. This may, however, be due to the small number of tackle events involving replacement players in the current cohort. Interestingly, tackle characteristics within injury inciting tackles differed between starter and replacement players when making a tackle. This suggests that injury risk mitigation strategies associated with the tackle event during matches should be incorporated at a player-specific level, considering the influence of players who started a match and those who are replacements. Further work is required to investigate the influence of replacement players within a larger cohort, particularly across a wider range of teams and countries to further understand the influence of replacement players within the tackle event.

Chapter 7: General discussion and practical implications

Overall summary

The aim of this thesis was to investigate current methods of analysis in injury surveillance research, specifically analysing injury rates within Welsh professional Rugby Union. Further, the thesis aimed to explore a player-specific approach to injury analysis and apply this method to examine starter and replacement player match injuries. A summary of each aim is outlined below.

Investigate the injury rates and mechanisms within Welsh professional Rugby Union

Chapter 3 followed the recommendations outlined in the consensus statement on injury definitions and data collections within Rugby Union and identified that the injury rate within the four regional professional Welsh Rugby Union teams was higher than previously reported. Though recent research in professional Rugby Union have reported match injury rates to be 87 injuries/1000 match hours (West, Starling, et al., 2020), Chapter 3 demonstrated an incidence rate of 99.1 injuries/1000 match hours. Further differences in the injury rates were identified for specific body areas, with the upper body showing higher injury incidence in comparison to the lower body. This contrasts to findings from previous research, where the lower limb has consistently shown higher injury incidence and severities the upper limb during matches (Brooks et al., 2005b; Fuller et al., 2008, 2020; Williams et al., 2013). Specifically, Chapter 3 demonstrated increasing injury rates to the head and the shoulder across the four seasons. An important contribution to this change in injury rates for the upper body was the identification of injury mechanisms, where the tackle was the contact event responsible for the highest proportion of match injuries (50-63%). Though the tackle event has consistently contributed to higher proportions of injuries in previous research (Fuller et al., 2020; West, Starling, et al., 2020), the changing injury rates for the upper limb shown in Chapter 3 provides an important insight into the tackle event within the current cohort. The changing injury rates to the upper and lower limbs, in combination with the high proportion of match injuries sustained within the tackle, suggest tackle technique may have been changing whereby over the years the tackler has been contacting the ball carrier higher up the body.

Identify whether the Subsequent Injury Categorisation model is implemented within professional or elite sports injury research

Though the team-level injury rates and mechanisms provided insight into the match injury problem within Welsh professional Rugby Union, the understanding of the underlying injury problems within individuals is limited, which is a consistent factor within previous research (Brooks et al., 2005b; Fuller et al., 2020; West, Starling, et al., 2020). Though individual approaches to analysing the relationships between injuries have been recommended by the application of the subsequent injury categorisation model (SIC 1.0 and 2.0; Finch & Cook, 2014; Toohey et al., 2018), Chapter 4 demonstrated the inconsistency associated with implementing this model within professional and elite sport. Furthermore, Chapter 4 emphasised the continued reporting of injuries across multiple teams or multiple seasons, a problem outlined in previous systematic reviews (Fortington et al., 2017). Where injury analysis is pooled across a large number of individuals, there is a lack of understanding regarding the influence of individual players on the team-level injury rates. Individual differences have been considered within previous research, reporting the number or proportion of individuals that sustain injuries (Moore et al., 2015, 2018; Chapter 3), though further detail is limited. Whilst the proportion of players sustaining injuries provides initial insight into differences between players within a team, the limited recommendations for analysing injuries at a player-specific level means that moving from a team-level approach to a player-specific approach is challenging.

Identify whether team-level injury rates account for player-specific differences and explore a player-specific method of analysing injuries

An important step in the analysis of injuries at an individual level was the publication of the six-stage injury framework by Roe and colleagues (2017), which emphasised the importance of considering the athlete-specific characteristics when developing adequate injury management strategies. However, the initial stages in this framework do not outline methods of analysis that investigate and identify the individual injury rates. Further, the lack of support for individual methods of analysis in consensus statements continue to encourage analysis to be implemented at a team-level. Therefore, Chapter 5 aimed to identify whether team injury rates could account for individual differences within a team. Interestingly, the proportion of players providing consent played a pivotal role in the calculation of team-level injury incidence when using the estimated match exposure hours. Specifically, comparing the team-level injury incidence using the estimated match exposure against the GPS-derived match hours accumulated across players showed that estimating the hours underestimated the incidence. The inaccuracies associated with using estimated match exposure hours emphasise that individual players within a team play a key role in the contribution towards the team-level injury rate, with estimated calculations only becoming appropriate if the full cohort of players provides consent. However, a key finding was that the team-level analysis failed to account for the player-specific differences in injury rates. Using a novel approach to analysing match exposure hours allowed for the calculation of player-specific injury rates, a method that has not been previously implemented. The high proportion of players falling outside of the 95% confidence intervals for the team-level injury incidence (>84%) further emphasises findings from Chapter 4, that pooling data across players does not provide an accurate representation of injury rates within a large cohort of players. However, the unintuitive nature of reporting injuries as the rate per 1000 hours required a more easily communicable method of reporting injuries to be established. In this circumstance, identifying the player-specific injury rates allowed the analysis of injury risk to be explored across the cohort using the Poisson model (Parekh et al., 2012). This method of analysing player-specific injury risk identified that players with higher injury incidence had a higher risk for multiple injuries when exposed to higher match hours. The use of the Poisson model in identifying injury risk within a large cohort of players has provided the opportunity to develop and implement a live risk calculator, establishing the extent of the injury risk to a player throughout a season. Chapter 5 therefore established an alternative method of interpreting injuries within a clinical setting, an important aspect of translating injury research into practice. Furthermore, the use of a live risk calculator may encourage increased squad rotation and use of tactical replacement during matches to reduce the match exposure at a player-specific level, consequently reducing injury risk.

Apply the player-specific method of analysis to investigate injuries sustained by starter and replacement players

Though increased squad rotation and tactical replacements may reduce injury risk at a player-specific level, the introduction of replacement players has been suggested to contribute to the higher injury rates within the third and fourth match quarters (Bathgate et al., 2002). The injury rates of starter and replacement players has therefore become an area of importance for medical professionals involved in professional Rugby Union. However, the extent to which replacement players influence injury rates is yet to be established. Therefore, Chapter 6 explored the injury rates and mechanisms of starter and replacement players. Though replacement players are typically exposed to substantially lower match hours, the method of analysing match exposure at a player-specific level developed in Chapter 5 was applied, allowing the specific calculation of match exposure hours using GPS-derived exposure for each player group separately. Chapter 6 demonstrated that starters had a higher injury incidence than replacement players. Differences in injury incidence between these playing groups are primarily due to the differences in exposure hours, with replacement players primarily involved within the final 20 minutes of matches (Lacome et al., 2016) meaning a lower exposure to potentially injury inciting events.

Although the lower exposure experienced by replacement players may reduce their involvement in injury inciting events, the suggestion that replacement players influence the changes in injury rates between match quarters was an important consideration in Chapter 6 (Bathgate et al., 2002). Initial investigations identified that the injury rate and proportion of players injured was similar for each number of replacements used within matches. However, when the effect of replacement players on the number of injuries was considered, there was a 12% increase in the number of injuries for every replacement player used. Though this reached significance (p = 0.037) the low proportion of matches using less than seven replacements (20%) may be an influencing factor. Whilst simulating matches using a lower number of replacements is not possible with real-time data collection, the small sample size associated with the number of replacements used may lead to a type II error. This may indicate that the results obtained in the current study is not applicable to a wider sample. Increasing the sample size would therefore reduce the chances of a type II error. Whilst errors associated with statistical testing cannot be completely removed, the small sample size is further emphasised when accounting for the time-in-game for replacement players. Though there was a 1% increase in the number of injuries for every 10 minutes of replacement player time-in-game, this did not reach significance (p = 0.099). As such, accounting for the time that replacement players were involved in matches is an important consideration in the analysis of injuries. Due to the potential for a larger range of exposure time for replacement players within matches, this may be a more appropriate method of analysing the association between replacement players and injuries during matches. The similarities between the injury rates and proportions for each number of replacements used within a match and the lack of significance identified for replacement time-in-game support the notion of utilising tactical replacements to reduce the risk of a player sustaining multiple injuries. The higher risk for multiple injuries when exposed to higher match hours identified in Chapter 5 demonstrate the importance of using tactical replacements within matches. Reducing the risk of injury to an individual player by utilising methods that reduce player-specific exposure could protect player welfare and consequently reduce the injury rates within Rugby Union matches.

An important finding within Chapter 6 was that although replacement players did not influence injury rates within a match, differences were shown between starter and replacement players when making a tackle. Firstly, the propensity of injures to starters was higher when the opposing ball carrier was a replacement. Though the small number of tackles involving replacement players may influence this finding, the differing characteristics shown by starter and replacement players as a tackler suggest different injury mechanisms are present within each group. Specifically, startiers exhibited higher body positions when sustaining an injury as a tackler, whereas replacement players exhibited lower positions, primarily implementing shoulder tackles. Previous research investigating tackle proficiency and the characteristics of injury inciting tackles support these findings, where head to head contact, active shoulder tackles and upright tackling techniques were important factors associated with injury (Davidow et al., 2018; Hopkinson et al., 2021; Tucker, Raftery, Kemp, et al., 2017).

Overall discussion

Subsequent injuries

Whilst Chapter 3 followed the recommendations outlined in the consensus statement, including the team-level injury rate, the type, mechanism and recurrent nature of injuries, inconsistencies remain in the way injuries are collected, analysed and reported within professional and elite sport. Specifically, the development of the subsequent injury categorisation (SIC) by Finch and Cook (2014) and update by

Toohey and colleagues (2018), provide a specific categorisation of subsequent injuries. These models have provided important insight into the inter-injury relationships within professional and elite sport (Moore et al., 2018; Toohey et al., 2019), however, the implementation of these models within research was unknown. Chapter 4 consequently identified that inconsistencies exist between research following consensus statements when reporting the recurrent or subsequent nature of injuries, with only 6% of studies using the SIC models. This may, in part, be due to the lack of recommendation within consensus statements on the use of SIC models when analysing the recurrent or subsequent nature of injuries. This was emphasised in Chapter 3, where following the recommendations outlined in the consensus statement by Fuller and colleagues (2007), only injuries reported as new or recurrent were analysed and reported. Consequently, the relationship between injuries defined as 'new' and any subsequent injury following this was not distinguished within Chapter 3. Therefore, further understanding of the role of subsequent injuries and the potential for multiple injury occurrences that may be related is yet to be established within the current cohort. Whilst the definition of a recurrent injury is provided within sport-specific consensus statements, this is often as far as epidemiological research goes in analysing the multiple injuries sustained by players. The SIC models provide an opportunity to improve the knowledge surrounding the relationship between multiple injuries that players may sustain throughout a season. The development of an automated coding system from the SIC 2.0 (Toohey et al., 2018) further provides an opportunity for subsequent injuries to be widely categorised within future research. With this in mind, advocating the use of a SIC model within consensus statements would increase the utilisation of subsequent injury diagnosis and provide a better understanding of the inter-injury relationship in professional and elite level sport.

Analysis of injury rates

A further issue outlined within Chapter 4 was the method in which injuries are analysed and reported. According to the recommendations in the consensus statement, Chapter 3 pooled injury data across players and utilised an estimated measure of match exposure to calculate the injury incidence. However, the pooling of data across individuals results in reduced quality research and does not provide insight into the underlying injury problems within the individuals. This was emphasised by the quality assessment tool from Downs and Black (1998), where studies that pooled data across players had a lower quality score. To improve the understanding of the underlying injury rates, the exploration into the injury rates at a player-specific level was warranted. However, recommendations on the analysis of injuries at an individual level are yet to be established. Though Roe and colleagues (2017) outlined a six-stage injury framework that emphasises the importance of considering the individual characteristics when developing injury risk mitigation strategies, the initial analysis of injury rates remain at a team-level. Perhaps the limited analysis of individual injury rates is due to the lack of recommendations within consensus statements as to the approach to take when calculating individual exposure. Therefore, Chapter 5 developed a method of analysing injury rates at a player-specific level that could be applied in future research. Whilst Chapter 3 provided insight into the team-level injury rates within the current cohort, Chapter 5 emphasised the importance of considering players within a team, showing substantial differences between the team and player-specific level of analysing injury incidence. Specifically, over 84% of players fell outside of the confidence intervals for the team-level injury incidence. The differences outlined between injury analysis at a team and player-specific level further emphasise the issues associated with pooling data identified in Chapter 4. However, due to team-level analysis being advocated within consensus statements, a consistent player-specific level of injury analysis is yet to be established and applied. Chapter 5 therefore highlights the potential for further analysis into the injuries sustained at a player-specific level, using GPS-derived exposure to calculate the injury incidence. Furthermore, the application of the Poisson probability, using the player-specific injury incidence, allows further interpretation into the injury risk at a player-specific level. Used in combination, these methods of analysis can accommodate for the lack of specificity associated with the team-level injury rates, providing an opportunity for the development of individualised injury risk mitigation strategies.

Starter and replacement player tackle characteristics

The importance of establishing a player-specific approach was further emphasised in Chapter 6, where the injury rates of starter and replacement players was investigated. Though Brooks and colleagues (2005b) initially identified differences between starter and replacement players within a match, the differing match exposure times experienced by players was not accounted for; an important factor in the calculation of injury incidence. However, the development of a player-specific exposure calculation within Chapter 5 could accommodate for the differences between match exposure times. Similar to Chapter 5, differences in injury rates between starter and replacement players were identified. This further emphasises that the team-level injury rate in Chapter 3 fails to identify the underlying match injury rates within players. Furthermore, by following the recommendations of the consensus statement (Fuller, Molloy, et al., 2007), factors within the match which may be considered higher risk for injury, such as the injuries incurred by starter and replacement players, cannot be identified. This is further emphasised by the analysis of injury mechanisms at a player-specific level, where injury-inciting tackle characteristics showed differences between starter and replacement players. This is an important finding, specifically when considering the changing injury patterns associated with the tackle event in Chapter 3. Taken together, these findings indicate that the changing tackle techniques identified at a team-level is more effectively addressed utilising analysis that investigates mechanisms at a player-specific level. This is the first study to consider the player-specific influence on tackle characteristics and identify important considerations for future research analysing tackle characteristics within matches. Furthermore, the findings from Chapters 5 and 6 signify the importance of targeting injuries at a player-specific level to develop effective injury risk mitigation strategies that reduce the risk of injury to a player, and consequently reduce the injury rates at a team-level. Whilst team-level analysis alone cannot account for individual differences within a team, the methods outlined in Chapter 5 provide an alternative method that can be applied to analyse injuries at a player-specific level. A player-specific approach to injury analysis consequently provides an opportunity for the development of injury risk mitigation, management and rehabilitation strategies that are targeted towards the individual characteristics of a player. This can in turn, contribute to improving injury risk mitigation and the protection of player welfare.

Limitations

The current study has implemented a novel method of analysis, from development to application, and has highlighted the importance of considering injuries at a player-specific level within future research. However, it is important to acknowledge the limitations associated with the current research. The key limitations are identified below.

This thesis only considered match exposure and match injuries, and therefore the impact of training exposure on the injury risk is unclear. Players are exposed to higher training exposure than match exposure throughout a season (West, Williams, et al., 2020), which could consequently influence the susceptibility of injury, specifically injuries associated with loading (i.e., muscular strains). The increased load associated with training exposure consequently results in different injury locations and mechanisms, with the posterior thigh and calf constituting the most commonly injured body site (0.47 injuries/1000 hours and 0.33 injuries/1000 hours, respectively) in a recent study within professional Rugby Union (West, Williams, et al., 2020). In addition, the mechanism responsible for the majority of training injuries was running (1.1 injuries/1000 hours), showing a different primary mechanism to match injuries (West, Williams, et al., 2020). However, research has consistently identified that the match injury incidence is substantially higher than training injury incidence, with Chapter 3 and a study by West and colleagues (2020) demonstrating an incidence of 99.1 and 87.0 injuries/1000 match hours at the professional level, respectively. When comparing this to the incidence of training injuries at the professional level, between 2.0 to 3.3 injuries/1000 training hours (Brooks et al., 2005c; Cross, Williams, et al., 2016; West, Williams, et al., 2020; Williams et al., 2013), the importance of analysing match injuries is further emphasised. In addition, the development of injury risk mitigation strategies and changes within the laws of the game have primarily been associated with reducing the injury rates within matches, specifically due to the consistent reports of increasing match injury rates (Taylor et al., 2014; Tucker, Raftery, Kemp, et al., 2017; West, Starling, et al., 2020).

Chapters 3, 5 and 6 included data collected from four professional Welsh Rugby Union teams across several seasons. Though previous research implementing injury surveillance within professional and international Rugby Union has included data collection across a number of seasons, limitations have been associated with the data collection procedures implemented within longitudinal studies (Kemp et al., 2008; Moore et al., 2015; Pearce et al., 2011; Rafferty et al., 2018; West, Starling, et al., 2020; Williams, Trewartha, Kemp, Cross, et al., 2017). Injury surveillance data within this thesis was collected between the 2012/13 season and the 2019/20 season, where it was the responsibility of medical professionals within each team to collect the injury surveillance data. Previous research collecting data across a number of seasons have indicated the potential for differences in the way injuries are reported across medical professionals involved within different seasons (Cosgrave & Williams, 2019; Mosler et al., 2018; Rafferty et al., 2018; West, Starling, et al., 2020; Williams, Trewartha, Kemp, Cross, et al., 2017). Specifically, a change in medical personnel between seasons could lead to inaccuracies in reporting injuries and increased potential for missing data (Mosler et al., 2018; West, Starling, et al., 2020). However, a number of data controlling procedures were in place throughout the injury surveillance period, including a standardised report form following recommendations from the consensus statement and monthly checking and cross-referencing of injury surveillance data provided by each region. The standardised approach to the injury surveillance data collection procedure therefore minimised the potential for incomplete or inaccurate injury records.

In addition to data collected across several seasons, the collection of data from four professional teams in Chapters 3, 5 and 6 may involve an element of selection bias. The four teams involved throughout the data collection of the thesis play at a professional level within Wales, restricting the analysis to a specific population of interest. Whilst selection bias associated with the population of professional Rugby Union players increases the internal validity of the study exploring the relationship between injury and exposure, this validity comes at the expense of generalisability of results (Pannucci & Wilkins, 2010). Furthermore, the association of professional level play and selection of first team squad members could result in selection bias towards players who sustain a lower number of injuries throughout a season. This selection bias may in turn effect the injury outcome within the study, and therefore bias the correlations between match exposure and injury outcomes, leading to erroneous conclusions (Borgen, 2018). In addition, the validity of injury reporting may be influenced by the types of injuries that occur and the interpretation of injury definitions. Specifically, injuries such as concussions, which occur more frequently than injuries such as thigh haematomas, may be reported more frequently in part due to the different associated severity and its relationship with the time-loss injury definition. However, within epidemiological research the nature of prospective injury reporting and the recruitment of a specific sample of individuals is fundamental, a factor which is further emphasised when analysing injury rates across professional Rugby Union within Wales (Zazryn et al., 2004).

The novel approach to analysing the injuries of starter and replacement players within matches has provided an initial insight into the injury rates and mechanisms. However, a limitation with this approach was the small number of injuries sustained by replacement players in the current cohort. The small sample size within this study mean that there may be a reduction in the ability of statistical testing to detect small effects, consequently resulting in analysis that may not reflect the true effect (Button et al., 2013). This effect is mitigated within studies with larger sample sizes where the improved statistical power allows for the detection of smaller effects (Button et al., 2013). Whilst sample size calculations can be implemented before data has been collected, this is challenging within exploratory research where data for preliminary power calculations is scarce (Jones et al., 2003). Therefore, the novel approach to prospectively analysing starter and replacement player injuries within matches in the current study, and the nature of exposure experienced by replacement players, who are predominantly introduced in the second half of matches, mean that potential exposure to injury inciting events was reduced. While this may be challenging to mitigate, further research should be implemented the analysis across a larger cohort of players, with a larger number of replacement match involvements to further investigate injury rates within these groups.

Practical Implications

This thesis has outlined several practical implications for injury surveillance, medical practitioners, coaches and the sport of Rugby Union. Based on the findings outlined in each Chapter, the following recommendations can be made.

Injury surveillance

- Identifying the proportion of players providing consent for their injury data to be collected and analysed may provide a more reflective analysis of injuries within the cohort, specifically if estimated match exposure is utilised to calculate team-level injury incidence.
- The addition of descriptive data to injury surveillance forms, such as the number of injuries sustained by a player within each season, may improve the understanding of multiple injury occurrence at a player-specific level.
- The incorporation of a clinical subsequent injury diagnosis, and the availability of a retrospective diagnosis within research, allows for further understanding of

the inter-injury relationship within players and whether multiple injuries sustained by players are related.

- Injuries can be analysed at a player-specific level using probability metrics, such as the Poisson model, as a more easily understandable method of presenting the injury risk.
- The Poisson probability as a 'live risk calculator' within injury surveillance can aid in the communication of injuries sustained by players at a player-specific level and identify players at higher risk for injury throughout a season.
- Additional information regarding the tackle event such as the type of players involved in a tackle (i.e., starter or replacement player), could be included in injury surveillance report forms. This will allow further understanding into the effect of replacement players within the tackle event.
- The time-in-game of replacement players is an important consideration when analysing match injuries in relation to the use of replacement players. The addition of descriptive data in injury surveillance systems associated with the time-in-game for a replacement player could provide further insight into the effect of player time-in-game on match injuries.

Laws of the game

- The tackle remains the contact event contributing to the highest proportion of injuries, specifically showing a difference in tackle characteristics between starter and replacement players. Sanctions associated with high tackles and head contact should continue to be advocated.
- The replacement player time-in-game did not influence the injuries, therefore tactical replacements should be encouraged within matches to reduce the risk of injury from increased match exposure and protect player welfare. Further research into the effect of the number of replacements on injuries within matches is warranted.

Coaches and medical practitioners

- Injury risk mitigation strategies can be developed and applied at a player-specific level, targeting individual injury risk characteristics in order to reduce the injury rate.

- Differences exist between the tackle characteristics of starter and replacement players during injury inciting tackles, therefore injury risk mitigation strategies associated with reducing the injury risk of starters specifically should be addressed. This may include focusing on the appropriate tackle technique when players are fatigued within training.

Future research directions

The analysis of injuries that incorporates a player-specific approach has been limited, primarily due to a lack of guidance on the methodology to implement when applying a player-specific approach. This thesis has developed a method for calculating injury rates at a player-specific level and has demonstrated its applicability with regards to injuries sustained by starter and replacement players. Though the thesis has provided insight into the variation in player-specific injury and differences in injury mechanisms between starter and replacement players, there remains potential for research to further these findings.

Player-specific exposure

Firstly, the use of GPS for the calculation of match exposure should be explored further. Specifically, the identification that team-level injury rates did not account for the player-specific differences in injury rates signifying the need for a more player-specific approach when conducting injury surveillance research. Though previous research has indicated that at an international level, players sustained multiple injuries across the study period (Moore et al., 2015), further insight into player-specific injuries across all levels of play is limited. Traditionally, the use of the standard match length and standard number of players within a team, as advocated in the consensus statement, has been used to calculate the team-level injury incidence. However, this provides an inadequate estimation of team-level injury incidence, specifically when the entire cohort has not provided consent. GPS units have previously been implemented within research exploring exposure to match events within Rugby (Cahill et al., 2013; Portillo et al., 2014; Roberts et al., 2008), therefore demonstrating the potential for use within epidemiological research. Future research should therefore look to implement the use of GPS-derived exposure at a player-specific level to provide a more accurate overview of injury incidence at both a team and player-specific level. In addition, analysing the injury rates at a player-specific level encourages further insight into the potential for variation between individuals within a team, allowing further understanding of the player-specific differences in injury occurrence.

Subsequent injury categorisation

Secondly, though subsequent injury categorisation models can be applied within research, both clinically and through using an automated coding system, to accurately distinguish between new, subsequent and recurrent injuries, the use of these models is not widely advocated (Finch & Cook, 2014; Toohey et al., 2018). The lack of subsequent injury diagnosis is a consistent factor across epidemiological research within professional and elite level sport, as outlined in Chapter 4, where, only 6% of studies used specific SIC models. This was emphasised in Chapter 3, where following the recommendations of the consensus statement meant that only recurrent injuries were analysed and reported. This means that the inter-injury relationship within the regional professional Welsh Rugby Union cohort is not yet understood. The development of a player-specific analysis of injuries and exposure provide an opportunity to improve the understanding associated with injury occurrence at a player-specific level, including the understanding of potential for multiple injury occurrence. This level of player-specific analysis, incorporating the SIC model, could provide further context to the multiple injuries incurred by players, as reported within Chapter 5. This provides an opportunity to improve the knowledge associated with player-specific injury analysis, specifically within Welsh professional Rugby Union, where the inter-injury relationship at a player-specific level is yet to be established.

Starter vs replacement player tackle analysis

Finally, though differences between starter and replacement players were identified in this thesis, the small sample size meant there were limitations when interpreting the results. Whilst Brooks and colleagues (2005b) analysed the injury incidence of starter and replacement players within the final quarter of a match, this thesis was the first to explore the differences between starter and replacement player injuries. The thesis has demonstrated the potential application of a player-specific method of analysing injury rates for the calculation of starter and replacement player injury incidence. Further, the analysis of tackle characteristics has provided insight into the potential for differing injury inciting tackle techniques. However, the current thesis addressed all injuries associated with the tackle, without consideration for the different types of injuries that may occur within different tackle events. Whilst Chapter 6 provided initial insight into the different injury-inciting tackle characteristics, the types of injuries sustained as a result of these differing characteristics was not analysed. Including the types of injuries from injurious tackle events could provide further insight into the important tackle characteristics associated with injury. This may consequently provide a more comprehensive analysis of injury-specific tackle characteristics, contributing essential knowledge for the development of effective injury risk mitigation strategies that target specific injuries associated with the tackle event.

Conclusion

This thesis explored the injury rates within Welsh professional Rugby Union, developing and applying a novel approach to injury epidemiology through a player-specific analysis of injuries. As advocated in the consensus statement within Rugby Union, the initial investigation of team-level injury rates showed a higher injury incidence than previously shown in professional Rugby Union. It would appear however, that despite the publication of consensus statements, not all epidemiological research follows these recommendations. The inconsistencies within research analysing recurrent and subsequent injuries highlight the need for a consistent advocation of SIC models, which aid in the understanding of inter-injury relationships within players. Furthermore, the consistent approach of pooling data across players within a team fails to quantify the injury risk within the cohort, specifically failing to identify the variation in player-specific injury incidence. This finding is further emphasised when considering the injury rates of starter and replacement players, where differences in the injury incidence was demonstrated. The novel approach to analysing the effect of replacement players on injuries sustained within matches identified that the current regulations associated with the use of replacement players within matches are appropriate. Importantly, however, injury inciting tackle characteristics differ between starter and replacement players. This thesis has therefore identified important findings for the development of player-specific injury risk mitigation strategies; an essential development in reducing the injury rates within Rugby Union and consequently improving player welfare.

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Appendices

Appendix A – Additional tables from Chapter 3.

Table A-18 Mean (±SD) and median (IQR) days unavailable for combined positions.

Body Area	Season			
	2012-13	**2013-14**	**2014-15**	**2015-16**
Head				
Mean (SD)	9.3 (7.5)	11.8 (13.2)	15.6 (22.5)	13.7 (21.0)
Median (IQR)	6.0 (6.0-10.5)	9.0 (7.0-11.0)	8.5 (6.0-14.0)	10.0 (6.0-14.3)
Neck				
Mean (SD)	31.9 (41.6)	7.2 (6.3)	11.0 (7.3)	20.0 (18.0)
Median (IQR)	15.0 (5.0-45.0)	4.0 (3.5-9.5)	9.0 (5.0-14.5)	13.5 (6.5-31.8)
Shoulder				
Mean (SD)	35.3 (40.0)	40.5 (49.5)	56.2 (63.4)	34.3 (37.1)
Median (IQR)	18.0 (6.0-51.0)	19.0 (10.0-37.0)	19.5 (12.0-	17.0 (10.0-
Elbow				
Mean (SD)	82.3 (74.2)	16.0 (16.7)	-	-
Median (IQR)	94.0 (48.5-	10.0 (5.0-19.5)	-	-
Forearm				
Mean (SD)	28.5 (2.1)	138.5 (14.8)	-	-
Median (IQR)	28.5 (27.8-	138.5 (133.3-	-	-
Wrist and				
Mean (SD)	16.6 (17.8)	29.0 (30.5)	53.8 (47.4)	59.3 (67.8)
Median (IQR)	8.0 (3.0-22.0)	26.5 (7.0-34.3)	45.5 (21.3-	40.5 (9.5-90.3)
Chest				
Mean (SD)	14.9 (8.6)	41.0 (38.3)	8.9 (6.7)	11.0 (7.1)
Median (IQR)	11.0 (10.0-	25.0 (20.5-45.5)	6.0 (5.0-9.5)	11.0 (7.3-14.8)
Lumbar				
Mean (SD)	4.8 (2.9)	6.4 (2.9)	7.0 (6.2)	8.5 (3.5)
Median (IQR)	4.0 (2.8-6.0)	5.0 (4.0-9.0)	4.5 (3.0-8.5)	8.5 (7.3-9.8)
Hip/Groin				
Mean (SD)	12.0 (10.6)	8.9 (7.2)	15.0 (13.6)	7.8 (4.1)
Median (IQR)	9.0 (8.3-12.5)	7.5 (2.8-11.0)	11.0 (7.0-	7.5 (4.5-10.5)
Posterior				
Mean (SD)	23.1 (20.5)	35.0 (43.3)	17.4 (17.2)	22.5 (39.7)
Median (IQR)	24.0 (5.0-32.5)	23.0 (11.0-24.5)	12.0 (9.0-	10.0 (5.0-24.5)
Anterior				
Mean (SD)	6.1 (3.2)	6.1 (5.3)	9.0 (8.4)	8.0 (7.8)
Median (IQR)	5.0 (4.0-9.0)	4.0 (3.0-5.5)	5.0 (3.0-10.0)	5.0 (3.0-12.3)
Knee				
Mean (SD)	38.6 (63.3)	53.0 (123.5)	37.5 (59.7)	59.4 (82.2)
Median (IQR)	6.0 (4.0-41.0)	11.0 (6.0-24.0)	15.0 (5.0-	23.0 (10.0-
Lower Leg				
Mean (SD)	27.8 (42.6)	15.2 (20.3)	9.7 (8.0)	10.1 (7.9)
Median (IQR)	10.0 (7.0-22.0)	9.0 (4.8-15.5)	8.0 (4.5-12.0)	10.0 (3.3-13.8)
Ankle/Achilles				
Mean (SD)	25.0 (31.0)	37.8 (64.2)	29.2 (34.5)	35.2 (38.1)
Median (IQR)	14.5 (4.3-28.8)	17.0 (7.0-33.0)	17.0 (6.0-	21.0 (6.0-53.0)
Foot				
Mean (SD)	52.3 (68.1)	-	22.3 (24.5)	40.0 (47.5)
Median (IQR)	11.0 (9.0-94.0)	45.0 (5.8-115.5)	18.0 (8.0-	18.0 (7.0-54.5)

Table A-19 The incidence (injuries per 1000 hours) with upper and lower CI and burden (days-lost per 1000 hours) of each injury mode of onset from the 2012/13 to the 2015/16 season.

Mode of Onset	**Season**			
	2012/13	**2013/14**	**2014/15**	**2015/16**
Impact				
Incidence	46.5 (39.2-55.2)	37.9 (31.3-45.9)	53.8 (45.9-63.0)	38.3(31.3-46.8)
Burden	964.2 (928.6-1001.1)	645.7 (616.6-676.2)	1329.0 (1287.4-1371.9)	645.6 (614.7-678.0)
Sudden Onset				
Incidence	40.1 (33.3-48.2)	42.1 (35.1-50.4)	45.8 (38.6-54.4)	43.5 (36.0-52.5)
Burden	1125.9 (1087.4-1165.8)	1708.9 (1661.2-1758.0)	1405.2 (1362.4-1449.3)	1639.1 (1589.5-1690.3)
Gradual Onset				
Incidence	9.6 (6.6-14.0)	3.2 (1.7-6.2)	7.3 (4.8-11.2)	8.1 (5.2-12.6)
Burden	237.6 (220.3-256.3)	24.6 (19.4-31.2)	67.8 (58.9-78.0)	160.5 (145.5-177.1)
Insidious				
Incidence	3.2 (1.7-6.2)	0.7 (0.2-2.8)	4.9 (2.9-8.3)	8.9 (5.9-13.5)
Burden	16.7 (12.5-22.2)	7.1 (4.6-11.0)	136.7 (123.8-150.9)	153.2 (138.5-169.4)

Appendix B – Additional figures and tables from Chapter 5.

Table B-20 The number and proportion of missing exposure instances for each player.

Subject	Number of Missing Exposures	Total Number of Exposures	Proportion of Missing Exposures (%)
1	4	40	10
2	3	50	6
3	2	64	3
4	2	39	5
5	2	16	12
6	1	5	20
7	2	21	10
8	2	58	3
9	1	6	17
10	2	16	12
11	2	75	3
12	2	38	5
13	2	46	4
14	1	63	2
15	1	15	7
16	2	22	9
17	2	13	15
18	3	71	4
19	2	77	3
20	2	61	3

21	1	58	2
22	4	47	9
23	3	59	5
24	1	45	2
25	4	20	20
26	1	38	3
27	1	20	5
28	1	8	12
29	1	55	2
30	3	31	10
31	1	73	1
32	4	56	7
33	2	47	4
34	1	17	6
35	1	69	1
36	1	86	1
37	6	43	14
38	1	16	6
39	1	14	7
40	2	68	3
41	1	15	7
42	1	60	2
43	2	38	5

44	1	58	2
45	3	22	14
46	5	38	13
47	2	50	4
48	4	12	33
49	4	22	18
50	3	47	6
51	1	43	2
52	2	20	10
53	2	24	8
54	1	53	2
55	3	46	7
56	3	59	5
57	5	32	16
58	1	45	2
59	3	67	4
60	1	28	4
61	2	49	4
62	1	26	4
63	1	23	4
64	1	68	1
65	1	19	5
66	5	49	10

67	3	61	5
68	2	78	3
69	2	76	3
70	6	34	18
71	2	14	14
72	1	8	12
73	1	12	8
74	1	14	7
75	3	10	30
76	2	34	6
77	1	19	5
78	3	51	6
79	2	84	2
80	2	31	6
81	1	16	6
82	1	59	2
83	2	43	5
84	2	29	7

Table B-21 The total number of injuries and match exposure hours per player.

Subject	Total Number of Injuries	Total Match Exposure Hours	Total Number of Matches
1	2	31	40
2	3	42	50

3	4	20	25
4	5	55	64
5	1	17	13
6	1	3	2
7	7	24	39
8	3	17	16
9	11	55	47
10	1	3	8
11	8	35	58
12	6	45	50
13	2	17	16
14	2	15	14
15	4	30	44
16	3	14	20
17	2	4	6
18	7	33	31
19	4	57	63
20	7	80	67
21	1	4	5
22	3	54	64
23	3	74	71
24	3	58	77
25	7	63	61

26	9	45	58
27	7	52	47
28	3	39	43
29	14	55	60
30	4	69	54
31	2	12	16
32	5	70	71
33	2	23	32
34	5	22	28
35	9	63	50
36	4	7	11
37	2	33	35
38	3	31	42
39	7	40	47
40	3	10	13
41	5	64	50
42	3	57	46
43	1	29	26
44	1	22	27
45	3	13	17
46	3	43	39
47	3	15	16
48	2	17	13

49	6	62	58
50	12	76	68
51	6	76	60
52	8	43	41
53	1	14	15
54	3	27	26
55	8	53	52
56	3	34	34
57	2	52	42
58	13	60	50
59	5	15	18
60	10	56	50
61	4	53	45
62	15	76	66
63	2	43	47
64	1	9	15
65	4	29	43
66	3	4	8
67	2	31	28
68	1	11	19
69	5	9	12
70	4	20	17
71	4	27	31

72	3	51	45
73	6	45	51
74	2	4	8
75	4	56	49
76	1	13	15
77	2	13	15
78	2	3	3
79	4	31	38
80	2	3	6
81	7	40	40
82	2	8	10
83	1	23	22
84	1	16	21
85	1	15	13
86	2	6	10
87	5	16	14
88	16	42	44
89	6	41	61
90	9	78	78
91	6	81	76
92	2	10	14
93	1	13	14
94	3	24	27

95	3	3	5
96	6	56	50
97	3	5	5
98	4	19	34
99	7	64	78
100	2	7	6
101	7	50	51
102	5	43	54
103	6	19	31
104	1	7	10
105	6	70	59
106	6	39	34
107	3	34	28
108	10	38	33
109	1	12	10
110	4	27	34
111	3	12	15

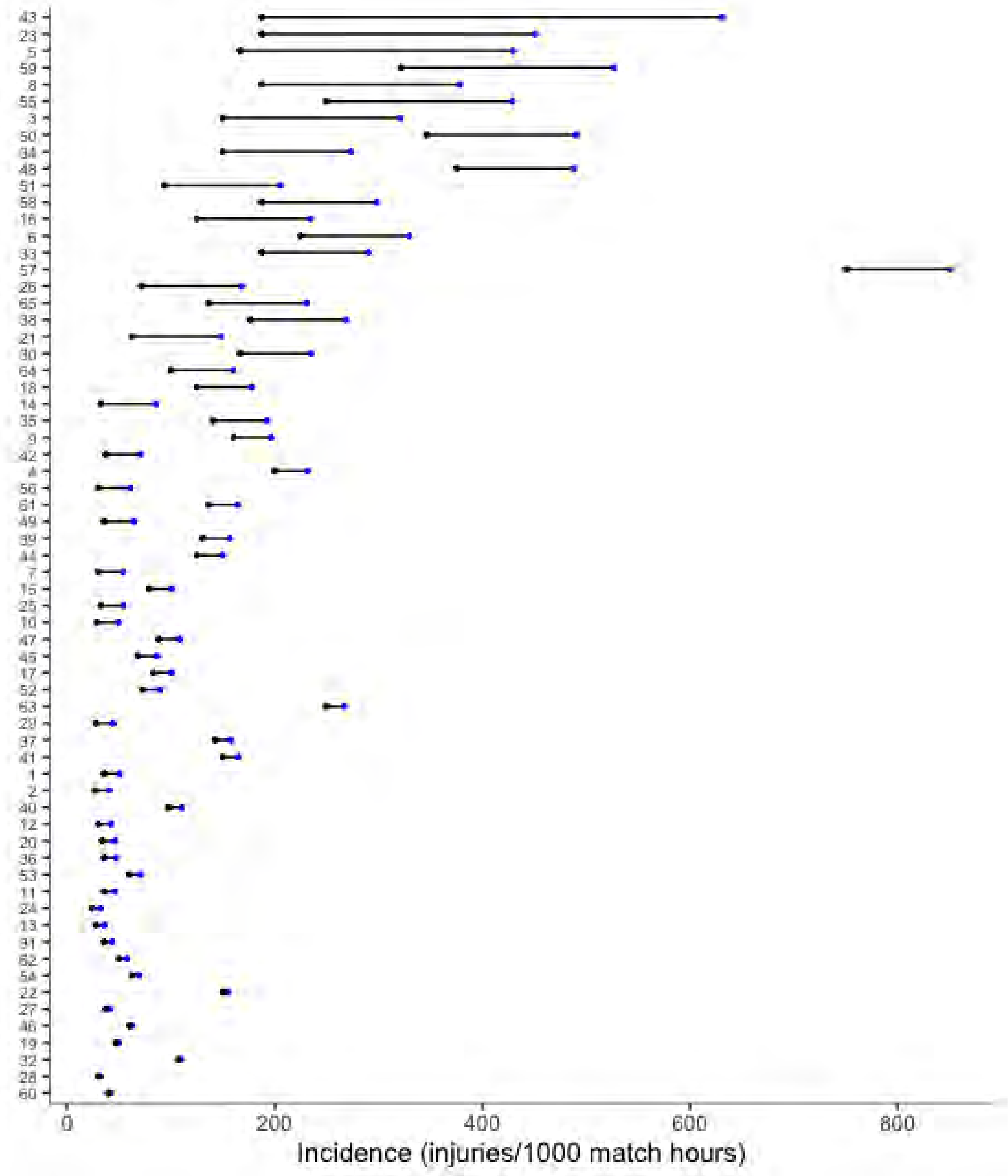

Figure B-15 The difference between the player-specific injury incidence for all players using standard match length and GPS-derived exposure for the 2016/17 season. Black points represent the standard match length, blue points represent the GPS-derived injury incidence.

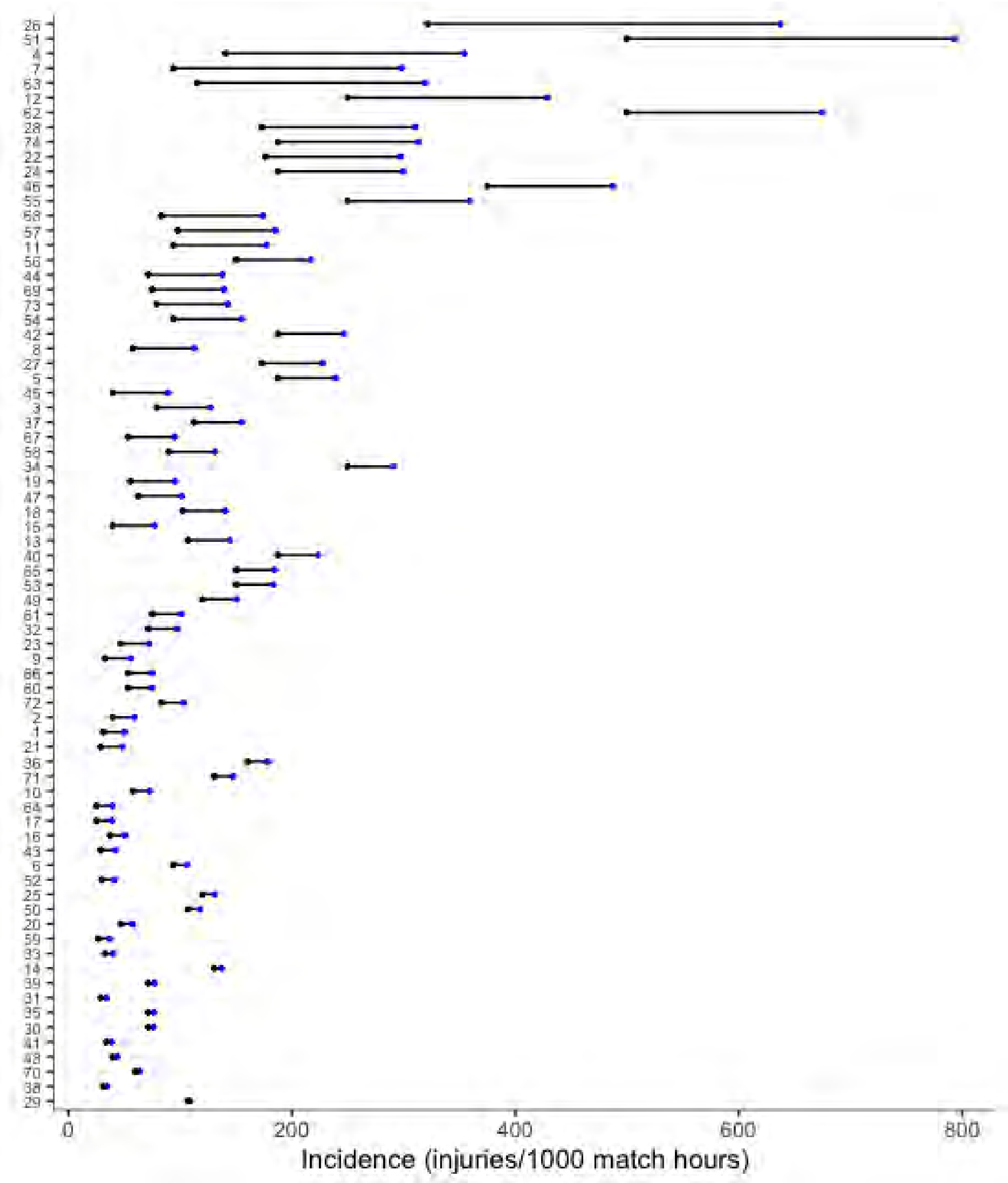

Figure B-16 The difference between the player-specific injury incidence for all players using standard match length and GPS-derived exposure for the 2017/18 season. Black points represent the standard match length, blue points represent the GPS-derived injury incidence.

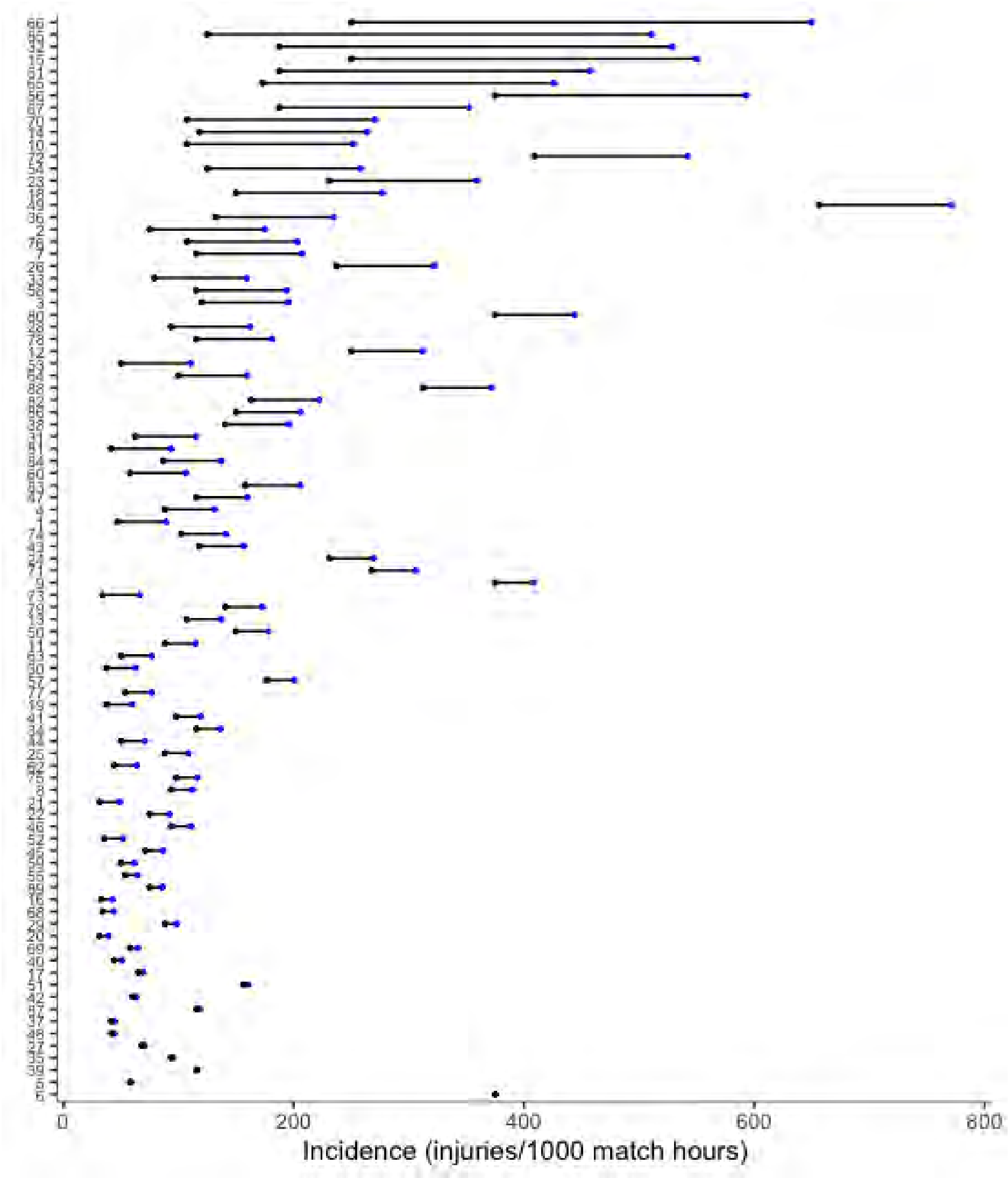

Figure B-17 The difference between the player-specific injury incidence for all players using standard match length and GPS-derived exposure for the 2018/19 season. Black points represent the standard match length, blue points represent the GPS-derived injury incidence.

Appendix C – Additional table from Chapter 6.

Table C-22 The descriptors for each tackle phase for ball carriers and tacklers.

Ball Carrier Tackle **Tackle Phase**	**Characteristic Group**	**Characteristic**
Pre-Contact (1 second before contact)	Player type	Starter
		Replacement
	Opposition player	Starter
		Replacement
	Position	1 to 15
	Pre-tackle event	Ruck
		Other tackle
		Line Out
		Maul
		Kick in Play
		Kick Off
		Open field running
		Scrum
		Static/Tactical – *standing/moving in line formation before receiving ball*
	Head position	Up and forward – *eye contact with tackler*
		Away – *not making eye contact with tackler*
		Down – *facing ground*
		Motion/Tracking – *gaze not fixed, head moving*
	Speed of ball carrier	Fast – *running or sprinting*
		Moderate – *jogging*
		Slow – *stationary or walking*
	Body position	Upright – *straight back*
		Medium – *moderate flexion at knees and hips*
		Low – *flexed at the hip*
		On Ground – *if was on the ground before making the contact*
	Pattern of running	Straight - *directly forwards towards tackler*
		Side-step
		Arcing run
		Lateral run – *from touchline to touchline*
		Diagonal run
	Anticipation	Yes – *aware of/attuned to impending contact*
		No – *unaware*
Contact – at point of being contacted by the tackler	Fend	Absent – *no attempt at fending*
		Moderate – *light to moderate fending into contact*
		Strong – *strong fend, strong straight arm into tackler to push off*
	Contact impact intensity	Low
		Medium
		High
	Body position	Upright – *knees slightly bent*
		Bent at waist – *presents shoulder towards tackler first, crouched*
		Falling/diving

		On Ground – *getting up onto all fours/trying to move whilst still on the floor*
	Body region contacted	Head and neck – *above the shoulder*
		Shoulder – *from armpit level to shoulder*
		Mid-torso – *above hip to armpit level*
		Legs – *area between hip and toes*
	Attacker sequence	One on One – *one defender, one attacker*
		Sequential – *one attacker, one defender followed by second attacker*
		Simultaneous – *two attackers contact one defender*
		Dual sequential – *two attackers, one defender followed by a third/fourth attacker*
Post-Contact – after the contact is made	Ball carrier leg drive	Absent – *no drive with legs*
		Moderate - *moderate knee movement, not much obvious knee lift*
		Strong – *high, rapid knee lift*
	Upper body usage	Yes – *ball carrier uses upper body to wrestle/push tackler*
		No – *no active upper body*
	Ground contact	No ground contact
		Go to ground and present ball

Tackler Tackle

Tackle Phase	**Characteristic Group**	**Characteristic**
Pre-Contact (1 second before contact)	Player type	Starter
		Replacement
	Opposition player	Starter
		Replacement
	Position	1 to 15
	Pre-tackle event	Ruck
		Other tackle
		Line Out
		Maul
		Kick in Play
		Kick Off
		Open field running
		Scrum
		Static/Tactical – *standing/moving in line formation before receiving ball*
	Head position	Up and forward – *eye contact with tackler*
		Away – *not making eye contact with tackler*
		Down – *facing ground*
		Motion/Tracking – *gaze not fixed, head moving*
	Speed of tackler	Fast – *running or sprinting*
		Moderate – *jogging*
		Slow – *stationary or walking*
	Body position	Upright – *straight back*
		Medium – *moderate flexion at knees and hips*
		Low – *flexed at the hip*
		On Ground – *if was on the ground before making the contact*
	Anticipation	Yes – *aware of/attuned to impending contact*
		No – *unaware*

Contact – at point of being contacted by the tackler	First point of contact on ball carrier	Lower leg – *below knee*
		Upper leg – *between hips and knee* Hip – *shorts line* Torso – *above hip to arm pit* Shoulder – *arm pit to shoulder* Arm – *below arm pit but not making contact on the body* Head and neck – *above shoulder*
	Body position	Upright – *standing in upright position, minimal flexion at knees and hips* Bent at waist – *presents shoulder towards tackler first, crouched* Falling/diving
	Direction of tackle	Front – *tackler tackles from front, contact with front of BC* Side – *tackler tackles from side, contact with side of BC* Behind – *tackler tackles from behind, contact with back of BC*
	Type of tackle	Arm – *impedes with upper limb first, then brings body round/towards using upper limbs* Shoulder tackle – *contacts ball carrier with shoulder without obvious wrap attempt, shoulder first then arms* Jersey – *first attempt of contact tackle using the jersey only* Smother tackle – *uses chest and wraps both arms around ball carrier – obvious use or attempt to wrap arms around and bring ball carrier into chest* Tap – *trips ball carrier, contact of tap below the knee*
	Tackler sequence	One-on-One – *one defender and one attacker* Sequential – *one defender, one attacker followed by second defender* Simultaneous – *two defenders and one attacker* Dual sequential – *two defenders and one attacker followed by third/fourth defender joining*
Post-Contact –after the contact is made	Tackler leg drive	Absent – *no drive*
		Moderate – *moderate knee movement, not much obvious knee lift* Strong – *high, rapid knee lift*
	Upper body usage	Yes – *uses upper body to pull/wrap/wrestle* No – *no active upper body*
	To ground	Releases – *releases BC and competes for possession* Pulls – *pulls BC to ground*

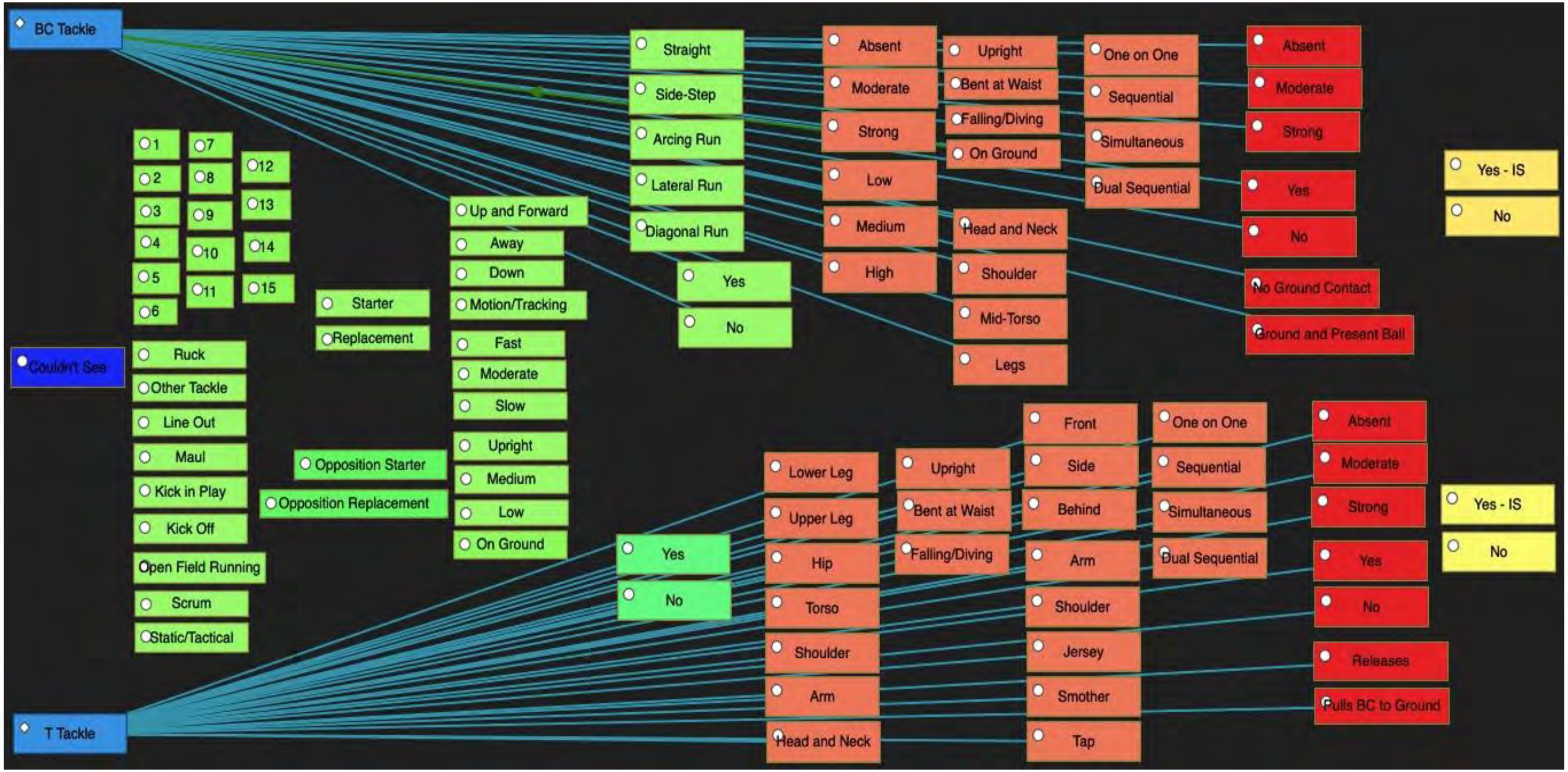

Figure C-18 The code window for the tackle descriptors used in the analysis of the tackle event.